SOLAR PV IN NORTH DAKOTA

Final Report

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1.0   INTRODUCTION

1.1   Introduction

Governments, businesses, and consumers are increasingly supporting and encouraging the development and application of renewable sources of energy like solar, wind, geothermal energy, etc. (1). The North Dakota Department of Commerce instructed the Energy and Environmental Research Center (EERC) to investigate the current status of solar power utilization and evaluate the advantages and challenges of its use in the state of North Dakota.

A fact sheet published by the Solar Energy Industries Association (SEIA) stated that only 220 kW of solar energy was installed in the state up to 2015 and that North Dakota ranked 50th in the country in total installed solar capacity (2, 3). This presents North Dakota with a significant opportunity to increase installed solar power capacity. This report studies the important factors that influence the practicality of the application of solar photovoltaics (PV) technology in North Dakota such as the kinds of technologies, availability of the solar resource, the performance of the technology under varying conditions, the number of federal and state incentives made available to encourage the application of the technology, and the cost of the technology.

Solar energy can be utilized several ways. Typically, the sun's energy can either be used in the form of heat or in the form of electricity. When used in the form of heat, the energy can be used to heat water or heat space. To use in the form of electricity, solar energy can directly be converted to electrical energy using PV cells or converted to heat and then converted to electricity using technology widely known as concentrated solar power (CSP) etc. (4, 5). The appropriate application of either technology (PV vs. CSP) depends on the scale of the application (residential or utility) and the availability of the solar resource (year-round high sunlight intensity or periodic high sunlight intensity). These two technologies are vastly different and are generally not considered competing technologies.

The amount of the sun's energy that is incident on the surface of the earth is measured as solar insolance or solar irradiance. Since the energy of the sun on a surface depends on the area and the amount of time that the energy is incident on the surface, it is measured as $kW/m^2/day$. The sun is closer to the equator than the poles. As a result, latitude plays an important factor on the insolance at a certain location on the surface of the earth (6).

To perform comparative studies, states that neighbor North Dakota were chosen in addition to Wisconsin since it lies within the latitudes that span South Dakota and North Dakota. Additionally, the similarities in the insolation in the states of North Dakota, Minnesota, Wyoming, and Wisconsin warrant the comparison shown in Table 1. To obtain these data, averages have been collated over a 22-year period between 1983 and 2005 based on a 3-hour sample rate. For the sake of comparison, insolation data for California and Washington have also been shown in Table 1 (7). Figure 1 shows the solar resource in the entire United States, and the effect of latitude is clearly seen.

Table 1. Insolance Data for North Dakota, Minnesota, Wisconsin, Montana, California, and Washington*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
North Dakota	1.48	2.35	3.47	4.77	5.72	6.26	6.49	5.48	4.06	2.73	1.71	1.27
Minnesota	1.71	2.55	3.44	4.54	5.32	5.96	6.05	5.19	4.00	2.78	1.76	1.37
Wisconsin	1.80	2.67	3.58	4.49	5.33	5.97	5.87	5.05	4.01	2.76	1.79	1.52
Montana	1.64	2.51	3.65	4.72	5.6	6.31	6.58	5.70	4.3	2.83	1.83	1.37
South Dakota	1.75	2.54	3.61	4.79	5.83	6.51	6.60	5.75	4.42	3.04	1.93	1.47
California	2.18	3.09	4.65	6.08	7.21	7.93	7.79	7.02	5.64	4.12	2.63	1.99
Washington	1.06	1.93	2.94	4.05	4.99	5.51	5.88	5.20	3.98	2.25	1.25	0.91

*All values shown are in kW/m^2/day for a panel laid flat (90°) on the ground.
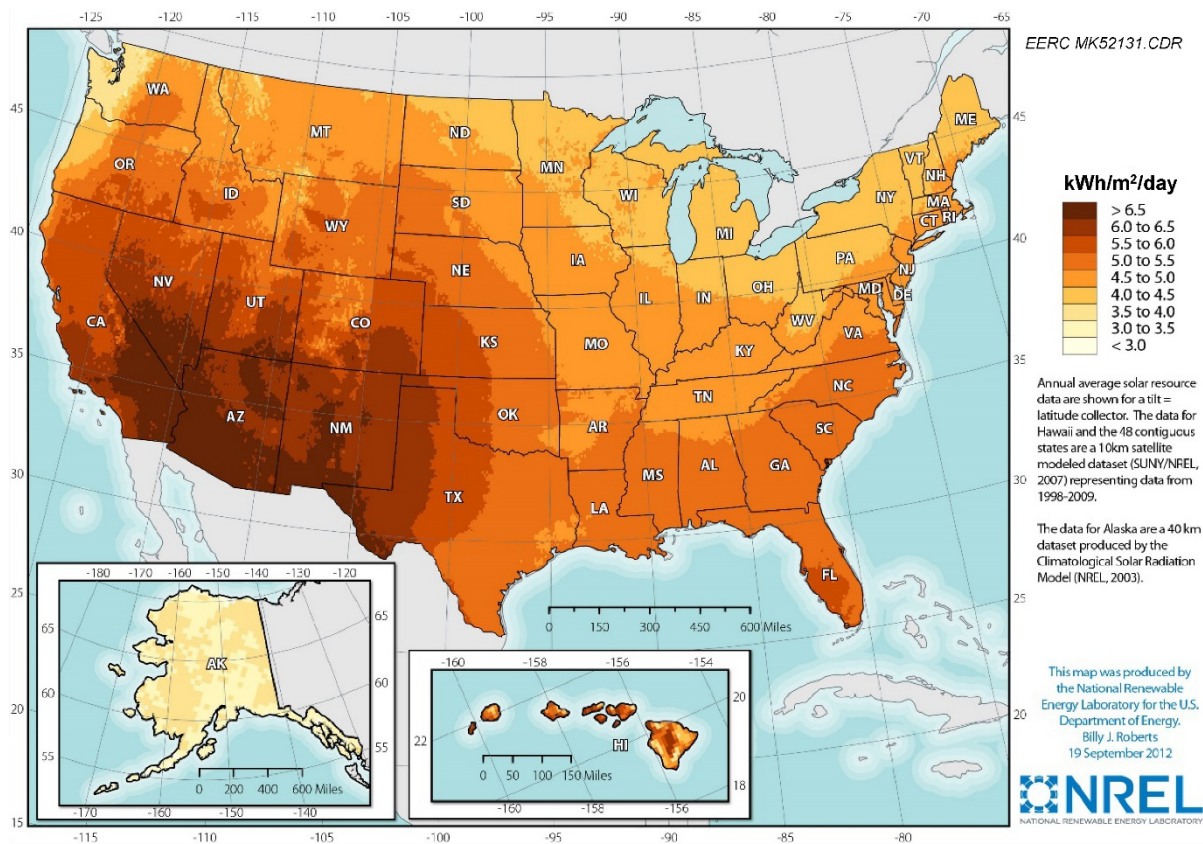
Figure 1. PV solar resource of United States (8).

1.2   What Is Solar PV?

Our present framework for understanding PV power comes largely from Albert Einstein, who in 1905 detailed the photoelectric effect (9). While previously light was thought to comprise electromagnetic waves, Einstein showed that light actually consists of individual particles of

energy, which he named photons. These photons carry energy between the electrons around different atoms (10). This movement of electrons is exploited to generate electricity.

Electrons orbit their atoms in predictable orbitals. The lowest level of these orbitals is known as the "ground state." When an electron is struck by a photon from sunlight, it sometimes moves into a higher un-occupied orbital. If a photon fails to energize an electron all the way into a stable higher orbital, the photon is reemitted, and the electron returns to its ground orbital. If a photon with enough energy strikes an electron, it is knocked out of orbit around its atom and into the space between atoms, known as the conduction band (shown in Figure 2), forming an electrical current (11).
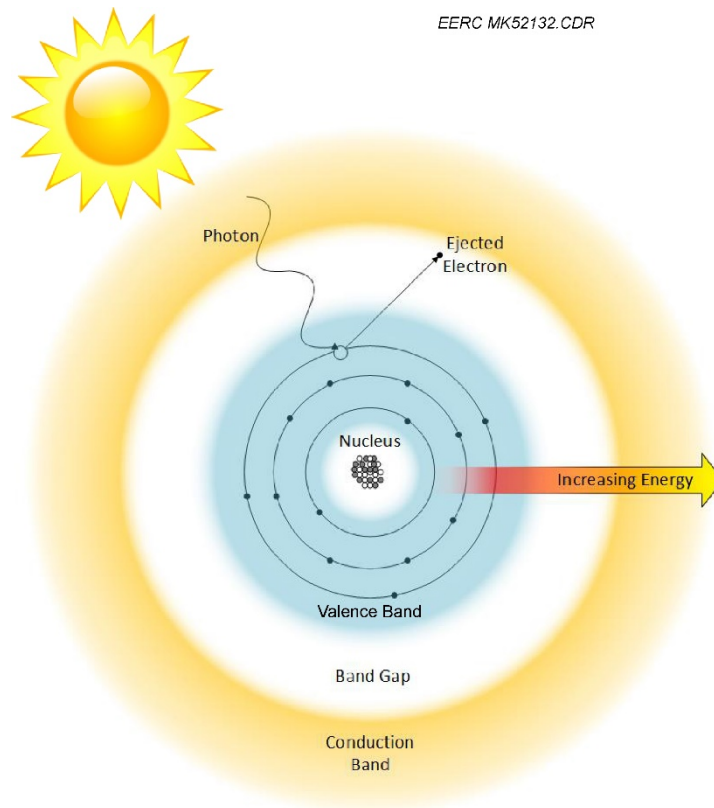
Figure 2. Schematic of atomic structure.

If too much energy is added to a given electron, that electron may end up in the orbit of a neighboring atom instead, causing much or all of that energy to be lost as heat because of "friction" with other electrons (6). As energy is added, the electrons move to progressively higher "bands" (shown in Figure 2), eventually forming an electrical current (7).

These bands determine the properties of the bulk materials. Metals have more electrons and hold them less tightly, so their outer electrons exist in the conduction band, making them good conductors. In semiconductors, these outer electrons do not overlap with the conduction band; they

have a small gap between their valence and conduction bands, known as the band gap. The smaller the band gap is, the lower the minimum energy a photon needs to elevate an electron into the conduction band. Semiconductors allow excited electrons to move but resist bulk electron flow, making them ideal for PV uses (5, 6).

A photovoltaic cell has limits to its efficiency. The band gap determines which photons can be absorbed and determines the theoretical maximum efficiency. Once absorbed, some energy is lost to friction with other electrons and is lost in the form of heat; some recombines into another vacant orbital around an atom. Structural flaws in the crystal present routes for electrons to cross back across the semiconductor rather than around the circuit. For these reasons, given our solar spectrum, a single solar cell has a theoretical maximum efficiency limit of about 31% (12).

$$Efficiency = \frac{Produced\ Electrical\ Energy}{Received\ Solar\ Energy} \qquad \text{[Eq. 1]}$$

It is, however, possible to exceed this limit by stacking multiple cells onto one another. Some materials allow their band gap to be "tuned" to certain wavelengths of light and more efficiently target these specific wavelengths, allowing the rest of the light to pass through to another layer. Such cells are known as multijunction cells and are less common than single-junction cells. These are more expensive to produce, so their use is generally limited to spaceflight-grade cells and silicon thin films (13).

Figure 3 shows the components that make up a typical solar array. A cell is the basic unit of a PV array. At its most basic, a cell consists of a photoactive material connected to a pair of electrodes. From face to back, a typical cell would consist of a glass outer covering, an antireflective coating, a thin layer of clear metal oxide or metal contacts to serve as an electrode, the photoactive material, and a back electrode. Cells are usually connected in series into substrings which are protected by a diode. Several substrings are connected in parallel in a module. Multiple modules can be connected in series to form a string of modules. Several strings are usually connected to form a solar array which is a part of a solar PV system that consists of inverters, batteries, and a load.

MODULE

STRING

CELL

SUB-
STRING
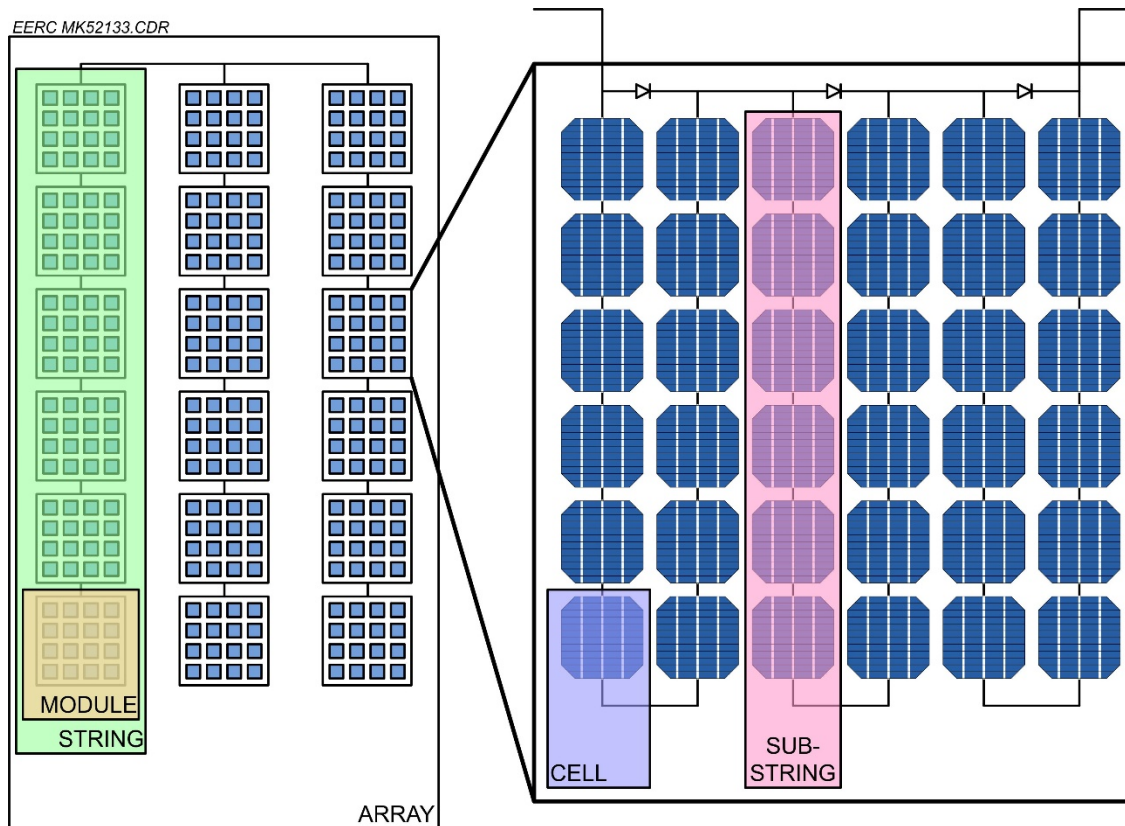
ARRAY

Figure 3. Components of a solar array.

2.0   MEANS OF SOLAR POWER UTILIZATION

2.1   Types of Solar Power Systems

The solar power sector can be broken up into two main categories: CSP and PV solar power. In the case of solar PV, the sun's energy is directly converted to electricity, whereas in the case of CSP, the sun's energy is converted to heat, which is then used to turn a turbine to produce electricity.

2.1.1   PV Cells

The photovoltaic market has a number of competing technologies. The commercially dominant varieties are monocrystalline and polycrystalline silicon. These cells are made from silicon wafers. The remaining major share of commercial PVs belongs to the broad category of thin-film solar cells, which encompass a wide variety of technologies sharing the common trait that they are deposited on a substrate as a thin, flexible layer. In addition to the crystalline silicon and existing thin-film technologies, a number of emerging technologies are in various stages of research and development and may not be commercially available.

2.1.2   *Monocrystalline Silicon*

Monocrystalline silicon PVs are the current high-performance mass-market solar technology. They are produced by cutting a single crystal silicon ingot into wafers a few hundredths of an inch thick. The silicon used must be of very high purity to allow for a single crystal of silicon to grow, increasing its cost. Monocrystalline silicon suffers from efficiency losses at higher temperatures. It does not absorb blue and ultraviolet light as well as longer wavelengths which gives crystalline silicon cells their dark-blue hue (14).

2.1.3   *Polycrystalline Silicon*

Polycrystalline silicon PVs compose the largest single share of the PV market. Polycrystalline silicon offers lower performance than monocrystalline silicon; however, it also does not require as pure a silicon feedstock, making them cheaper to produce. The production itself is similar; a thin wafer is cut from an ingot. Like monocrystalline silicon PV, polycrystalline silicon suffers efficiency losses at high temperatures. It also absorbs blue and ultraviolet light poorly relative to longer wavelengths, giving it a blue color. Its distinctive speckled blue shades make it easy to visually identify compared to the solid blue tint that monocrystalline silicon cells have, as shown in Figure 4 (14).

2.1.4   **Thin Film**

Thin-film solar cells are made by depositing one or more thin layers of PV material on a substrate material. The advantage to thin-film technologies compared to wafer-silicon is that they require significantly less photoactive material to create the cell. Current thin-film technologies tend to make use of much rarer and expensive materials than bulk silicon, such as tellurium, indium, or gallium. Most commonly, the film is sandwiched between two layers of glass, although metals and plastics are used as well. This tends to make them heavier than equivalent crystalline silicon panels, which typically needs only a single sheet of glass. Some examples of thin-film cells are given below (Table 2).

2.1.4.1   *Thin-Film Amorphous Silicon (a-Si)*

Amorphous silicon is the oldest and previously most common thin film. a-Si is noncrystalline, with silicon atoms arranged randomly. The variations in atomic arrangement give its silicon atoms different band gaps, meaning a wide variety of wavelengths of light can be absorbed with higher efficiency. Unfortunately, its amorphous nature hinders conduction and causes more interactions with other electrons, significantly harming efficiency. a-Si is produced as a multijunction cell. While less efficient than either crystalline silicon or other commercial thin films, amorphous silicon uses no rare or toxic materials and works well in ambient and dim light relative to other technologies. These are most commonly used in consumer applications but see use for grid-production as well (15).

Figure 4. Monocrystalline (top left), polycrystalline (top right), and thin-film solar cells (bottom).

2.1.4.2   Thin Film Cadmium Telluride (CdTe)

Cadmium telluride is currently the dominant thin-film material and accounts for over half the thin-film PV market. Its efficiency, currently 16%, is above that of a-Si but lower than polycrystalline silicon. It has the shortest energy payback time of any current solar technologies. Because of its low cost and high performance, it is the most common thin-film technology commonly used in utility-scale PV plants (16).

Cadmium telluride systems have two major weaknesses. Tellurium is produced as a trace by-product of lead, copper, and gold refining. Only a few hundred tons are produced globally a year, meaning CdTe panels will not be a primary technology in the future without significantly improved tellurium sourcing (17). Cadmium and tellurium are also toxic heavy metals, and some forms used in production are water-soluble. CdTe panels are sealed from the environment to prevent leakage, and this has proven to be reliable and effective (8). Given these weaknesses, cadmium telluride recycling programs have been developed to reuse tellurium and to prevent future heavy metal pollution (14, 18).

Table 2. Comparison of Monocrystalline, Polycrystalline, and Thin-Film Solar Cells

	Mono-Si	Poly-Si	A-Si	Thin Film CdTe	CIGS*
Retail Module Efficiency, %	16–22	16–17	12	16	14
Record Cell Efficiency, %	26	21	14	22	22
Global Production, GW/yr	17	26	1	2	2
Advantages	High efficiency	Moderate cost Moderate performance	Low cost Good performance across the spectrum and in low light	Low cost	Good performance across spectrum and in dim light
Disadvantages	High cost Poor blue-light performance Reduced efficiency at high temperatures	Poor blue-light performance	Low efficiency	Toxic materials Limited material availability	Limited material availability

* Copper indium gallium selenide.

2.1.4.3 *Thin-Film Copper Indium Gallium Selenide (CIGS)*

Copper indium gallium selenide panel types are the third major thin-film technology. This technology is more recently developed than cadmium telluride but has made developments in performance in recent years and now offers similar efficiency. Some CIGS research has led to materials with trace or no gallium, which are often referred to as copper indium selenide (CIS) cells. Like tellurium in CdTe panels, the indium, gallium, and selenium used in these panels face a number of competing uses and have limited annual production as by-products (19). Copper indium gallium selenide is a very strong light absorber, allowing film to be significantly thinner than other types, minimizing the limitations of mineral availability (20).

2.2 Emerging Technologies

2.2.1 *Perovskite*

Perovskite is the most recently developed thin-film technology. It was first investigated as a PV material in 2009. Since then, its development has been growing and has now matched or surpassed all but monocrystalline silicon in record laboratory efficiency. Perovskite is a water-soluble lead-organic molecule that forms near perfect crystals when allowed to dry. This means that perovskite does not require the expensive and complicated vacuum deposition techniques used to create other thin films. Lead is neurotoxic, so like cadmium telluride, the cell must be fully enclosed and sealed to prevent damage to the cell or lead pollution. Because of the low cost of its materials and relative simplicity of manufacturing, perovskite is anticipated to cost a fraction of

current panel types. Silicon and perovskite have complementary band gaps, making them an ideal combination for future multijunction cells. The first commercial panels are projected to reach the market in 2017 (14).

2.3   Concentrating Solar Power

Concentrating solar power (CSP), also a form of solar thermal power, is currently a relatively minor player in the solar power market, accounting for less than 10% of installed capacity in the United States. Concentrating solar uses energy from the sun to produce steam, which turns a turbine generator to produce electricity. In most systems, liquid salts are used as an intermediate heating fluid, which is used to store and carry heat from the concentrator to a central point to produce steam. Being able to store heat is a major benefit for concentrating solar power, and some facilities can generate electricity continuously from residual heat, helping balance power production to better match demand. This helps reduce the intermittency problem. Thermal solar power requires significant scale to produce enough heat to power a generator, making it of limited use for anything but utility-scale generation.

CSP has primarily two forms. In the more common, a parabolic trough mirror focuses its light on a central receiver, which heats the fluid flowing through it to a high temperature. The fluid is then used to generate steam. The other method involves an array of tracking mirrors which focus light on a central tower, heating a reservoir of liquid salt, which is used to generate steam. Tower CSP allows higher temperatures to be reached, resulting in a more efficient system and greater power storage than trough CSP (19, 21). Figures 5 and 6 illustrate parabolic trough-type and central receiver-type CSP systems.

EERC MK52135.CDR

Figure 5. Parabolic trough-type concentrating solar power (22).

Figure 6. Central receiver-type concentrating solar power (19, 22).

For the purpose of this report, solar PV is of particular interest. As a result, further analysis will be limited to solar PV and the important factors that influence the practicality of the application of solar PV in North Dakota such as the kinds of technologies, availability of the solar resource, the performance of the technology under varying conditions, the number of federal and state incentives made available to encourage the application of the technology, and the cost of the technology.

3.0   TYPES OF SOLAR PV SYSTEMS

3.1   Types of PV Systems

A PV power system requires more than just a simple panel; in fact, for a typical installation, the panel only accounts for about a fifth of the costs. The supporting equipment is often more expensive than the panel itself. Systems can be categorized by the type of power they produce, alternating current (AC) or direct current (DC), and whether the system is grid is integrated. Only AC power systems can be grid-integrated (23).

3.1.1 PV Direct Systems

In a PV direct system, the solar cells power DC circuitry directly and may have an integrated battery. These systems are common to household goods, including calculators, garden lights, signs, alarms, and many others. PV direct systems are best where mobile operation is needed or where grid integration is impractical (8). A schematic of a PV direct system is shown in Figure 7.

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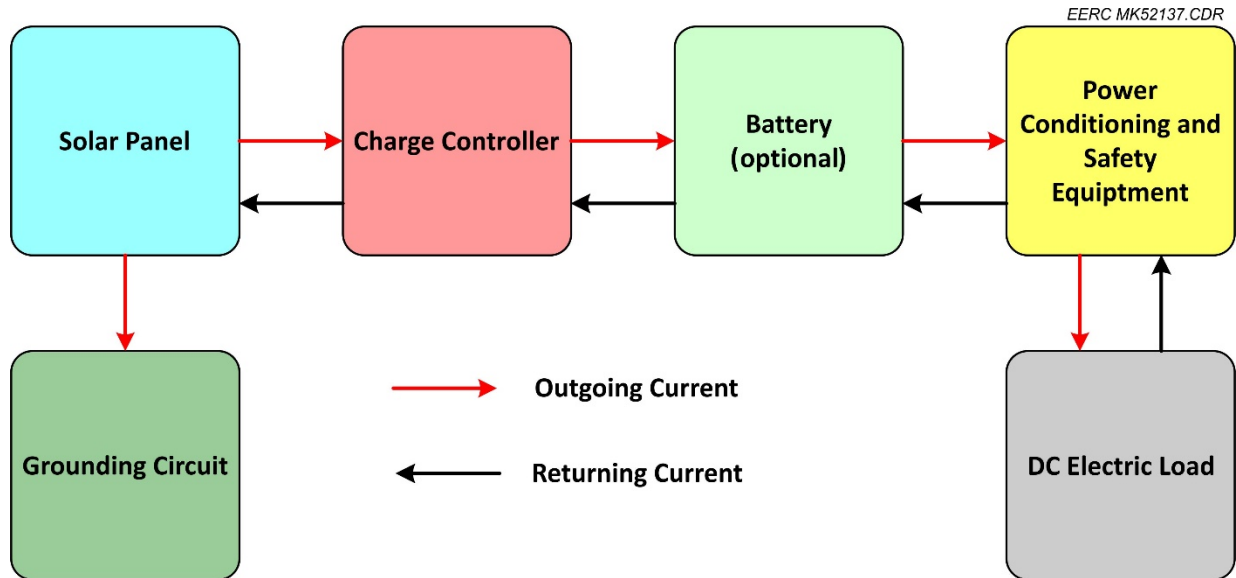
Figure 7. Schematic of a PV direct system.

3.1.2 Off-Grid Systems

Off-grid systems are similar to direct systems but convert their power to AC through an inverter. These systems typically use a DC battery backup before the inverter to supply power when it is needed (Figure 8). Off-grid systems can range in scale from a small handheld system to systems large enough to power large manufacturing facilities.

Off-grid systems are generally used in remote locations where the installation of a power line is cost-prohibitive, in areas with no or low-quality electrical grids, or for large mobile systems such as recreational vehicles. Because there are no alternative power sources, off-grid systems need battery storage to provide power after dusk and enough excess capacity to charge the battery for nighttime use (24).

| Solar Panel | Charge Controller | Battery (Optional) | Inverter |
| Grounding Circuit | | Local Grid | Power Conditioning and Safety Equiptment |

→ Outgoing Current

← Returning Current
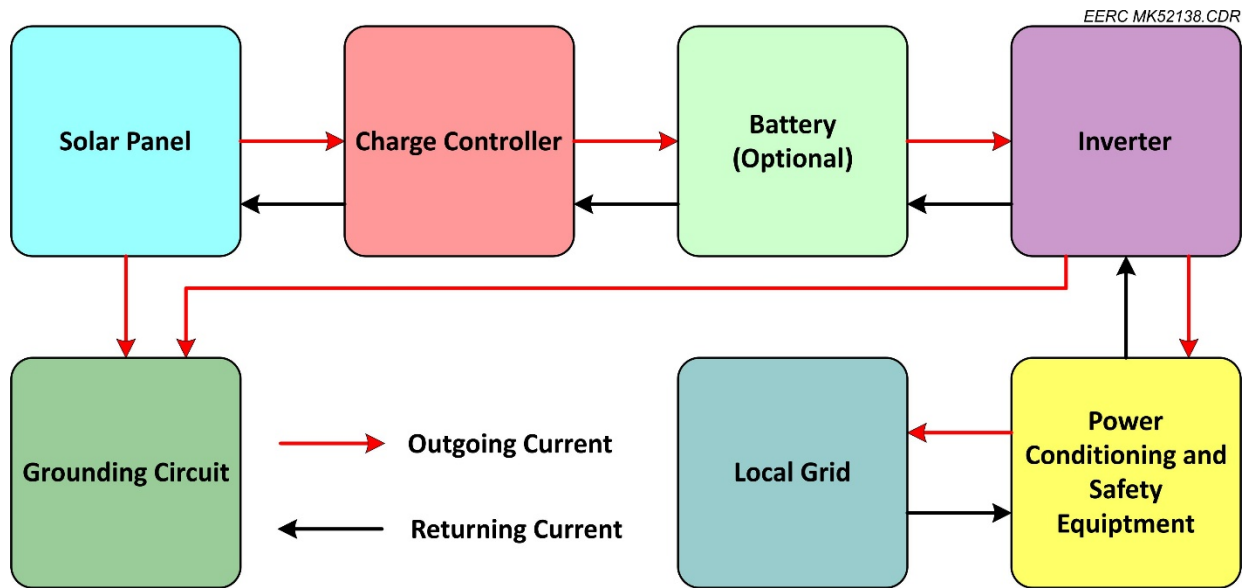
Figure 8. Schematic of an off-grid system.

3.1.3   *Grid-Connected Systems*

Grid-connected systems differ from off-grid systems in that they are connected to a utility grid while being able to measure electricity metered back to the utility grid. Grid-connected systems range in size from a few hundred watts to hundreds of megawatts for large utility-scale projects. A grid-integrated system requires the panel, inverter, and additional electronic controls to manage the grid system operation. A grid-integrated system must monitor the rest of the grid to condition the AC power correctly (Figure 9).

Grid-connected power needs additional instrumentation, metering, safety, and power conditioning equipment to work with the grid. The inverter must match the frequency and cycle of the grid, which must be actively monitored. Electrical flow to and from must be metered for billing. The system also needs to know to shut itself down if the grid goes offline. Electricity from local power sources, like solar, is a significant hazard for unsuspecting utility workers doing maintenance (24).

Being connected to the grid has several advantages of. The biggest advantage is being able to fall back on to the grid when there is no solar power being produced (night) or when there is low-intensity sunlight prohibiting the optimum functionality of the cells (cloudy days). Another advantage of being connected to the grid is the ability to sell excess power to the grid operator or utility company.
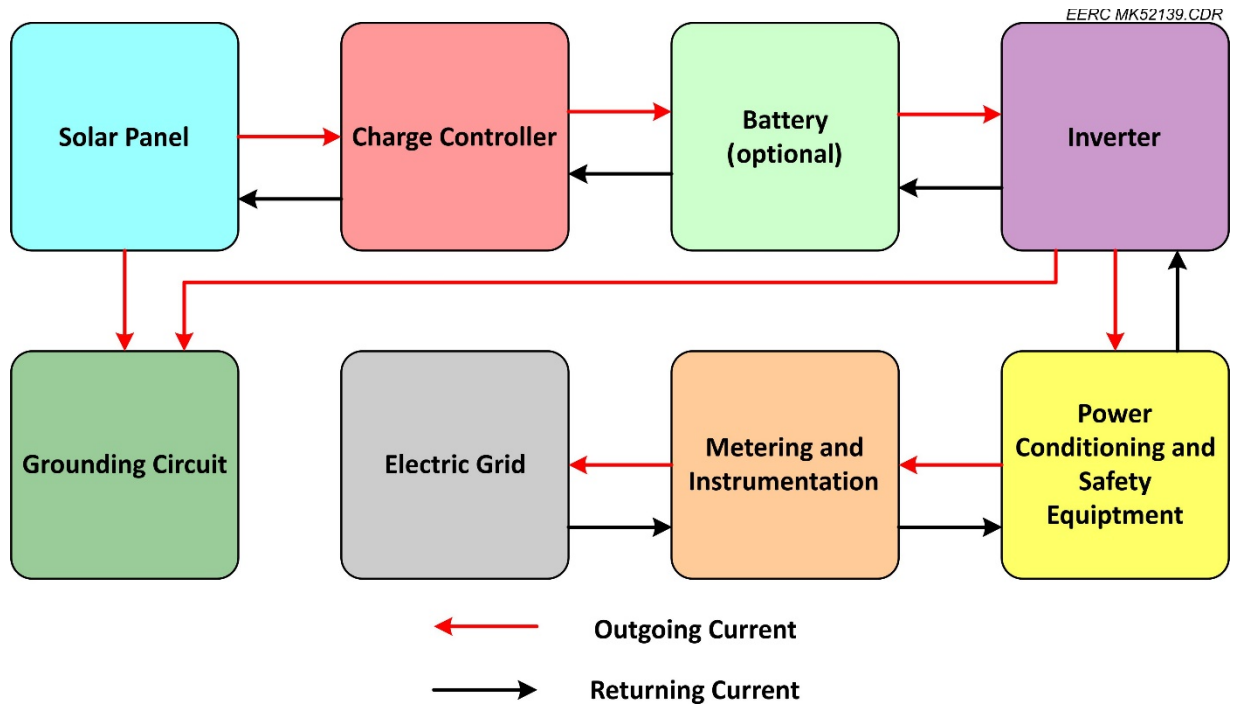
Figure 9. Schematic of a grid-connected system.

3.2   Analysis of Systems Best Suitable for North Dakota

Of the types of systems described before, a grid-connected system typically provides monetary and functional advantages compared to a PV direct system and an off-grid system. However, this is true only when the location of the solar panel already has grid connectivity and sufficient net metering benefits.

In comparing the advantages of having a grid-connected system in North Dakota with other states in the country, the monetary advantages are small because of the metering rules and electricity costs.

North Dakota's net metering policy, adopted in 1991 by the state's Public Service Commission, applies to renewable energy systems and combined heat and power systems up to 100 kilowatts (kW) in capacity. If a customer has net excess generation (NEG) at the end of a monthly billing period, the utility is required to purchase the NEG at the utility's avoided cost rate. "Avoided costs" means the costs of electricity for an electric utility (25). This may be understood as being the cost price of electricity to a utility company. Avoided cost is always lower than the price at which electricity is sold to the consumer. Further, in North Dakota, electricity costs are among the lowest in the nation, reducing the monetary benefit of solar PV. Virtually all states credit excess generation within the year. North Dakota where insolence is up to 143% higher between the months of highest insolence in July to the months of lowest insolence in December, as shown in Table 8, is an exception to this practice and reconciles excess generation only monthly at the avoided-cost rate (26). This is of disadvantage to the beneficiaries of net metering in North Dakota because of the difference in the solar insolance during the months of the year in North

Dakota. In many other states, credit of excess generation during the summer months can be used to offset the need of consumption of grid power during the months of low solar insolance. Additionally, North Dakota ranks 47th in the country for the average cost of electricity to residential consumers. By comparison, Minnesota ranks 19th, Wisconsin 13th, Montana 37th, and South Dakota 40th (27).

The economic advantage of PV electricity improves when the location is not serviced by the electrical grid. In such instances, the cost to run an electrical transmission line can, depending on distance, be greater than the cost of installing a PV system. Economics are highly dependent on location and transmission line installation costs and need to be evaluated on a case-by-case basis.

4.0   PERFORMANCE

4.1   Physical Location of a PV System

The overall performance of a PV system is influenced by several components, including PV cells, wiring, batteries, inverters, MMPTs (maximum power point tracking), and controls, etc., and each component imparts its own inefficiencies, causing a decrease in the overall efficiency of the system. Many inefficiencies are inherent to the components, and little can be done to improve their performance. The physical location of the array also affects the performance of a PV system since the amount of sun incident on the array changes according to the vertical angle, orientation, shading, etc. PV siting, therefore, is an important factor in maximizing the performance of the system.

4.1.1   Shading

Shading losses can be substantial and need to be accounted for if shade over the module cannot be avoided. Shading losses represent a reduction of the solar radiation incident on the array because of shadows created by nearby objects such as trees, buildings, light poles, etc. (8). Shading may also occur because of other solar arrays and is referred to as self-shading. The power lost is not proportional to the area of the system in shade but is, in fact, greater (28).

Although there are some instances in which shading cannot be avoided, such as clouds, there are, however, some ways to avoid shading. The most obvious way of avoiding shading is by placing the array in a location that receives the most sunlight through the course of the day and from season to season as the sun's position in the sky changes. Growing trees, future building development, and other structural changes should be considered when siting a PV array. This is especially important since most arrays are fixed type, have a long life and payment plan, and may be impractical to move to a different location.

The use of several microinverters on the PV system is one way of avoiding the effects of shading since the microinverters are connected to individual modules and convert all power from each panel, hence avoiding power losses from shaded strings (29).

A bypass diode can be installed on a substring that electrically removes the affected module from the string. In addition, the bypass diode prevents hot spots, a phenomenon in which PV cells get damaged when the light hitting the surface of a PV cell in a module is not uniform, as in the case of shading (28, 30).

4.1.2   PV Array Position: Tilt and Azimuth

The efficiency of a PV system is significantly impacted by the amount of time sunlight falls directly on the PV array. Tilt and azimuth are two words used to describe the orientation of a PV array toward the sun.

The tilt of a PV array describes the angle a panel is positioned from vertical (0°) to flat or horizontal (90°). In the northern hemisphere (North Dakota), the sun travels along a southerly path. The azimuth angle defines the compass direction from which sunlight is incident on the PV arrays. Therefore, in North Dakota, a tilt of some angle with azimuth toward the south should be used to capture the maximum amount of direct sunlight.

The angle of the sun changes between sunrise and sunset, and also between seasons. As a result, the angle of the PV array must be set to maximize the amount of the sun's energy incident on the solar panel. This angle or tilt can be fixed to one location, adjusted seasonally, to capture more solar energy or tracked continuously with an electronic tracking system. Tracking systems can be 1-axis or 2-axis trackers, allowing the PV array to track the sun along its daily path, adjust to the sun's position throughout the year, or both. Some examples of different PV array positions are described below.

To get the best array performance using a fixed position requires determining the position that will provide the best year-round average sunlight. This is achieved using the following equation:

- Optimum full-year tilt = 90° − your latitude
  The angle of the sun in the sky changes by 7.8°: higher in the summer and lower in the winter. For example, given that Grand Forks, North Dakota, has the coordinates 47°55'31"N and 97°1'57"W, an optimum year-round tilt would be 43°.

- Optimum winter tilt = 90° − your latitude – 15.6°
  For a location in Grand Forks, North Dakota, an optimum winter tilt will be approximately 27° from vertical.

- Optimum summer tilt = 90° − your latitude + 15.6°
  For a location in Grand Forks, North Dakota, an optimum summer tilt will be approximately 59° from vertical.

Figure 10 shows the typical effect of tilt on the amount of irradiation. It can be seen that when a tracking system is installed, the highest amount of solar exposure can be utilized compared to when the tilt is fixed all year long or adjusted according to the season.
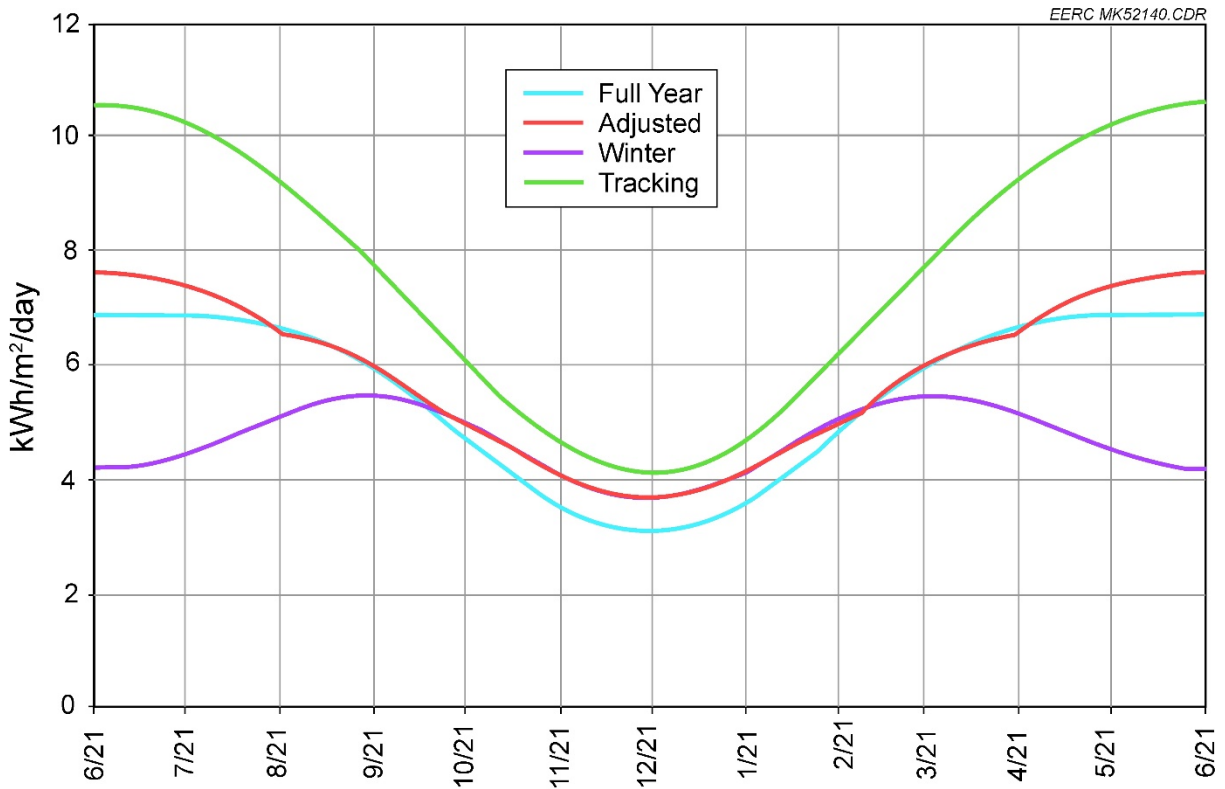
Figure 10. Effect of tilt on insolance.

The energy of the sun that is available to utilize in a certain part of the world is measured in the form of irradiance. Irradiance, also called insolance is measured in $W/m^2/day$ or $kW/m^2/day$. This value is used in knowing how much a power a solar panel will give per day based on the power output of the installed PV cell.

Table 3 gives year-round insolance data at different angles for North Dakota. The data in the table show that tilting the panels has definite advantages. For example, adjusting the tilt to 43 degrees—as the best year-round angle—gives cumulatively higher insolance (50.88 $kW/m^2/day$) over an entire year compared to when the panel is installed flat (45.79 $kW/m^2/day$) or upright (36.06 $kW/m^2/day$). Similarly, the best winter tilt gives better insolance than the year-round tilt during the winter, and summer tilt gives better insolance than year-round tilt during the summer. To obtain these data, averages have been collated over a 22-year period between 1983 and 2005 based on a 3-hour sample rate (8).

When a panel is installed such that it faces south, the azimuth angle is 180°. If the panel faces straight north, the azimuth angle is 0°. In the northern hemisphere, the amount of losses that the solar panel will have depends on the azimuth angle and how much it points away from optimum. It can be seen in Figure 11 that as the panel points 90° away in either direction from south, a loss of 20% is seen. This loss can be avoided if a tracking system is used to move the PV array to follow the sun's path across the sky through the day.

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Table 3. Insolance Data for North Dakota*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flat – 90°	1.48	2.35	3.47	4.77	5.72	6.26	6.49	5.48	4.06	2.73	1.71	1.27
Upright – 0°	2.36	3.02	3.29	3.29	3.06	2.98	3.22	3.36	3.47	3.25	2.61	2.15
43° – Angle Year-Round Tilt	2.49	3.46	4.28	5.01	5.27	5.43	5.79	5.5	4.78	3.85	2.8	2.22
27° – Angle Best Winter Tilt	2.58	3.48	4.13	4.6	4.63	4.67	5.01	4.95	4.54	3.83	2.88	2.32
59° – Angle Best Summer Tilt	2.28	3.26	4.22	5.19	5.68	5.96	6.3	5.78	4.78	3.67	2.57	2.01
Tilt Adjusted Each Month	2.58	3.5	4.28	5.19	5.68	6.3	6.3	5.82	4.78	3.87	2.88	2.32
	27°	35°	43°	51°	59°	66°	59°	51°	43°	35°	27°	20°

* All values shown are in kW/m^2/day.
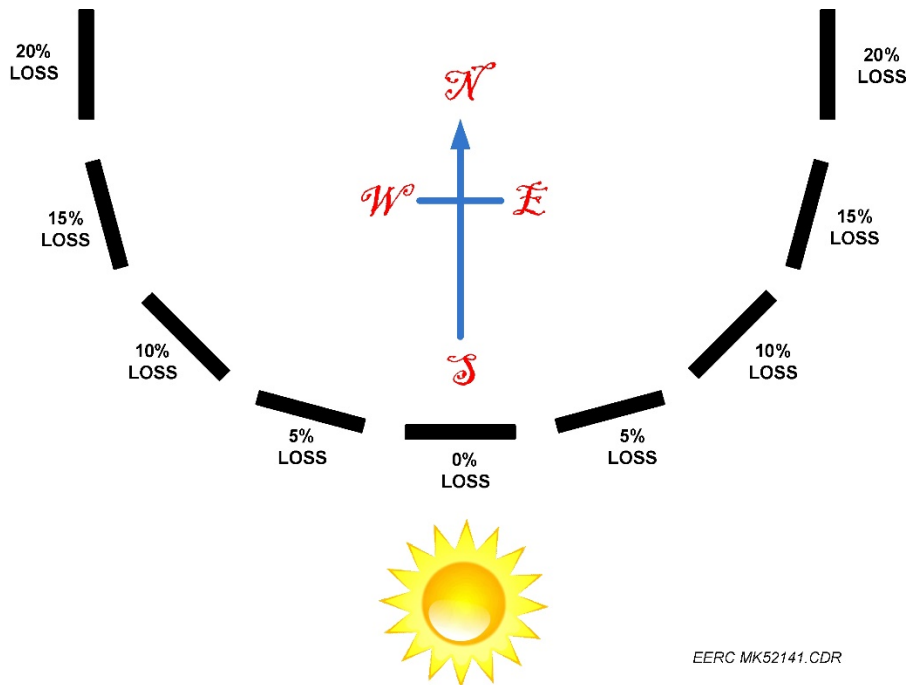
Figure 11. Effect of azimuth angle on losses.

4.2 Battery and Inverter Efficiencies

It is important to take into account the inefficiencies of the battery and the inverter when a PV system is designed. Usually there is a 5% loss in the energy stored in the battery after charging and using the charge. Similarly, the DC to AC conversion efficiency of an inverter is approximately 95%.

4.3 Other Inefficiencies

Other important factors that may cause a drop in the efficiency of a system are soiling, snow, mismatch, wiring, connection, temperature, and age. Although each of the inefficiencies provides only up to 4%, cumulatively they can reduce the efficiency of a system by almost 15% (31).

5.0 INCENTIVES FOR SOLAR POWER UTILIZATION

To encourage the use of renewable energy, government agencies (state and federal) offer a variety of tax credits, rebates, and other incentives. These incentives apply to all forms of renewable energy including but not limited to solar energy, geothermal energy, and wind energy. In addition to incentives for installation of energy conversion systems such as solar energy to electricity, wind energy to electricity, geothermal to heat, etc., the use of energy-efficient products is also encouraged to support efforts to diversify energy supply and improve energy conservation.

Incentives are offered by state governments and the federal government. Mentioned below are the incentives that are offered for solar power installations only and are specific to solar power in the state of North Dakota. Details of federal incentives have also been given and are applicable to all 50 states.

5.1 North Dakota State Incentives

Based on the information found on the DSIRE Web site (32), North Dakota offers 17 incentives for solar power. Not all of them are incentives in the financial sense but are concessions for owners that use solar power. Following are the financial incentives specific to PV in North Dakota.

5.1.1 Renewable Energy Property Tax Exemption (33)

There is a renewable energy property tax exemption for installations, machinery, and equipment or systems in new or existing buildings or structures designed to provide heating or cooling or to produce electrical or mechanical power, or any combination of these, or to store any of these, by utilization of solar, wind, or geothermal energy; provided that if the solar, wind, or geothermal energy device is part of a system which uses other means of energy, only that portion of the total system directly attributable to solar, wind, or geothermal energy is exempt. Any exemptions granted by this incentive are valid for a 5-year period following installation of such system and apply only to locally assessed property. For the purposes of this subsection of the North Dakota Century Code, solar or wind energy devices shall have the meaning provided in Section 57-38-01.8, and geothermal energy device means a system or mechanism or series of mechanisms designed to provide heating or cooling or to produce electrical or mechanical power, or any combination of these, by a method which extracts or converts the energy naturally occurring beneath the earth's surface in rock structures, water, or steam.

5.1.2   Net Metering (25)

Net metering allows residential and commercial customers who generate their own electricity from solar power to feed electricity they do not use back into the grid. North Dakota's net-metering policy, adopted in 1991 by the state's PSC, applies to renewable energy systems and CHP systems up to 100 kW in capacity only.

5.1.3   Sales and Use Tax Exemption of Electrical Generating Facilities (34, 35)

This incentive applies to electricity-generating facilities that are exempt from sales and use taxes. The exemption is granted for the purchase of building materials, production equipment, and any other tangible personal property that is used for constructing or expanding the facility. In order to qualify, the facility must have at least one electrical generation unit with a capacity of at least 100 kW. Because of the limit on the capacity of the electricity-generating facility, it is unlikely that this incentive would be of use for residential users of solar power.

5.2   Federal Incentives

Several incentives for the application of solar power, the investment in solar power, etc., on a residential scale, commercial scale, and utility scale have been made available by the federal government. These incentives are in the form of tax credits, loans, mortgages, etc.

The 17 incentives detailed below can be applied to other renewable sources in addition to solar power utilization; however, several additional incentives are not applicable to solar power and can be found on the DSIRE (32) Web site.

5.2.1   Business Energy Investment Tax Credit (36)

The solar investment tax credit (ITC) is a tax credit that can be claimed on federal corporate income taxes for 30% of the cost of a solar PV system that is placed in service during the tax year (37).

Eligible solar energy property includes equipment that uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat. Hybrid solar lighting systems, which use solar energy to illuminate the inside of a structure using fiber-optic distributed sunlight, are eligible. Systems that are considered passive solar systems and solar pool-heating systems are not eligible. Technologies that directly convert solar energy to electric, heat water, and heat space are included in the tax credit. Solar credits do not have a maximum. 30% of all expenditures can be included in the credit.

The federal business energy ITC has been amended a number of times, most recently in December 2015. Table 4 shows the value of the ITC for each technology by year. The expiration date for solar technologies and wind is based on when construction begins. For all other technologies, the expiration date is based on when the system is placed in service (fully installed and being used for its intended purpose).

Table 4. Business Energy Tax Credit for Future Years (36)

Technology	PV, Solar Water Heating, Solar Space Heating/Cooling, Solar Process Heat	Hybrid Solar Lighting, Fuel Cells, Small Wind
12/31/2016	30%	30%
12/31/2017	30%	N/A
12/31/2018	30%	N/A
12/31/2019	30%	N/A
12/31/2020	26%	N/A
12/31/2021	22%	N/A
12/31/2022	10%	N/A
Future Years	10%	N/A

If the system was installed utilizing a lease scheme, or on a loan, the business is not eligible to use the ITC. The 30% credit is applied after any state incentives have been applied to the total cost of the PV system installation.

5.2.2 *Residential Energy Conservation Subsidy Exclusion (personal) (38)*

According to Section 136 of the U.S. IRS (Internal Revenue Service) Code, energy conservation subsidies provided directly or indirectly to customers by public utilities are nontaxable. A "public utility" is defined as an entity "engaged in the sale of electricity or natural gas to residential, commercial, or industrial customers for use by such customers." The term includes federal, state and local government entities. Means of energy conservation include installations or modifications primarily designed to reduce consumption of electricity or natural gas or to improve the management of energy demand. The definition of "energy conservation" implies that utility rebates for residential solar-thermal projects and PV systems may be nontaxable. However, the IRS has not ruled definitively on this issue.

If a taxpayer claims federal tax credits or deductions for the energy conservation property, the investment basis for the purpose of claiming the deduction or tax credit must be reduced by the value of the energy conservation subsidy (i.e., a taxpayer may not claim a tax credit for an expense that the taxpayer ultimately did not pay).

5.2.3 *Modified Accelerated Cost-Recovery System (MACRS) (39)*

Under the federal MACRS, businesses may recover investments in certain property through depreciation deductions. MACRS establishes a set of class lives for various types of property, ranging from 3 to 50 years, over which the property may be depreciated. A number of renewable energy technologies are classified as 5-year property (26 USC § 168(e)(3)(B)(vi)) under the MACRS, which refers to 26 USC § 48(a)(3)(A), often known as the energy ITC to define eligible property (37). In relation to solar power utilization, such property currently includes a variety of solar-electric and solar-thermal technologies.

The 5-year schedule for most types of solar, geothermal, and wind property has been in place since 1986. The Federal Energy Policy Act of 2005 classified fuel cells, microturbines, and solar

hybrid lighting technologies as 5-year property as well by adding them to § 48(a)(3)(A). This section was further expanded in October 2008 by the addition of geothermal heat pumps, CHP, and small wind under the Energy Improvement and Extension Act of 2008.

The Federal Economic Stimulus Act of 2008, enacted in February 2008, included a 50% first-year bonus depreciation (26 USC § 168(k)) provision for eligible renewable energy systems acquired and placed in service in 2008. The allowance for bonus depreciation has since been extended and modified several times since the original enactment, most recently in December 2014 by the Tax Increase Prevention Act of 2014 (H.R. 5771, Section 125). This legislation extended the "in-service" provision for qualifying property through to December 31, 2014, and thus also did so retroactively for property placed in service after December 31, 2013, through to enactment.

5.2.4 Residential Energy Conservation Subsidy Exclusion (corporate) (40)

This residential energy conservation subsidy exclusion for corporate applications is similar to the exclusion for personal uses.

5.2.5 Energy-Efficient Mortgages (41)

Homeowners can take advantage of energy-efficient mortgages (EEM) to either finance energy-efficiency improvements to existing homes, including renewable energy technologies, or to increase their home buying power with the purchase of a new energy efficient home. The U.S. federal government supports these loans by insuring them through Federal Housing Authority (FHA) or Veterans Affairs (VA) programs. This allows borrowers who might otherwise be denied loans to pursue energy efficiency, and it secures lenders against loan default.

The FHA allows lenders to add up to 100% of energy-efficiency improvements to an existing mortgage loan with certain restrictions. FHA mortgage limits vary by county, state, and the number of units in a dwelling. The maximum amount of the portion of an energy-efficient mortgage allowed for energy improvements is now the lesser of 5% of:

- The value of the property.
- 115% of the median area price of a single-family dwelling.
- 150% of the Freddie Mac conforming loan limit.

Loan amounts may not exceed the projected savings of the energy-efficiency improvements. These loans may be combined with FHA 203 (h) mortgages available to victims of presidentially declared disasters and with financing offered through the FHA 203 (k) rehabilitation program. FHA loan limits do not apply to EEM. Homebuyers must submit a Home Energy Rating (HER), contractor bids, and an FHA B Worksheet.

Borrowers may include closing costs and the up-front mortgage insurance premiums in the total cost of the loan. The loan is available to anyone who meets the income requirements for FHA's Section 203 (b), provided the applicant can meet the monthly mortgage payments. New and existing owner-occupied homes of up to two units qualify for this loan. Cooperative units are

not eligible. Homebuyers should submit applications to their local HUD Field Office through an FHA-approved lending institution.

5.2.6   USDA Rural Energy for America Program (REAP) Grants (42, 43)

The U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) provides financial assistance to agricultural producers and rural small businesses in America to purchase, install, and construct renewable energy systems, make energy-efficiency improvements to nonresidential buildings and facilities, use renewable technologies that reduce energy consumption, and participate in energy audits and renewable energy development assistance.

Eligible project costs include purchasing energy-efficiency improvements or a renewable energy system, energy audits or assessments, permitting and licensing fees, and business plans and retrofitting. For new construction, the replacement of older equipment with more efficient equipment may be eligible as a project cost only when a new facility is planned to be more efficient and similarly sized than the older facility. Working capital and land acquisition are only eligible for loan guarantees. Eligible areas include businesses that are in an area other than a city or town with a population of greater than 50,000 inhabitants and the urbanized area of that city or town. Agricultural producers may be in rural or nonrural areas.

Renewable energy projects for the Renewable Energy Systems and Energy Efficiency Improvement Guaranteed Loan and Grant Program include wind, solar, biomass and geothermal, and 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. The combined amount of a grant and loan guarantee must be at least $5000 (with the grant portion at least $1500) and may not exceed 75% of the project's cost. In general, a minimum of 20% of the funds available for these incentives will be dedicated to grants of $20,000 or less.

Application due dates are published annually in the Notice of Funding Availability.

5.2.7   Tribal Energy Program Grant (44, 45)

The U.S. Department of Energy (DOE) Tribal Energy Program promotes tribal energy sufficiency, economic growth, and employment on tribal lands through the development of renewable energy and energy-efficiency technologies. The program provides financial assistance, technical assistance, and education and training to tribes for the evaluation and development of renewable energy resources and energy efficiency measures. The DOE regularly puts out solicitations for current funding opportunities.

5.2.8   Residential Renewable Energy Tax Credit (46, 47)

A taxpayer may claim a credit of 30% of qualified expenditures for a system that serves a dwelling unit located in the United States that is owned and used as a residence by the taxpayer. Expenditures with respect to the equipment are treated as made when the installation is completed. If the installation is at a new home, the "placed in service" date is the date of occupancy by the homeowner. Expenditures include labor costs for on-site preparation, assembly or original system

installation, and piping or wiring to interconnect a system to the home. If the federal tax credit exceeds tax liability, the excess amount may be carried forward to the succeeding taxable year.

The credit that can be claimed has been projected to drop in the upcoming years from the current value of 30% to 10% in 2022 and ahead. Table 5 shows the maximum allowable credit by year. The dates in the first column specify the dates that the system must be installed by to be able to claim a tax credit during the same year. In the case of a solar water heating property, the equipment must be certified for performance by the Solar Rating Certification Corporation (SRCC) or a comparable entity endorsed by the government of the state in which the property is installed, at least half the energy used to heat the dwelling's water must be from solar, and does not apply to solar water-heating property for swimming pools or hot tubs.

Table 5. Residential Renewable Energy Tax Credit for Future Years

Technology*	Solar Electric Property, Solar Water Heating Property
12/31/2019	30%
12/31/2020	26%
12/31/2021	22%
12/31/2022	10%
Future Years	10%

* Date the service is installed by.

5.2.9   Clean Renewable Energy Bonds (CREBs) (48)

Clean renewable energy bonds (CREBs) may be used by certain entities—primarily in the public sector—to finance renewable energy projects. CREBs may be issued by electric cooperatives, government entities (states, cities, counties, territories, Indian tribal governments, or any political subdivision thereof), and by certain lenders. The bondholder receives federal tax credits in lieu of a portion of the traditional bond interest, resulting in a lower effective interest rate for the borrower.

The tax credit rate is set daily by the U.S. Treasury Department. Under past allocations, the credit could be taken quarterly on a dollar-for-dollar basis to offset the tax liability of the bondholder. However, under the new CREBs allocation, the credit has been reduced to 70% of what it would have been otherwise. Other important changes are described in IRS Notice 2009-33.

5.2.10 USDA Rural Energy for America Program (REAP) Loan Guarantees (49)

The REAP loan guarantee is similar in policy to the REAP grants differing only in the incentives offered and in maximum loan offered. The REAP grant offers renewable grants of $2500–$500,000, efficiency grants of $1500–$250,000, and loan and grant combinations in which the grant portion must exceed $1500 while REAP loan guarantees are $25 million per loan guarantee.

5.2.11 U.S. Department of Energy Loan Guarantee Program (50)

Under Section 1703, DOE is authorized to issue loan guarantees for projects with high technology risks that "avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies in service in the United States at the time the guarantee is issued." Loan guarantees are intended to encourage early commercial use of new or significantly improved technologies in energy projects. The loan guarantee program generally does not support research and development projects.

Loan guarantees are provided in response to open solicitations. The updated supplemental guidance for Renewable Energy Projects and Energy Efficiency Projects included an application solicitation schedule, with a final Part I application due date of July 13, 2016. Up to $3 billion is available in loan guarantees for projects in renewable energy, efficient end use, and efficient generation, transmission, and distribution technologies (plus an additional amount that may be imputed based on the credit subsidy cost of the loan guarantee authority). See the program's Web site for more details on eligibility and the application process.

Section 1703 requires either an appropriation to cover the Credit Subsidy Cost (the expected long-term liability to the federal government for providing the loan guarantee) or payment of the Credit Subsidy Cost by the borrower. A credit-based interest rate spread will be added to certain loans receiving a 100% loan guarantee from DOE and financing from the Federal Financing Bank. Rates and more information are available at its Web site.

5.2.12 Qualified Energy Conservation Bonds (QECBs) (51)

The Energy Improvement and Extension Act of 2008, enacted in October 2008, authorized the issuance of QECBs that may be used by state, local, and tribal governments to finance certain types of energy projects. QECBs are qualified tax credit bonds and in this respect are similar to new CREBs. In contrast to CREBs, QECBs are not subject to a U.S. Department of Treasury application and approval process. Bond volume is instead allocated to each state based on the state's percentage of the U.S. population.

With tax credit bonds, generally the borrower who issues the bond pays back only the principal of the bond, and the bondholder receives federal tax credits in lieu of the traditional bond interest. The tax credit may be taken quarterly to offset the tax liability of the bondholder. The tax credit rate is set daily by the U.S. Treasury Department; however, energy conservation bondholders will receive only 70% of the full rate set by the Treasury Department. Credits exceeding a bondholder's tax liability may be carried forward to the succeeding tax year but cannot be refunded. Energy conservation bonds differ from traditional tax-exempt bonds in that the tax credits issued through the program are treated as taxable income for the bondholder.

5.2.13 USDA High-Energy-Cost Grant Program (52)

The USDA offers an ongoing grant program for the improvement of energy generation, transmission, and distribution facilities in rural communities. This program began in 2000.

Eligibility is limited to projects in communities that have average home energy costs at least 275% above the national average. Individuals, nonprofits, commercial entities, state and local governments (including any agency or instrumentality thereof), and tribal governments are eligible for this grant. Individuals must work on a project that will benefit the community in order to qualify.

The most recent solicitation for this program closed August 1, 2014, and it is unclear if the USDA will continue future solicitations.

5.2.14 FHA PowerSaver Loan Program (53)

FHA through its PowerSaver loan program offers three financing options for homeowners to make energy-efficiency and renewable energy upgrades in their residences. For all three PowerSaver products, borrowers must select from a list of approved PowerSaver lenders.

To qualify for the FHA loan, the homeowner must meet certain criteria of credit scores, income-to-debt ratio, a certified appraisal of the property, etc. Eligible home energy upgrades include, but are not limited to, insulation and air sealing; replacing doors and windows; upgrading of heating, cooling, and ventilations; installation of PV systems; solar hot water systems, etc.

5.2.15 USDA REAP Energy Audit and Renewable Energy Development Assistance (EA/REDA) Program (54)

The REAP EA/REDA Program provides assistance to agricultural producers and rural small businesses for energy audits and renewable energy technical assistance including renewable energy site assessments.

Eligible project costs for eligible applicants include salaries directly related to the project, travel expenses directly related to conducting energy audits or renewable energy development assistance, office supplies (e.g., paper, pens, file folders), administrative expenses, and up to a maximum of 5% of the grant, which include but are not limited to utilities, office space, operation expenses of the office, and other project-related equipment.

5.2.16 Low Income Home Energy Assistance Program (LIHEAP) (55)

The Low Income Home Energy Assistance Program (LIHEAP) provides resources to assist families with energy costs. This federally funded assistance helps in managing costs associated with home energy bills, energy crises, weatherization, and energy-related minor home repairs.

The program is available in all 50 U.S. states, Indian Tribe or Tribal organization, and U.S. territories that include American Samoa, Guam, the Northern Mariana Islands, Puerto Rico, and the Virgin Islands.

The LIHEAP statutes establish 150% of the poverty level as the maximum income level allowed in determining LIHEAP income eligibility, except where 60% of the state median income

is higher. Income eligibility criteria for LIHEAP may not be set lower than 110% of the poverty level.

6.0   ANALYSIS OF NORTH DAKOTA INCENTIVES

6.1   State Incentive Comparison

Section 5.1 of this report gives details of the incentives available to residents of North Dakota for solar power. Of the four tax credits that are available, the renewable tax credit has currently expired, giving residents access to three incentives in the state.

Table 6 lists and compares the incentives offered to residents of North Dakota, Minnesota, Wisconsin, Montana, and South Dakota. Comparisons of the available incentives have been made by color coding the cells. Cells highlighted in green are sales tax exemptions, blue are property tax exemptions, and orange are net metering incentives. This has been done to list incentives that are common in all of the states being compared. As mentioned previously, states that neighbor North Dakota were chosen in addition to Wisconsin because it lies within the latitudes that span South Dakota and North Dakota. All North Dakota incentives are state-sponsored, and no current incentives are offered by utilities for solar PV. Inversely, several incentives are being offered by utility companies in Minnesota. What is important to note is that most of these utility incentives are localized within Minnesota. Within North Dakota, it is important to note that while several incentives are being offered by utility companies for other forms of renewable energy such as geothermal and wind power, they are not shown in the table.

In 2007, Minnesota legislation modified the state's 2001 voluntary renewable energy objective to create a mandatory renewable portfolio standard (RPS). Public utilities (i.e., invester-owned utilities), generation and transmission electric cooperatives, municipal power agencies, and power districts operating in the state are now required to have at least 25% of retail electricity sales generated or procured using eligible renewable sources by 2025, with a higher standard for Minnesota's nuclear utility, Xcel Energy. In 2013, an additional requirement was made that all public utilities have 1.5% of retail electricity sales be generated or procured using solar energy by 2020. A statewide goal of 10% of retail electric sales from solar by 2030 was set. As a result, individual utility companies offer rebate programs that can be seen in Table 6. Wisconsin and Montana have similar RPSs with different targets which encourage utilities to offer rebate programs not seen in South Dakota and North Dakota.

Table 6. Comparison of State Incentives

Entity	Description	Incentive
North Dakota		
ND State Tax Commissioner	Sales and use tax exemption	100% tax exemption
ND Department of Commerce	Property tax exemption	100% exemption
ND Public Service Commission	Net metering	Monthly avoided cost rate
ND Department of Commerce	REC tax credit	3%/year
Minnesota		
State Department of Revenue	Solar energy sales tax exemption	100% exemption
State of Minnesota	Property tax credit	No limit
MN Public Utilities Commission	Net metering	Payment/credit
New Ulm Public Utilities	Solar electric rebate program	$1/watt
Farm Opportunities Loan Program	Loan program	3% loan
Excel Energy Solar Rewards	Performance based incentive	$0.08/kWh
Minnesota Power	Power grant program	$200/kW
Minnesota Power	Residential new const. Rebate	$2000
Made in Minnesota	Solar PV incentive program	$0.13/kWh
Made in Minnesota	Solar PV incentive program	$0.23/kWh
Minnesota Power	Solarsense solar rebate program	$750/kW-DC
St. Paul Port Authority	PACE loan program	5% interest rate
Rural Minnesota Energy Board	PACE loan program	4% interest rate
Excel Energy	Renewable dvl. Fund grants	Variable grants
Owatonna Public Utilities	Solar rebate program	$0.50/watt
Rural Finance Authority	Value-added stock loan	4% rate for 8 years
Rochester Public Utilities	Solar rebate program	$0.50/watt
MN Housing Finance Agency	Fix up loan	5.99% interest rate
Austin Utilities	Solar rebate program	$0.50/watt
Brainerd Public Utilities	Renewable incentives program	$2/watt
Moorhead Public Service Utility	Renewable energy incentives	Grant
Steele-Waseca Coop. Electric	Sunna project	Grant
Shakopee Public Utilities	Energy efficiency rebate program	$1.25/watt
Wisconsin		
Department of Revenue	Sales and use tax exemption	100%
Department of Revenue	Property tax incentive	100% of value added
State Electric Utilities	Net metering	Payment/credit
Shaw Envr. & Infrastructure, Inc.	Focus on energy – grant	Up to $0.50/kWh
Madison Gas & Electric Co.	Performance-based incentive	$0.25/kWh
City of River Falls	Performance-based incentive	$0.35/kWh
City of River Falls	PACE loan program	4% interest rate loan
WI Energy Conservation Corp.	Rebate program	$600/kW
City of Milwaukee	Loan program	Prime + 1.5 − 2.25% loan

Continued . . .

Table 6. Comparison of State Incentives (continued)

Entity	Description	Incentive
Montana		
Department of Envr. Quality	Res. Alt. Energy system tax credit	100% of system cost
Department of Revenue	RE systems property tax exemption	100% for 10 years
Department of Revenue	Corporate property tax reduction	50% of system $ for 5 years
Department of Revenue	Property tax abatement	50% tax abatement
Northwestern Corporation	Net metering	Payment/credit
Electric Coop. (MECA members)	Net metering	Payment/credit
Northwestern Energy	USB renewable energy rebate program	$2k/customer, $0.50/W cmrcl.
Department of Revenue	Alt. Energy inv. Tax credit – commercial	35% tax credit
Department of Revenue	Alt. Energy inv. Tax credit – corporate	35% tax credit
Department of Revenue	Alt. Energy inv. Tax credit – individual	35% tax credit
Department of Envr. Quality	Alt. Energy revolving loan program	3.25% loan up to 10 years
Department of Revenue	Generation facility corp. Tax exemption	100% for 5 years
South Dakota		
State Office of Econ. Dvlp.	Sales tax exemption	100% of all sales tax
State Department of Revenue	Property tax exemption	$50,000 or 70% of value

6.2 Case Study

An attempt was made to compare the time it would take to break even after a solar power system was installed in all of the states mentioned above: North Dakota, Minnesota, Wisconsin, Montana, and South Dakota.

A tool developed by the National Renewable Energy Laboratory (NREL) that estimates the energy production and the cost of energy of PV systems was used in the calculation of annual savings by the use of a solar PV system. An additional simulation software called the System Advisor Model (SAM) also created by NREL was used to calculate the cost of a standard solar PV system (33). SAM calculations showed that a system with nameplate size of 6-kWdc cost approximately $20,000. In calculating this price of a solar PV system, the following assumptions were made. For example, when the system nameplate is 6-kWdc and an assumption is made for a DC to AC ratio of 1.1, the inverter rating is 6-kWdc ÷ 1.1 = 5.45 kWac.

System nameplate size: 6-kWdc
Module type: Standard
DC to AC ratio: 1.1 *(rated inverter size: 5.45 kWac)*
Inverter efficiency: 96%
Total system losses: 14.08%
Module cost: 0.78 $/Wdc *(module cost: $4680)*
Inverter cost: 0.55 $/Wac *(inverter cost: $3300)*
Balance of system equipment: 0.80 $/Wdc *(balance of system cost: $4800)*
Installation labor: 0.30 $/Wdc *(installation cost: $1800)*
Installer margin and overhead: 0.80 $/Wdc *(installer margin and overhead cost: $4800)*
Total direct cost: $19,380
Permitting fees: 0.10 $/Wdc *(permitting fees: $600)*

Sales tax basis, percent of direct cost: 5% *(sales tax: $48.5)*
Total indirect cost: $648.5
Total installed cost: $20,028.5 *($3.34/Wdc)*

While the assumptions mentioned above were made in calculating the cost of the PV system, and were applicable to all the locations shown in the table below, other constants such as total system losses (14.08%) and azimuth (180°) were chosen and were consistent for all the locations shown in the Table 7. Variables chosen based on location were the angle of tilt—which was chosen to be the optimum year-round fixed angle of tilt based on the latitude—and the cost of electricity. Varying locations gave varying insolances and have been included in the table below.

An example has been showcased above to compare the cost savings by the hypothetical installation of a similar 6kWdc system in each of the five states in a physically similar manner. To calculate this, the cost of electricity in each of the five states was required and that information was collected from the U.S. Energy Information Administration (EIA) that provides data of the average price of electricity (59). These data were then input in the PVWatts tool, and the output provided the total savings in a year in dollars which can be explained as the total cost that would offset the cost of purchasing electricity from a utility.

The total savings by installing a solar PV system are directly proportional to the insolance in a particular location and the cost of purchasing electricity from a utility in that location. It can be seen from Table 7 that the savings were highest for Wisconsin ($1098), and lowest for North Dakota ($800). This was because, among the five states compared, the cost of electricity in 2016 was highest in Wisconsin ($0.1409/kWh) and lowest in North Dakota ($0.0941/kWh). The savings in Wisconsin were high despite the fact that the average annual radiation received by the state of Wisconsin compared to the four other states annually was the lowest at 4.43 kWh/m^2/day.

It is clear from this analysis of five locations at similar latitude that the cost of electricity plays a very important role in determining the cost savings from a solar PV system. However, some factors can increase system efficiency and offset the impact of the cost of electricity; namely, the angle of tilt and the kind of module can have big impacts on overall system performance and payback. From Table 7 it can be seen that, for North Dakota, the tilt of the system was set at 43°. This angle of tilt was calculated as an efficient year-round angle. However, if this angle of tilt were adjusted using a single-axis tracker or a double-axis tracker, the insolance is higher, thus giving a higher amount of energy that can be offset, which can be seen from Table 8. The electricity cost savings associated with the installation of a two-axis tracker is approximately 37% higher than a fixed tilt system. However, a higher cost is associated with the installation of a two-axis tracker, making the system more expensive, a factor not accounted for in Table 8.

An additional factor to add to the savings is any kind of incentive offered to a potential installer of solar PV. In the case of a resident of North Dakota, where there are no significant savings in the form of state incentives, where the cost of electricity is low in addition to the lack of savings in the form of state incentives, the installation of solar power does not provide any financial advantage purely when compared to the four other states of Minnesota, Wisconsin, Montana, and South Dakota.

Table 7. Cost Savings of a Typical Panel in North Dakota, Minnesota, Wisconsin, Montana, and South Dakota

	North Dakota		Minnesota		Wisconsin		Montana		South Dakota	
Requested Location	58502		55111		53704		59602		57501	
Location	Bismarck Municipal Arpt [ISIS], ND		Minneapolis-St Paul Int'L Arpt, MN		Madison Dane Co. Regional Arpt, WI		Helena Regional Airport, MT		Pierre Municipal Arpt, SD	
Lat. (deg N)	46.77		44.88		43.13		46.6		44.38	
Long (deg W)	100.77		93.23		89.33		111.97		100.28	
Elev (m)	502		254		262		1167		528	
Module Type	Standard		Standard		Standard		Standard		Standard	
Array Type	Fixed (open rack)		Fixed (open rack)		Fixed (open rack)		Fixed (open rack)		Fixed (open rack)	
Array Tilt (deg)	43		45		47		43		46	
Elect. Cost ($/kWh)	0.0941		0.1214		0.1409		0.1052		0.1034	
Month	Solar Radiation, kWh/m²/day	Value, $	Solar Radiation, kWh/m²/day	Value, $	Solar Radiation, kWh/m²/day	Value, $	Solar Radiation, kWh/m²/day	Value, $	Solar Radiation, kWh/m²/day	Value, $
Jan	3.3243	52.43	3.5438	72.04	3.3371	79.40	3.0514	51.58	3.6118	61.81
Feb	3.5148	49.20	4.2955	75.89	3.9922	82.66	4.0289	60.62	4.2535	64.10
Mar	4.7473	70.16	4.8753	91.95	4.3388	95.34	4.8239	78.56	5.0330	81.89
Apr	5.6463	77.37	5.1330	90.02	4.8802	99.59	5.6162	86.42	5.1642	77.16
May	5.8647	80.06	5.7098	99.55	5.4282	109.94	5.6705	88.10	5.4442	81.43
Jun	6.1046	78.89	5.7788	95.41	5.6491	108.20	6.1250	88.84	6.0159	84.94
Jul	6.4039	83.30	5.5673	94.07	5.5741	109.33	6.8622	100.50	6.2794	89.84
Aug	6.0160	79.74	5.3044	91.34	5.4073	106.90	6.1908	91.77	5.7730	83.79
Sep	5.7134	75.32	4.9411	83.19	4.8771	94.77	5.5343	80.56	5.7472	82.37
Oct	4.6220	66.92	4.1957	76.49	3.9441	83.59	4.1950	65.76	4.8235	75.39
Nov	3.1145	45.49	2.9326	54.69	2.9128	62.57	3.2303	51.71	3.2840	52.39
Dec	2.6331	41.54	2.5518	50.74	2.7777	65.30	2.8307	47.84	2.9991	51.28
Total	–	800.42	–	975.38	–	1097.6	–	892.26	–	886.39
Average	4.8087	–	4.5691	–	4.4266	–	4.8466	–	4.8691	–

A break-even analysis was conducted to compare the time required to recover the capital expense of the hypothetical 6-kWdc system described previously. In North Dakota, no state incentives exist to reduce the cost of the PV system. However, federal ITC can be used to reduce the effective cost of a new PV system. Assuming no state incentive was used, the cost of the system would drop from $20,000 to $14,000.

Since electricity costs are a significant factor in the break-even analysis of a solar PV system, a projected electricity rate increase was used on information from EIA. The average electricity rate increase for each state has been shown in Table 9.

Based on these capital costs, including federal ITC and projected electricity costs, the break-even point for a 6-kWdc system in North Dakota is 14 years, compared to only 10 years in Wisconsin. The breakeven time for Minnesota, Montana, and South Dakota was 11, 12, and 13 years, respectively, and is illustrated in Figure 12. Over a period of 30 years, which is considered to be the average lifespan of a solar power system, the cumulative savings can also be seen in Figure 12. As expected, because of the low cost of electricity, the cumulative savings in electricity costs in North Dakota is projected to be nearly $25,000, the lowest in the five states compared. Cumulative savings in Wisconsin are the highest at $55,000 (57).

Table 8. Comparison of Trackers and Types of Modules for a North Dakota Installation

Module Type: Array Type: Month	Standard Fixed (open rack) Solar Radiation, kWh/m^2/day		Value, $	Standard 1-Axis Tracking Solar Radiation, kWh/m^2/day		Value, $	Standard 2-Axis Tracking Solar Radiation, kWh/m^2/day		Value, $	Thin-Film 2-Axis Tracking Solar Radiation, kWh/m^2/day		Value, $
Jan	3.324263		52.43	3.829017		60.51	4.186094		65.51	4.186094		62.57
Feb	3.514797		49.20	4.081533		57.40	4.322036		60.55	4.322036		58.02
Mar	4.747297		70.16	5.584315		82.91	5.888574		87.34	5.888574		85.87
Apr	5.646315		77.37	6.999944		96.64	7.869609		108.43	7.869609		109.27
May	5.864657		80.06	7.416659		102.35	8.609977		118.60	8.609977		121.83
Jun	6.104559		78.89	7.831125		102.21	9.512698		123.77	9.512698		129.00
Jul	6.403867		83.30	8.262650		109.02	9.714577		127.72	9.714577		134.94
Aug	6.015967		79.74	7.600695		101.82	8.510154		113.82	8.510154		119.00
Sep	5.713402		75.32	6.995339		92.98	7.605548		101.08	7.605548		104.02
Oct	4.622045		66.92	5.486454		79.77	5.871004		85.08	5.871004		84.87
Nov	3.114531		45.49	3.502313		51.37	3.793308		55.40	3.793308		53.89
Dec	2.633080		41.54	2.973106		46.93	3.282262		51.47	3.282262		49.05
Total:			800.42			983.91			1098.77			1112.33

Table 9. Average Increase in the Rate of Electricity

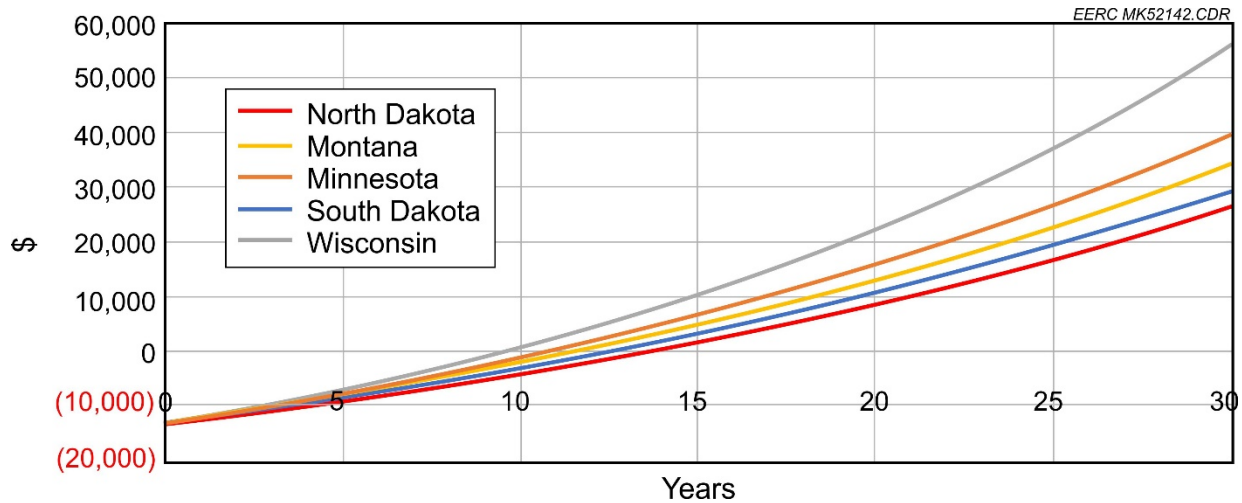|	North Dakota	Minnesota	Wisconsin	Montana	South Dakota
Average Annual Increase in the Rate of Electricity	3.00%	3.51%	4.39%	3.42%	2.83%

Figure 12. Break-even analysis of the time and cost to repay a solar PV system.

7.0 DEDUCTIONS

- North Dakota has a solar resource similar or better than other states with similar latitude.

- State incentives in Minnesota and Wisconsin have resulted in a substantial increase in installed solar capacity, causing them to be ranked 25th and 30th, respectively, in the nation in installed solar capacity.

- PV installations in North Dakota have the potential to provide positive economic benefit to residents; however, the payback period can exceed 15 years using the federal tax credit and over 20 years without the tax credit.

- Technological advancements that improve efficiency and bring down capital costs can help to improve the economic benefit of solar installations in North Dakota.

- Solar tracking systems that align PV arrays with the sun daily and seasonally can greatly improve efficiency of the system but add complexity and cost to operation.

- In locations where an electrical grid is unavailable, an appropriately sized solar PV system could be installed to avoid cost of transmission installation, hence reducing the break-even time.

- Net metering in North Dakota allowing the credit NEG over an entire year will add benefit to net metering because of the large insolance difference between the summer and winter months.

- Net metering at a rate higher than the avoided cost rate would provide an added benefit to NEG.

- RPS encourages utilities to offer incentives for all renewables, including solar power, making utilization of solar power more affordable.

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