Spring 2011

A study of solar power implementation business model options for Grand Junction, Colorado

Virginia Phillips
James Madison University

A STUDY OF SOLAR POWER IMPLEMENTATION BUSINESS MODEL OPTIONS
FOR
GRAND JUNCTION, COLORADO

A dissertation presented in part fulfillment of the requirements for the Degree of Master of Science in Sustainable Environmental Resource Management/Master of Science in Integrated Science and Technology.

Virginia Marie Phillips

November 2010

Supervisor: Dr. Jonathan Miles

University of Malta – James Madison University

ABSTRACT

VIRGINIA PHILLIPS

A STUDY OF SOLAR POWER IMPLEMENTATION BUSINESS MODEL OPTIONS FOR GRAND JUNCTION, COLORADO

This dissertation analyzed three solar power implementation business models that would transfer the burden of capital, operational, and maintenance costs from an individual to an entity with available funding. Solar power has long been touted as an emissions free and environmentally friendly alternative to more conventional forms of energy, such as coal. Most of Colorado's electricity is generated from coal-fired power plants. To combat climate change and reduce health risks, Colorado has implemented a Renewable Portfolio Standard (RPS) requiring that 30% of electricity produced in 2020 come from a renewable resource, such as solar. Of this, three percent must derive from distributed generation (DG). Grand Junction is a large town located on the western slope of Colorado that receives over 300 days of sunshine per annum. In the ongoing effort to satisfy Colorado's RPS, this dissertation identifies and examines: Grand Junction's solar resource potential; various solar technologies; their attributes, environmental impacts, and advantages/disadvantages of a solar power plant, rooftop solar leasing program, and a third party solar power purchase agreement (SPPA). It then compares each solar power implementation business model options' attributes and analyzes how each will contribute to Colorado's RPS, the reduction of greenhouse gases (GHGs), to satisfying a portion of Grand Junction's electricity demand in 2020.

Supervisor: Dr. Jonathan Miles
Readers: Dr. Luciano Mule'Stagno and
Dr. Robert Ghirlando

MSc. SERM/MSc. ISAT
November 2010

SOLAR, INCENTIVES, TECHNICAL, ROOFTOP, ENVIRONMENTAL, IMPACTS

The undersigned declare that this dissertation is based on work carried out under the auspices of SERM/ISAT by the candidate as part fulfillment of the requirements of the degree of MSc.

______________________________ ______________________________

Candidate *Supervisor*

This dissertation is dedicated to the memory of Jaidyn who selflessly sacrificed her time with me so that I could pursue my goals.

Special thanks is due first and foremost to my family for forever giving me undying support in so many ways too numerous to articulate. I would also like to thank Dr. Jonathan Miles for his unreserved scrutiny and detailed analysis; and Dr. Luciano Mule'Stagno for providing me with his professional expertise, for being available when needed despite the eight hour time difference, for his constructive analysis, and for his positive feedback.

Table of Contents

Table of Figures

Tables

Appendix

Acronyms

Alternating Current (AC)
Arsenic (As)
Balance of System (BOS)
British Thermal Units (Btu)
Bureau of Land Management (BLM)
Cadmium (Cd)
Cadmium Telluride (CdTe)
Capital Expenses (Capex)
Carbon Dioxide (CO_2)
Carbon Monoxide (CO)
Chronic Obstructive Pulmonary Disease (COPD)
Code of Federal Regulations (CFR)
Combined Cycle Gas Turbine (CCGT)
Concentrated Photovoltaic (CPV)
Concentrated Solar Power (CSP)
Copper Indium Diselenide (CIS)
Crystalline Silicon (c-Si)
Degree Celsius (°C)
Degree Fahrenheit (°F)
Department of Energy (DOE)
Department of Interior (DOI)
Direct Current (DC)
Distributed Generation (DG)
Energy Efficiency and Renewable Energy (EERE)
Energy Information Agency (EIA)
Energy Payback Time (EPBT)
Energy Policy Acts (EPActs)
Environmental Impact Statement (EIS)
Environmental Protection Agency (EPA)
Feet (ft)
Gallons (gals)
Gallium (Ga)
Gallium Arsenide (GaAs)
Gigawatt (GW)
Gigawatt hour (GWh)
Gigawatt hour per year (GWh/yr)
Greenhouse Gases (GHG)
Heating, Ventilation, and Air Conditioning (HVAC)
High Noon Solar (HSN)
Hours per year (hrs/yr)
Independent Systems Operator (ISO)
International Energy Agency (IEA)
Interstate 70 (I-70)
Investment Tax Credits (ITC)
Investment Tax Deductions (ITD)
Investor-Owned Utility (IOU)

Kilometer (km)
Kilovolt (kV)
Kilowatt (kW)
Kilowatt hour (kWh)
Kilowatt peak (kWp)
Leaders in Energy and Environmental Design (LEED)
Levelized Cost of Electricity (LCOE)
Life Cycle Assessment (LCA)
Linear Fresnal Reflector (LFR)
Methane (CH_4)
Megawatt (MW)
Megawatt hour (MWh)
Megawatt per year (MW/yr)
Meter (m)
Microgram per cubic meter ($\mu g/m^3$)
Mile (mi)
Millimeter (mm)
Million Metric Ton (MMT)
National Environmental Policy Act (NEPA)
National Renewable Energy Lab (NREL)
National Toxicology Program (NTP)
Nitrogen Oxide (N_2O)
Nitrogen Oxides (NO_x)
Occupational Safety and Health Administration (OSHA)
Operational Expenses (Opex)
Operation and Maintenance (O&M)
Organization for Economic Cooperation & Development (OECD)
Organization of Petroleum Exporting Countries (OPEC)
Particulate Matter (PM)
Performance Ratio (PR)
Photovoltaic (PV)
Plan of Development (POD)
Pounds (lbs)
Pounds per kWh (lbs/kWh)
Power Conversion Unit (PCU)
Production Tax Credits (PTC)
Programmatic Environmental Impact Statement (PEIS)
Publicly Owned Treatment Work (POTW)
Renewable Energy Credits (REC)
Renewable Portfolio Standard (RPS)
Research and Development (R&D)
Right of Way (ROW)
Sandia National Laboratory (SNL)
Silicon (Si)
Solar Electric Power Association (SEPA)
Solar Energies Technologies Program (SETP)
Solar Power Purchase Agreement (SPPA)

Solar Service Provider (SSP)
Southern California Edison (SCE)
Spill Prevention, Control, and Countermeasure (SPCC)
Square feet (ft^2)
Square kilometer (km^2)
Square meter (m^2)
Square mile (mi^2)
Sulfur Dioxide (SO_2)
System Advisor Model (SAM)
United States (US)
Watt (W)
Watt peak (Wp)
Xcel Energy (Xcel)

1. Introduction

1.1 Energy

Energy is the ability to do work, to cause physical things to change. This is a concept humans have long understood and exploited, whether it is benefiting from the heat of a fire, the light from a bulb, a cold beer in the fridge, food from the garden, or a slow Sunday drive in the car. Human civilization has flourished by pioneering techniques in which to acquire and employ sundry sources of energy. (Randolph) Today, energy is important to us because it provides the means to enjoy an enhanced quality of life, supporting the comforts of a life alleviated from hard labor. Most importantly, it is the modus operandi to our survival, supporting our most basic biological and physiological needs by furnishing our tools power to divert water to irrigate our crops, to grow food, to stay warm, to satiate our basic fundamental needs as humans to live and proliferate.

There are many forms of energy at our disposal. Some are more difficult to harness than others, but by far the most exploited form of energy since the industrial revolution has been fossil fuels. By definition, fossil fuels (i.e. coal, natural gas, and petroleum) are non-renewable forms of energy; they cannot be replenished as fast as they are being consumed. It takes natural processes millions of years to form fossil fuels; therefore, as a finite resource, fossil fuels are subject to eventual depletion. Approximately 83% of US energy consumption derives from fossil fuels. (Institute for Energy Research) A pie chart has been provided as **Figure 1** to illustrate the amount of energy consumed by both fossil fuel and alternative energy sources. Although petroleum meets only 37% of total US energy demand, it meets essentially 100% of US transportation fuel demand. Coal accounts for 21% of the energy consumed by the US and is largely used to generate electricity. Approximately 56% of the electricity produced in the US is coal-generated. (American Coal Foundation) The US is a highly industrialized country largely dependent on fossil fuels and the world's largest energy consumer in terms of total use and per capita use. (Randolph)

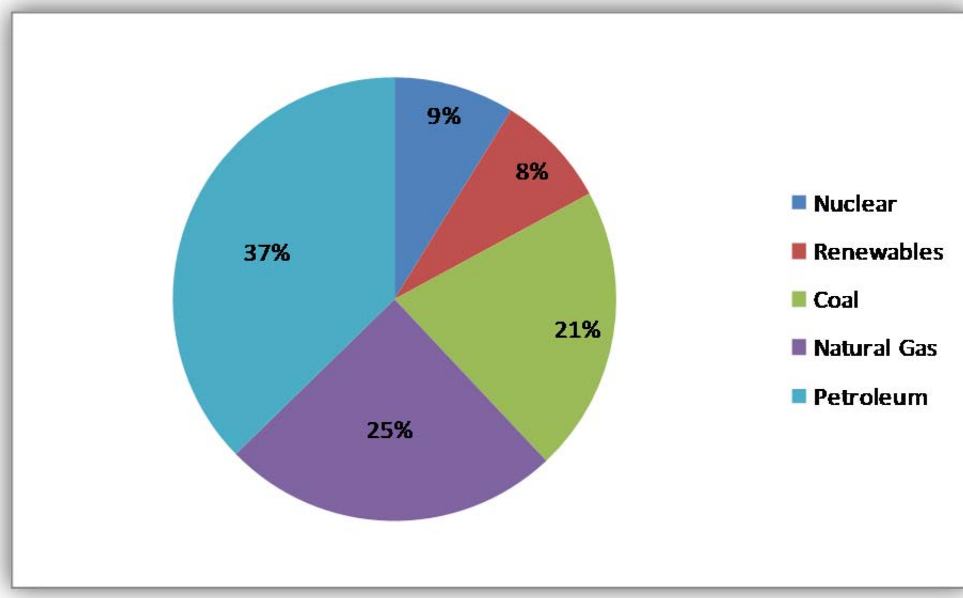


Figure 1. 2009 US energy consumption by source. (Institute for Energy

Global energy demand is growing and most of this growth is coming from non- Organization for Economic Cooperation and Development (OECD) countries such as developing Asian countries (e.g. China and India). As projected in the 2009 World Energy Outlook report by the International Energy Agency (IEA), an intergovernmental organization that provides energy policy advice to 28 OECD member countries, coal experiences the biggest increase in demand between the years 2007 and 2030. During this time period, coal remains the main fuel source in the global power sector which is expected to grow 2.5% annually to the year 2030. Non-OECD countries are responsible for 80% of this growth. (IEA)

Conventional energy reserves may not be able to sustain increasing global energy demands. As of 2006, the world has an estimated 930 billion short tons (2,000 pounds per short ton) of total recoverable coal reserves. Although this has been predicted to sustain world consumption for 138 years, this assumes current rates of consumption and does not account for growth. (EIA) To meet future energy demands, research has been focused on developing techniques to exploit other forms of energy, such as unconventional oil resources like oil sands and oil shale. This will be arduous, expensive, environmentally damaging, and generally have a low net energy gain.

In addition, recent research has determined traditional energy sources to be harmful to our environment, resulting in what is known as anthropogenic climate change. Energy produced by fossil fuels contribute to the release of Greenhouse Gases (GHG's) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that influence climate change. These gases trap heat much like glass panels of a greenhouse. Climate change in this context is the process in which direct or indirect human activity changes average global temperatures, weather conditions, and distribution of weather events. While certain events, like El Niño/La Niña, cause short-term changes in modern weather patterns, anthropogenic climate change alters the composition of the global atmosphere having a long-term effect on weather conditions. (EPA "Climate Change") GHG's enter into the atmosphere during the production, transport, and burning of fossil fuels (coal, natural gas, and oil). (EPA) The biggest emitters of GHGs in the US are large stationary sources such as power plants. (EPA "Climate Change")

One major result of climate change is its affect on energy use and supply. As average temperatures rise, more energy will be consumed to cool buildings and less will be needed for heating. In 2001, the Energy Information Administration (EIA), reported electrical consumption by 107 million US households to total 1,140 billion kilowatt hours (kWh). Electricity consumption for heating, ventilation, and air conditioning (HVAC) accounted for 356 billion kWh. Most of this went to air-conditioning as illustrated in **Figure 2**. (EIA "Electricity Report")

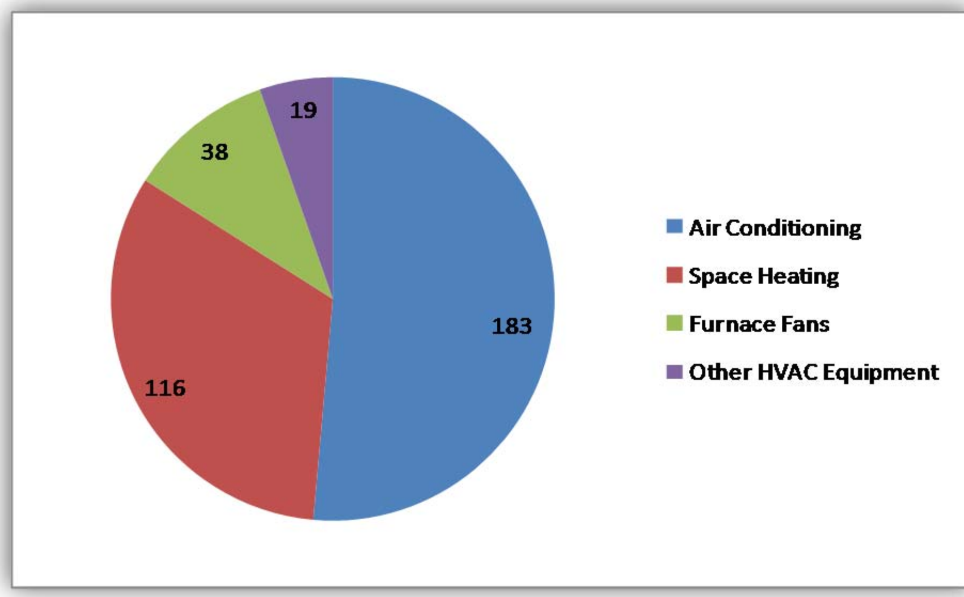


Figure 2. HVAC energy consumption in billion kWh by US households in 2001. (EIA "Electricity Report")

In 2008, the EIA estimated approximately 518.5 billion kWh of electricity was used by residential and commercial sectors for cooling and ventilation. This accounted for almost 18% of the US's total electricity consumption. (EIA "FAQS") An increased demand for air conditioning results in an increased demand for energy. This could potentially overload transmission grids and stress the capacity of power plants causing brownouts (dimming lighting from a drop in voltage) or blackouts (complete loss of power to an area) during elevated electrical demands caused by heat waves. Power plants are heavily reliant on water to function; therefore, operational difficulties may also ensue in areas with limited water supplies. (Office of Air and Radiation)

The world faces an energy predicament that will challenge all nations to find alternative energy sources that are environmentally as well as economically sustainable and will satisfy future energy demand on a long-term basis while providing for the quality of life currently attained by developed countries such as the US. Conventional energy sources are finite and incapable of supporting long-term energy growth currently being experienced without detrimental effects to the environment. As developing countries like India and China become industrialized, the amount of GHG's released to the atmosphere increases and fossil fuel reserves decrease. The amount of CO_2 being released by India and China compared to the US over the next 25 years is represented in **Figure 3**. (EIA "Energy Outlook")

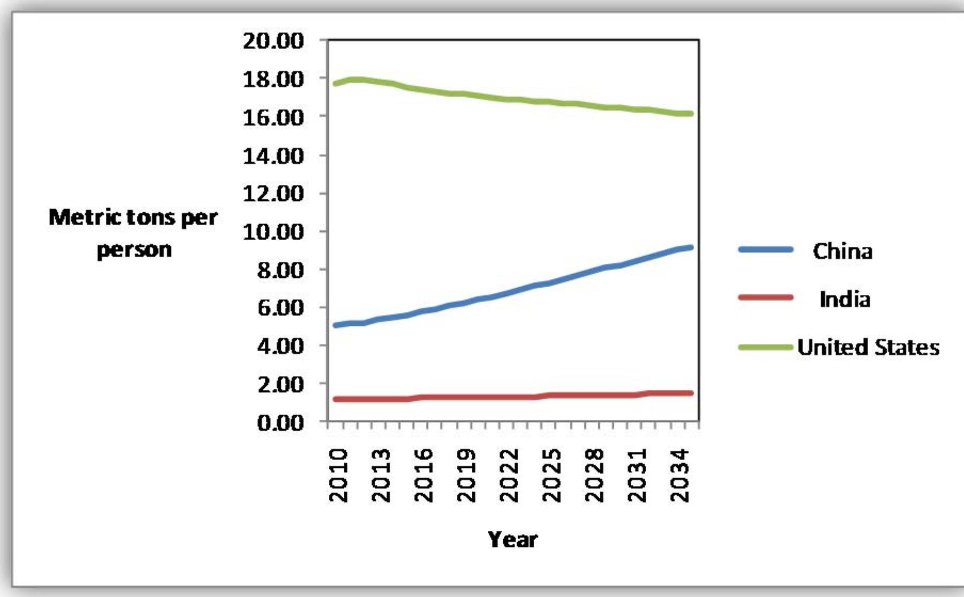


Figure 3. Predicted CO2 emissions per capita for India, China, and the US. (EIA "Energy Outlook")

Global political issues between governments further complicate an energy economy almost entirely dependent on fossil fuels. In 2008, the US imported 57% of its petroleum. (EIA "Energy In Brief") While petroleum accounts for a very small portion of electricity generation in the US, the following described energy crises illustrate how these challenges stimulated domestic research and development (R&D) towards renewable energy like solar power.

For nearly the past four decades the US has experienced several energy events which have caused a rise in energy prices and a reduction in energy supplies. By the early 1970's the US experienced a dramatic rise in energy consumption, a fall in domestic energy production, and an increase in foreign imports. Between 1960-1970 energy consumption rose 51% from 44.1 quadrillion British thermal units (Btu) to 66.8 quadrillion Btu's. (Keuchel) In 1970, the US imported 3.2 million barrels of oil per day. This increased to 4.5 million barrels in 1972 and by 1973 foreign imports were at 6.2 million barrels per day. (Rowe) In 1973 – 1974 the US was hit with an Arab oil embargo, because of their support of Israel during the Yom Kippur War in the Middle East. The action taken by the Arab members of the Organization of Petroleum Exporting Countries (OPEC) was a complete stop on flow of Arab oil into the US. (Newton) Crude oil quadrupled in price from approximately $3.00 per barrel to $12.00 per barrel. (Williams) Soaring energy prices caused energy shortages in all sectors prompting then President Nixon to ration petroleum products, extend daylight savings time year round in an effort to reduce electrical consumption, and introduce tax credits for the development and use of alternative forms of energy. (Recession.org) Shortly after the 1973 Arab oil embargo, the US again underwent another oil supply shortage which increased the cost of energy. In 1979 protests in Iran, a country in the Middle East which at the time supplied the US with 5% of its petroleum needs, sparked a revolution which caused the Shah of Iran, Mohammed Reza Pahlavi, to flee the country. The protests disrupted the production of oil in Iran causing a brief suspension of exports to the US. (Time) Upon the institution of the new Iranian regime, oil exports resumed, but were inconsistent and of lower volume than before the overthrow of the Shah. This resulted in yet another energy price increase. To compound the energy problem, Iraq invaded Iran in 1980 and once again Iranian oil exports nearly stopped while Iraqi oil production was reduced to half its normal output. Iraqi oil production went from 2,526 thousand barrels per day to 1,009 barrels per day. (EIA "Iraq") Over a period of time, the 1973 oil embargo and the 1979-1981 Iranian political crises caused domestically produced oil prices to skyrocket from $3.50 per barrel to $34.00 per barrel. (Wiser) The climbing trend of oil prices from 1973, the first oil shortage crisis, to 1981, the end of the second US oil crisis, is represented in **Figure 4**.

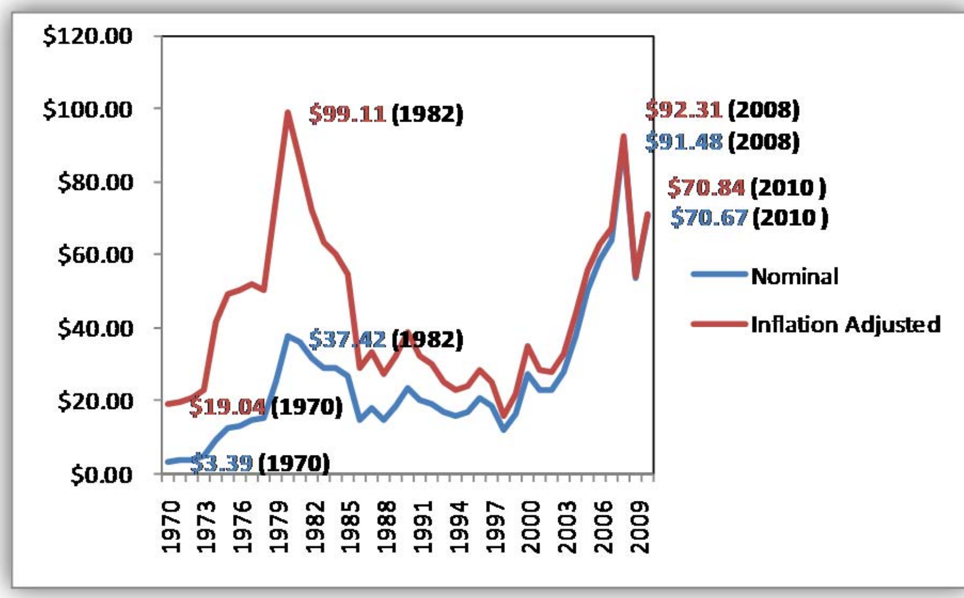


Figure 4. Annual averages for domestic crude oil prices. Prices are adjusted for inflation to June 2010 prices. (Inflation Data)

Between 1979 and 1981, then President Carter proclaimed a national energy shortage and announced a solar energy program to stimulate the growth of solar power. Immediately following, President Carter signed the 1980 Energy Security Act consisting of six major energy acts which included the Renewable Energy Resources Act. (DOE) The purpose of this act was to

> establish incentives for the use of renewable energy resources, to improve and coordinate the dissemination of information to the public with respect to renewable energy resources, to encourage the use of certain cost effective solar energy systems and conservation measures by the Federal Government, to establish a program for the promotion of local energy self-sufficiency, to broaden the existing program for accelerating the procurement and use of photovoltaic systems, and to provide further encouragement for the development of small hydroelectric power projects. (Center for Regulatory Effectiveness)

Although the energy crisis seemed to dissipate following Carter's term as president and the idea of solar power with it, it was during Carter's term as President that marked the advent of solar energy technology.

Even today oil prices remain volatile. Since the 2003 Iraq War, the US invasion of Iraq, the price of oil has been on an almost constant increase (**Figure 4**), as a result of reserve uncertainties and political instability in the Middle East. The uncertainty of fossil fuel – particularly oil – prices, supply, and climate change effects once again push us to look into solar technology, because solar power can be produced domestically, compete with current retail electricity prices, and generate emission-free power. Solar power will not alleviate our dependence on oil anytime soon, but it was the oil shortages of 1973 and 1979-1981 that encouraged the US to invest more time and money into to solar power.

At the beginning of the 21st century the US struggled with its own energy generating issues. In the year 2000, California (CA) suffered multiple large-scale rolling blackouts. Rolling blackouts are deliberate electrical power outages caused by power companies as a last resort attempt to reduce the load on power plants and the grid during times of high energy demand. This specifically engineered technique is designed to lessen the threat of an overload or crashing transmission systems. (Smith) On June 14, 2000 San Francisco, California temperatures exceeded 100 degrees Fahrenheit (°F) (37.8° Celsius). California's Independent Systems Operator (ISO) ordered rolling blackouts affecting 97,000 consumers in the area to alleviate stressed power systems. Six months later on December 7, 2000 California's power reserves were below three percent (3%) because of limited energy supply and high energy demand. In this case, rolling blackouts were narrowly avoided when two large state and federal water pumps were shutdown in order to conserve electricity. (PBS) In 2003, a major blackout (complete power failure) affected 45 million people in eight northeastern US states and ten million people in Ontario, Canada. It has been the largest blackout ever experienced in North America and cost nearly six billion dollars. (Minkel)

According to the University of Minnesota, US blackouts have increased 124% in the last two decades. Between 1991 and 1995 there were 41 blackouts. This increased to 92 blackouts from 2001 to 2005. Many of these blackouts can be attributed to an outdated transmission grid that is quickly reaching capacity and overburdened power plants unable to meet high energy demands. (Patterson)

During the 2003 northeastern blackout, 100 coal-fired power plants were shut down resulting in a 90% decrease of ambient air (ground-level) sulfur dioxide (SO_2) levels and 50% decrease of nitrogen oxides (NO_x). This demonstrated just how much impact conventional power plants had on air quality. (Randolph) Ground-level pollutants are expelled into the air from antiquated coal-fired power plants and can damage human health. Mercury is perhaps one of most serious pollutants of concern. As a neurotoxin, it is especially detrimental to the health of fetuses, infants, and children causing adverse neurodevelopment effects. (USGS) Nearly 50 tons of toxic mercury is emitted annually from coal-fired power plants contributing to 40% of the total emitted in the US. (NY Times) Federal regulations administered by the Environmental Protection Agency (EPA) now require fabric filters to capture particulate matter (PM), scrubbers to reduce SO_2, and selective catalytic reductions (SCRs) to control NO_x output. (EPA) While these tactics have eliminated approximately 25 tons of mercury the problem still persists in the wastes (fly ash, bottom ash, and scrubber sludge) of coal-fired power plants. Most of this is either deposited in landfills (typical disposal method), ponds, or old mines where it can leach into the groundwater or be absorbed by plants and microorganisms and transferred into the food chain. (NRDC) The protection of human health both present and future is yet another reason to move towards solar energy.

To find new solutions to foreign oil dependency, protect human health, and alleviate encumbered power plants and a taxed transmission system, comprehensive national Energy Policy Acts (EPActs) were passed in 1992 and 2005. These EPActs are, in part, financial incentives designed to encourage the growth of renewable energy systems. (Randolph) The purposes of the 1992 EPAct was to promote the production and utilization of renewable energy, advance renewable energy technology, and promote the exportation of US renewable energy technologies and services. (U.S. Government) The 2005 EPAct allotted 4.5 billion dollars in renewable energy incentives and aimed to uphold the purposes previously stated of the 1992 EPAct. (CRS) The 2005 EPAct is further explained in the following section (Section 1.2).

1.2 Renewable Energy: Standards and Incentives

In the on-going effort to achieve energy independence and reduce greenhouse gas (GHG) emissions, the State of Colorado has established a Renewable Portfolio Standard (RPS). Other important reasons why Colorado would instate a RPS are to:

- Reduce the cost of renewables
- Reduce price volatility of electricity
- Increase fuel diversity
- Increase marketplace acceptance of renewables
- Create strong constituent support for renewables. (O'Connell)

In summation, the Colorado RPS states that investor-owned utilities (IOU) are required to generate 30% of their energy from renewable resources and/or recycled energy by the year 2020. Of this, three percent (3%) must derive from distributed generation (DG). For electric cooperatives and municipal utilities serving more than 40,000 customers, 10% of their electricity sales in Colorado must come from renewable energy and/or recycled energy by the year 2020. (Mignogna)

In order to meet the above established RPS, IOU companies, such as Xcel Energy (Xcel), – Colorado's largest utility company – are investing in and deploying renewable energy sources (e.g. solar) as a power source. To date, solar makes up less than one percent (<1%) of Xcel's energy portfolio, but Xcel has been ranked by the Solar Electric Power Association (SEPA) as having the fifth largest solar power capacity in the nation. (Xcel Energy) Xcel has introduced customer incentives such as Solar Rewards™ to help expand renewable energy into the market. In short, Solar Rewards™ offers rebates and Renewable Energy Credits (REC) for customers who wish to install solar photovoltaic (PV) systems on their homes or businesses. (Xcel Energy)

As mentioned in the previous section (Section 1.1), the Federal Government is also encouraging the implementation of solar power systems. There are three types of tax incentives issued by the Federal Government under the 2005 EPAct. These are investment tax credits (ITC), production tax credits (PTC), and investment tax deductions (ITD); however, only the ITC applies to solar as a corporate tax credit. ITC's reduce the capital costs by allowing investors to claim credit for a portion of the money invested in a renewable energy system such as solar. Key solar ITC incentives of the 2005 EPAct include a residential ITC of 30% or up to $2,000 for the cost of a PV solar system and a business ITC of 30% for a PV solar system with the requirement that both residential and business PV systems be installed by 2008. The American Recovery and Reinvestment Act of 2009 extended this tax credit until December 31, 2016 and dropped the tax credit cap of $2,000. (US DOE (Energy Tax Incentives))The Federal Government has implemented these financial incentives to support the goal of overcoming the US's energy predicament and protect human health.

On July 21, 2010 the Ten Million Solar Roof Act was introduced by the Energy and Natural Resources Committee. The goal of the act is to have 10 million solar rooftop systems atop homes and commercial and industrial buildings within 10 years. When the goal is met, it is expected that there will be approximately 30,000 megawatts (MW) of new installed PV capacity. (B. Sanders)

The bill is intended to act as an incentive. In addition to states' rebates and the federal investment tax credit mentioned previously (30% return of the solar system's cost) the bill provides a rebate of as much as $1.75 per watt (W) to offset up to 50% of the remaining cost of the system. (B. Sanders) For example, Xcel offers a rebate payment of $2.00/W through their Solar Rewards™ program. To date, the installed costs of solar panels runs between $5 – $6/W. (Devlin) Therefore a five (5) kilowatt (kW) solar system nominally costs approximately $28,000 to purchase and install, but the actual cost to the consumer is much less as represented in **Table 1**. The $5.50/W installed solar panel cost was derived from the National Renewable Energy Lab (NREL) simulation model Solar Advisor Model (SAM), designed to model performance and costs of different solar energy systems. This model is explained in Section 2.2.6.

Table 1. Example of approximate consumer cost savings accrued from rebates for the purchase of a PV system. Rebates apply in order as listed from left to right.

System Size (kW)[1]	Installed Solar Panel Cost ($/W)	Cost Before Rebates ($)[2]	Cost After $2.00/W Xcel Rebate ($)[3]	Cost After 30% Federal ITC ($)[4]	Cost After *50%* 10 Million Solar Roof Rebate ($)	Total Cost to Consumer ($)[5]
5	5.50	27,500	17,500	12,250	6,125	6,125

[1] $1kW = 1{,}000W$

[2] $5{,}000W\ x\ \frac{\$5.50}{W}$

[3] $5{,}000W\ x\ \frac{\$2.00}{W} = \$27{,}500 - \ \$10{,}000$

[4] $\$17{,}500 - \ \$5{,}250$

[5] $\$12{,}250 - \ \$6{,}125$

The Xcel rebate reduces the nominal cost by $10,000 to $17,500. This is the out-of-pocket paid for the system. The 30% federal tax credit then reduces this cost to $12,250. (B. Sanders) With the new bill in place, the remaining cost will be reduced by half. The resulting final cost is now $6,125. The consumer is now only responsible for 22.3% of the original cost. Eligible recipients are any residential, business, non-profit, and state or local government entity with a system sized at two (2) MW or less. After all federal and state incentives have been recognized, the maximum amount received under this bill shall not exceed 50% of the remaining cost for purchase and installation of the system. (B. Sanders)

Other Colorado State incentives include: Property Tax Incentives, Sales Tax Incentives, State Grant Program, State Rebate Program, and Utility Rebate Program.

Table 2. A brief overview of Colorado renewable energy incentives applicable to solar technology.

Colorado State Incentives	Type	Applicable Sectors
Property Assessed Clean Energy (PACE) Financing	Local Option	Industrial, Commercial, Residential
Property Tax Incentive	Local Option	Commercial, Industrial, Residential
	Property Tax Exemption	Residential
	Property Tax Assessment	Commercial
Sales Tax Incentive	Local Option	Commercial, Industrial, Residential
	Property Tax Exemption	Residential
State Grant Program	New Energy Economic Development Grant Program	Commercial, Industrial, Residential
State Rebate Program	Renewable Energy Rebate Program	Commercial, Residential
Utility Rebate Program	Solar*Rewards Program (Xcel)	Commercial, Residential, Nonprofit, Installer/Contractor (3rd Party)

Table 2 does not list all applicable sectors nor does it identify eligible renewable technologies. These components in full, including a short summary describing each incentive are provided in **Appendix I**.

The Federal Government, especially particular agencies such as the Bureau of Land Management (BLM), the Department of Energy (DOE), and the National Renewable Energy Lab (NREL), have been working toward developing and supporting a renewable energy powered infrastructure that leverage such technologies as wind, solar, and geothermal. At the beginning of 2010, the BLM identified all national utility scale solar power projects that are operational, under construction, or under development. The DOE focuses on the development of and education about solar technologies as energy sources nation- and world-wide. NREL mapped out both PV and concentrated solar power (CSP) solar resource potential for the entire US. Solar resource potential is explained in further detail in Chapter 3. Areas identified as having the best solar resource potential are found mainly in the southwestern US. Open-land in this region is largely managed by the BLM. The BLM has taken this information from NREL and is currently composing a Programmatic Environmental Impact Statement (PEIS) to begin leasing this land to operators interested in installing large-scale solar power plants. Solar power plants and the BLM's role in their development are further discussed in detail in Chapter 4.

1.3 Purpose of Study

In addition to finding solutions to foreign energy dependency, protecting human health, alleviating encumbered power plants and taxed transmission systems, meet a growing energy demand, and limiting environmental degradation, it is thought that the deployment of solar power will contribute toward satisfying the requirements prescribed by Colorado State's RPS and that it will also support the goal of the 10 Million Solar Roofs Bill if passed. Solar power is also expected to offset a portion of coal produced power, thereby reducing GHG emissions into the atmosphere which contribute to climate change. The goal of this study is to identify available solar power implementation business model options that would transfer the burden of capital, operational, and maintenance costs from an individual to an entity with available funding, analyze their advantages and disadvantage, and determine which is the most appropriate for Grand Junction, Colorado. These options considered are stated below:

Option 1. Solar power plant utilizing either CSP or PV

Option 2. Solar rooftop leasing program operated by the IOU

Option 3. Third party solar power purchase agreements (SPPA).

This study is designed to support the assumption that the utilization of one or more of the solar power implementation business model options in Grand Junction will not only help to satisfy state and federal standards, but will also reduce GHG emissions. The information provided in this study can be used to inform the community of Grand Junction of the solar options available to meet their energy needs as it considers the implementation of solar power.

1.4 Background

Grand Junction is the largest city in western Colorado, is the county seat (administrative center) of Mesa County, and is approximately 247 miles (mi) (398 kilometers) from Denver, the state capital of Colorado. Grand Junction lies on the western border of Colorado and occupies approximately 33 square miles (mi^2) (85.5 km^2) of Mesa County's total 3,309 mi^2 (8,570 km^2). The following figure, **Figure 5**, is a Google map of Colorado and Utah and shows the location of Grand Junction relative to Denver and the Utah border. The geographical coordinates of GJ are 39°03'53"N 108°33'52"W. (Mesa County) Grand Junction is the focus area of this study.

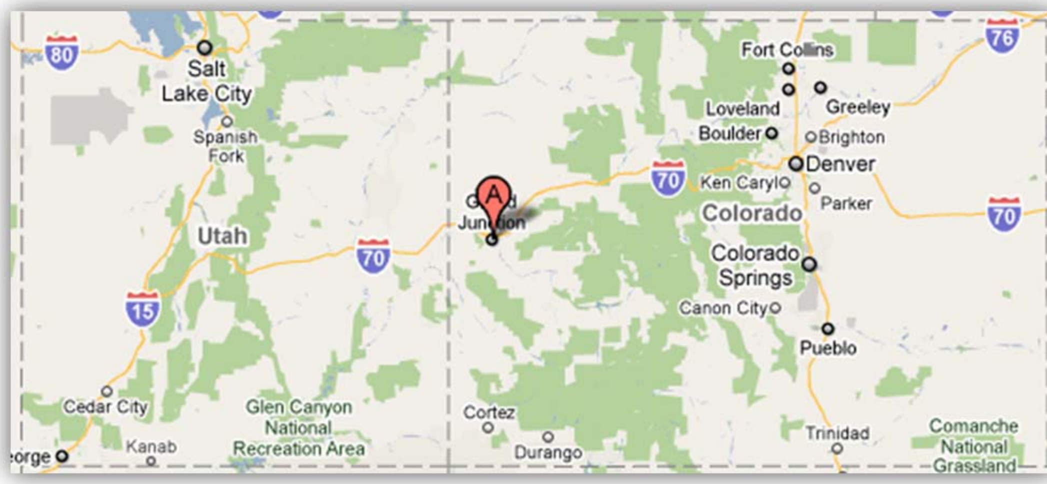


Figure 5. Grand Junction is on the southwest border of Colorado and southeast border of Utah. (Google)

Most of Grand Junction is surrounded by public lands managed by the BLM and may serve as prime solar power plant real estate. The area receives more than 280 days of sunshine in a typical year. In the winter, sunshine hours remain abundant and average just over 3200 hours per year (hrs/yr). At 4,597 feet (ft) (1,401 m), Grand Junction is described as a high-altitude desert ecosystem. Average winter temperature lows reach 17 °F (-8.4°C) while average summer temperature highs reach 93°F (34°C). (Weather Channel) Given the mild and arid climate, Grand Junction receives on average only 9.1 inches (in) (230 mm) of precipitation annually. (NOAA)

As of 2008, there were approximately 53,930 people living in Grand Junction. Total housing units including occupied and vacant structures number approximately 24,104. (U.S. Census Bureau) The roofs of residential infrastructure, including commercial (i.e. hotels, restaurants, groceries/pharmacies, museums, libraries, schools, and miscellaneous retail stores) and industrial (i.e. warehouses) buildings provide the foundation for prime solar generation real estate as discussed in Chapters 5 and 6.

The major IOU servicing Grand Junction is Xcel Energy which recently deployed its first Innovative Clean Technology demonstration hybrid solar-coal power plant project at the Cameo Generation Station located a few miles east of Grand Junction. (Proctor) The Cameo Station has been providing power to the city since 1957. (Xcel Energy) The coal-fired portion of the power plant generates 49 MW. On June 30, 2010, it became the world’s first known operating hybrid project of its kind using parabolic trough solar technology. Eight rows of solar troughs each 500 ft in length cover a total of 6.4 acres (2.6 hectares) to provide approximately 1 MW of power to the power plant and are projected to offset approximately 900 tons of coal and 2,000 tons of CO_2 emissions per year. (Xcel Energy)

There are three coal-fired power stations servicing Grand Junction. According to Fred Eggleston, area manager of the Western Region for community and local government affairs of Xcel, a portion of each station's MW capacity supplies Grand Junction with power: 49 MW comes from the Cameo Station, 83 MW from the Craig Station, and 237 MW from the Hayden Station. These provide a total capacity of 369 MW. This is sufficient to cover peak demand. The Craig Station is located approximately 151 mi (243 km) north east of GJ and has the capacity to produce 1200 MW. The Hayden Station is located approximately 208 mi (335 km) to the northeast and has the capacity to produce 750 MW. A 345 kilovolt (kV) transmission lines carries the power approximately 107 mi (172 km) to an interconnection point in Rifle, CO. From this point power is transmitted to Grand Junction, approximately 61 mi (98 km) west of Rifle. In all electrical power transmissions, especially those of long distances, some transmission losses will occur. These losses are also dependent on the voltage level and construction details (i.e. conductor resistance) of the system. (DOE) A diagram has been provided in **Figure 6** illustrating a typical US electrical network system.

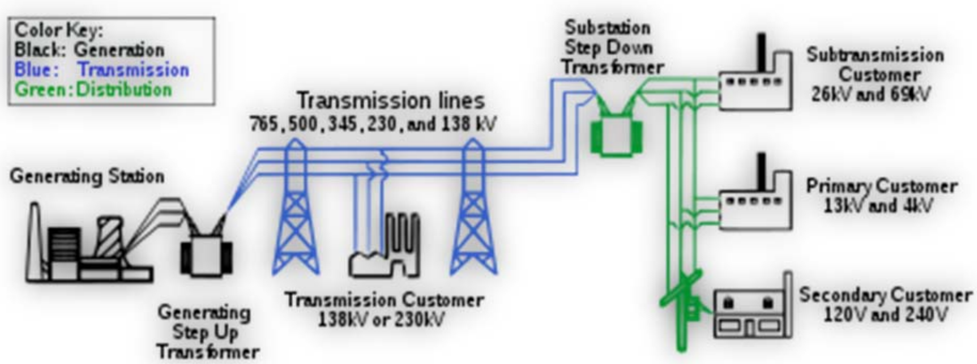


Figure 6. An electrical network system typically found in the US. (U.S.-Canada Power System Outage Task Force)

1.5 Electrical Demand

In order to understand how implementing solar renewable energy in Grand Junction will assist in meeting Colorado's RPS of 30% renewable energy by 2020 (Section 1.2) it is important to have a basic understanding of the electrical demand for the entire state of Colorado. Many economists link electricity growth with economic and population growth. In Colorado and for the US in general, the electric power sector is the fastest growing sector in the energy economy. In 2005 there were approximately 4,665,177 people living in Colorado. (EERE "CO Stats") Two years later, in 2007, the population was estimated at 4,842,770, a 3.6% increase. (SWEEP) According to the U.S. Census Bureau, Colorado again grew by 3.6% in two years resulting in 5,024,748 residents in 2009. This averages about a 1.8% annual increase in growth.

Colorado ranked as the US's 25th largest electrical consumer in 2005. During this year, it was estimated that Colorado consumed 48.4 billion kilowatt hours (kWh). The commercial sector was the largest consumer, followed by the residential sector. Most of the electricity consumed was produced from coal. The following figures (**Figure 7** and **Figure 8**) illustrate electrical consumption by sector and electrical production by fuel source for the year 2005.

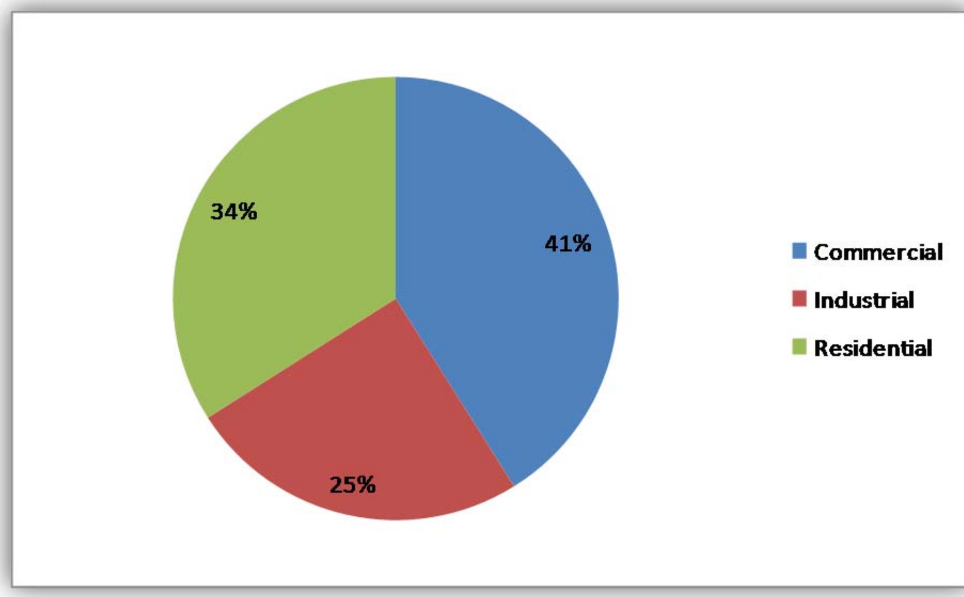


Figure 7. Colorado electrical consumption by sector for 2005. (EERE "CO Stats")

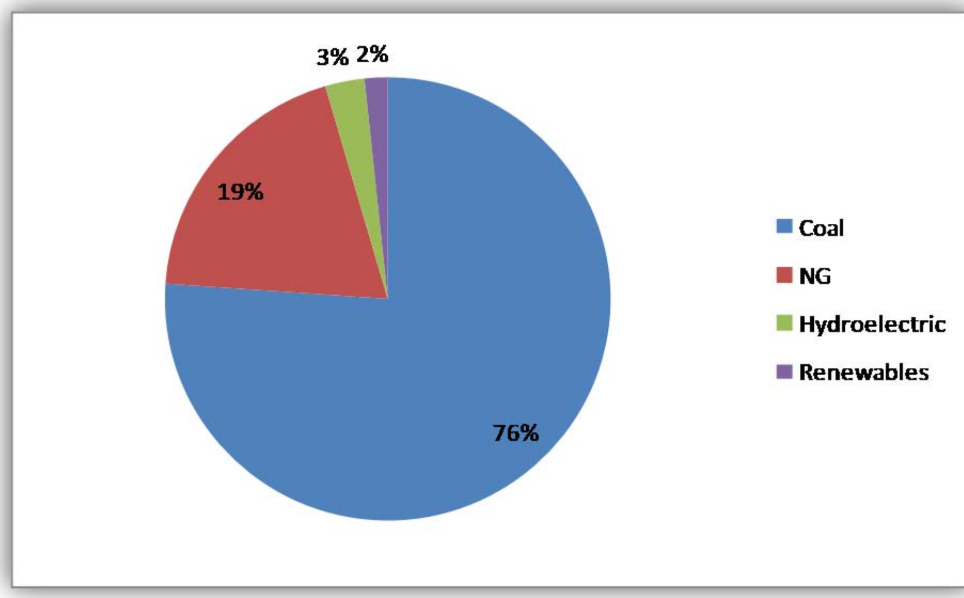


Figure 8. Fuel source for electric power generation for 2005. (EERE "CO Stats")

Two years later, in 2007, Colorado's electric consumption increased by 5.7% to 51.3 billion kWh ranking the state as the 27th largest electric consumer in the US. (SWEEP) The DOE's office of Energy Efficiency and Renewable Energy (EERE) describe a 3.3% electric consumption increase between the years 1980 and 2005. Between 2005 and 2007 Colorado averaged a 2.9% annual increase in electric consumption. This is close to the rate of increase stated by the EERE.

The main purpose of the EERE is to invest in clean and renewable energy technologies that protect the environment, help to strengthen the US economy, and increase energy independence. The EERE does so by forming partnerships within the private sector, state and government offices, the DOE, national laboratories like NREL, and universities. The EERE has organized ten energy programs, one of which is dedicated to solar energy technology. (EERE "About").

If Colorado is to meet 30% of their energy demand with renewables, then it helps to know how much electrical energy might be consumed in 2020. From the above given data, electric consumption and population growth can be extrapolated with relative confidence. Although between the years 2005 and 2007 there was a 2.9% increase in electricity consumption this only accounts for two years of data. For 25 years (1980 – 2005) the average electric consumption rate in Colorado increased by 3.3% as documented by the EERE. The conservative 3.3% rate of increase given by the EERE was used to estimate electricity consumption in the year 2020. The years 2009 – 2010 were predicted because no data yet exists for actual consumption quantities. Based on a

3.3% increase, Colorado will consume approximately 78.2 billion kWh in the year 2020 as illustrated in **Figure 9.** By the year 2020 approximately 23.5 billion kWh (30%) of Colorado's electrical demand should be generated from renewable energy.

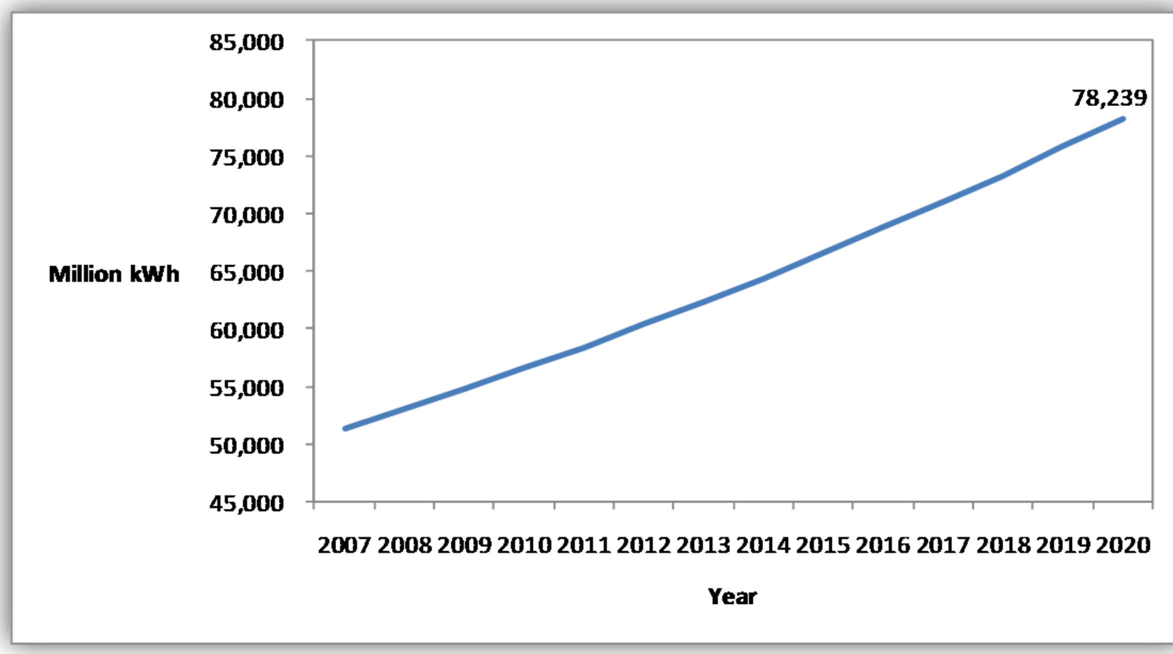


Figure 9. Electricity consumption prediction in million kWh for Colorado from 2008 to 2020.

As of 2008, the current population of Grand Junction was approximately 53,930. Given a 1.8% increase in population growth each year, as described above at the beginning of this section, the expected population of Grand Junction in the year 2020 will be approximately 60,725. To approximate the amount of electricity consumed by Grand Junction in the year 2020, electricity consumption per capita (per person) was roughly determined for the entire state of Colorado. Electricity consumption per capita was extrapolated by dividing Colorado's population in a given year by the amount of electricity consumed that same year. This represents the amount of electricity consumed per person per year for all applications including residential, industrial, and commercial. For example, electricity consumption for 2005 was 48.4 billion kWh. This was divided by 4.67 million people; Colorado's total population for 2005:

$$\frac{48.4 \; billion \; kWh \; per \; year}{4.67 \; million \; people} = \; 10{,}375 \; kWh \; per \; person \; per \; year$$

Based on the annual 1.8% population growth already determined, Colorado's population between the years 2010 and 2020 was estimated. Together with predicted future population and yearly electrical consumption data (**Figure 9**) electricity consumption per capita for the year 2020 was roughly forecasted. This is data is shown in **Figure 10**. Estimated electricity consumption per capita per year for the state of Colorado is approximately 12,601 kWh. If in the year 2020, Grand Junction's population is about 60,725 and electricity consumption per capita is approximately 12,601 kWh, then it is expected that Grand Junction's electricity demand will be roughly 765,196,725 kWh.

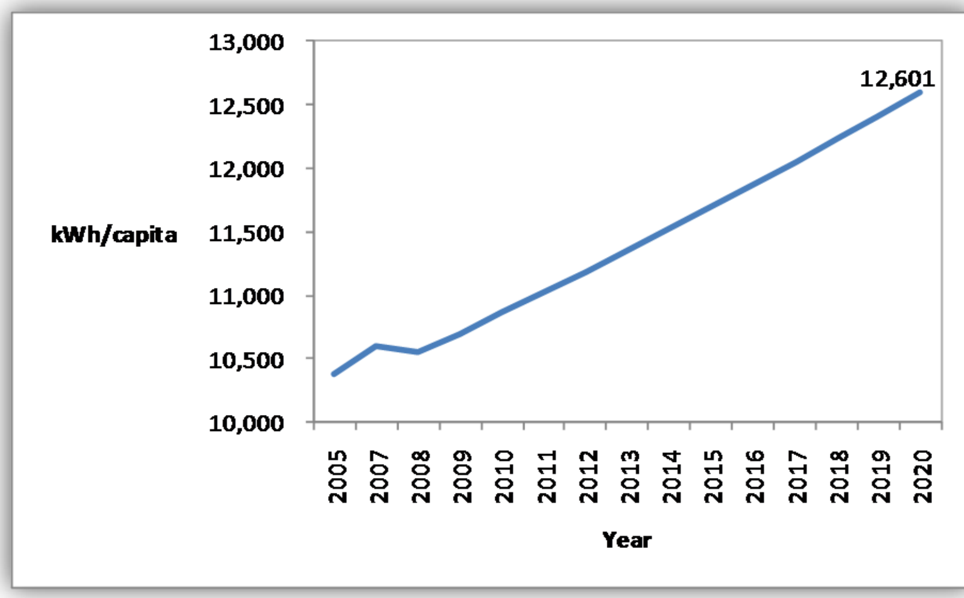


Figure 10. Estimated Colorado electricity consumption per capita per year in kWh.

1.6 Solar Power Production

In May this year (2010) NREL released a study performed by GE Energy for NREL titled *Western Wind and Solar Integration Study* (WWSIS). The WWSIS examines the operational impacts 35% penetration of renewable energy, specifically wind, PV, and CSP, would have on the power system operated by WestConnect, a group of utilities (including Xcel) in Arizona, Colorado, Nevada, New Mexico, and Wyoming. The technical analysis performed in the study showed that 30% wind and 5% solar penetration was feasible for WestConnect to accommodate without the need for additional back-up systems should utilities coordinate operations. Three scenarios were described in the study: In-Area, Mega-Project, and Local-Priority. The data provided by the In-Area scenario was chosen because this allowed Colorado to meet its RPS target independently of the other states by developing wind and solar resources within its borders. This scenario determined a total of 300 MW installed solar for western Colorado. (GE Energy)

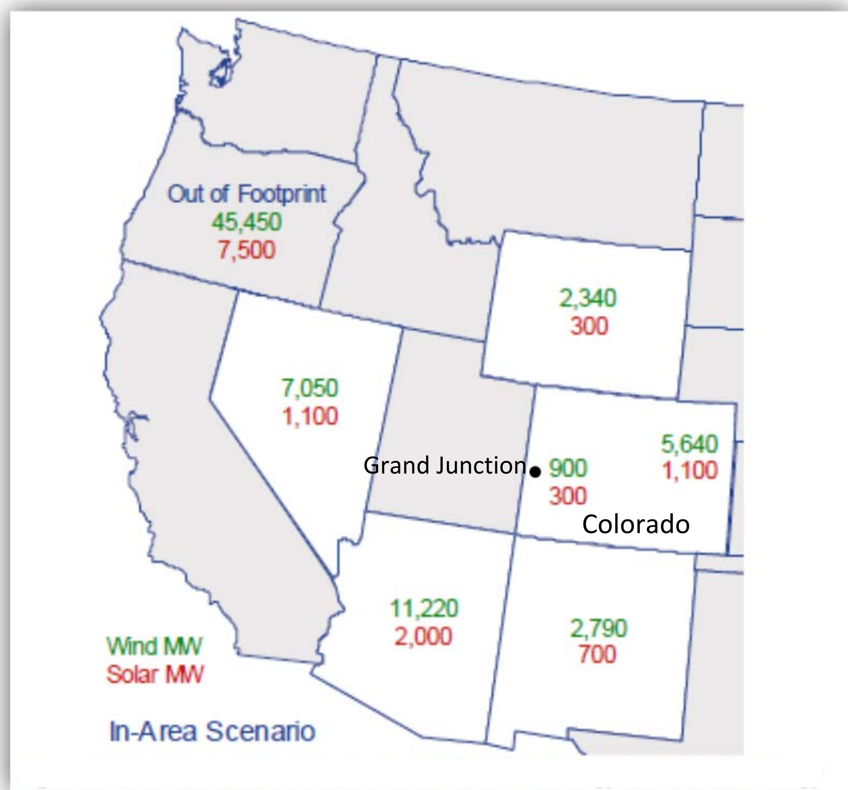


Figure 11. Overview of In-Area scenario with 30% wind and 5% solar energies. (GE Energy)

The WWSIS findings and the definition of distributed generation (DG) were used as a guideline when determining solar operation business model size in terms of MW capacity for Grand Junction. The three business models considered and described in Chapters 4, 5, and 6 are to generate power from solar energy for DG. The characteristics of DG are loosely defined by both size and location. The location definition refers to DG as power generation at or close to the point of consumption. This reduces the amount of energy lost in transmission and reduces the size and number of power lines that must be constructed. Grid reliability increases, because DG does not connect directly into the bulk transmission system. This also eliminates the need to update existing transmission/distribution lines. (Solar Buzz) Those who characterize DG by size consider a maximum generation of 100 MW to still be DG. (Therein) Therefore, the size of the solar business models, particularly a solar power plant, examined in this study will not exceed 100 MW. This is approximately 27% of the power currently provided Grand Junction as described in the previous section (Section 1.4). Solar power production of 100 MW will also not overburden the Westconnect power system and will allow for further solar development across western Colorado.

2. Solar Technology

The purpose of this chapter is to introduce the reader to the different types of materials and technologies used for the development of a solar array in large and small scale applications (i.e. solar power plants and rooftop installations). This is to provide a general understanding of available solar technology options and not to decide which of these is best for Grand Junction.

The two major solar energy technologies used for the implementation options discussed by this study are solar photovoltaics (PV) and concentrated solar power (CSP). This chapter will provide a brief description of each major technology. It will also discuss the pros and cons of using each by describing current applicability in power stations and rooftop installations.

2.1 Photovoltaics

Photovoltaics make use of semiconductor materials to transform solar radiation into direct current (DC) electrical energy. These are commonly referred to as solar cells which connect together to form solar modules. Several modules are combined to make a solar array. Solar arrays can vary in power output depending on the module and number of modules in the array. An example of a solar cell, module, and array is illustrated in **Figure 12.** The basic PV solar cell generally produces a small amount of power, one (1) or two (2) watts. To generate more power, individual solar cells are interconnected to one another to form a module. Modules are connected together to form arrays which generate even more power. This gives PV the advantage of building customized units to meet electrical needs of any scale, small or large. (Department of Energy)

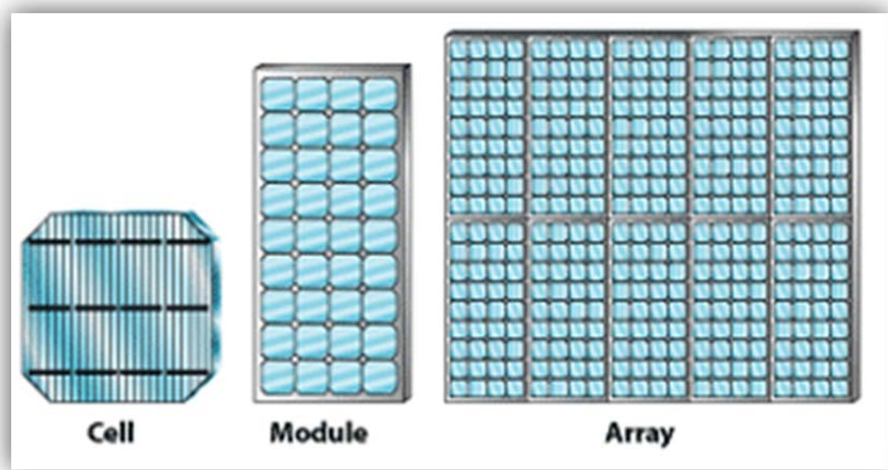


Figure 12. An example of a typical cell. These cells are arranged together to form modules and modules are then coupled together to form arrays. (Department of Energy)

2.1.1 Materials

The most widely used material in PV cells is crystalline silicon. This section will provide an overview of two different categories of semiconductor materials, Silicon (Si) and thin films, used in the manufacturing of solar cells. (Department of Energy) The technologies are divided according to the elements and crystalline structure used in their construction. The first (Silicon category) comes in various forms such as single-crystalline Si and multicrystalline Si. The single-crystalline molecular structure forms from the same crystal creating a uniform platform for the efficient transferring of electrons through the material. Multicrystalline materials consist of multiple smaller crystals and are, in general, less efficient and less expensive to produce than the former. (Department of Energy)

There are three types of thin-film technology: polycrystalline, single-crystalline, and thin film silicon (amorphous Si). Polycrystalline thin-film is composed of a top-layer (< 0.1 micron) called the “window” layer. This layer absorbs light only from the high-energy, shorter-wave end of the solar spectrum. It is designed to be thin enough to allow all available light through to the absorbing layer and is typically only one (1) to two (2) microns thick. There are two different types of polycrystalline materials. One is composed of copper indium diselenide (CIS) and the other cadmium telluride (CdTe).These are referred to as compound structures, because each material consists of two or more chemical elements. Both CIS and CdTe are highly absorbent with about ten (10) percent conversion efficiency (Mule'Stagno); however, CdTe often experiences large internal resistance losses because of its high electronic resistance. It is also difficult to recycle and/or dispose of properly due to its high toxicity levels. (Department of Energy)

Single-crystalline thin films, also compound semiconductors, are composed of gallium (Ga) and arsenic (As) with an extremely high absorptivity. When bonded, they form the chemical compound gallium arsenide (GaAs) which is relatively insensitive to heat and allows for flexibility in cell design. The latter benefit gives designers more control over the generation and collection of electrons, thus pushing efficiencies closer toward theoretical levels. Due to the high cost of a GaAs cell they are used mainly in concentrator systems since less substrate is needed to produce power as described in the following section (Section 2.1.2). (Department of Energy)

Amorphous silicon absorbs 40 times more solar radiation than single-crystalline silicon while requiring less material to do so. This gives amorphous silicon an economic advantage over the other silicon based technologies and could potentially decrease the cost of PV. Additional economic advantages include lower production costs due to lower production temperatures, and it can be installed on low cost substrate such as glass, plastics, and metal. Thus, it can be easily integrated into building envelopes. (Department of Energy) Unfortunately, it only has about a five (5) to eight (8) percent solar to energy conversion efficiency. (Mule'Stagno)

2.1.2 System Options

There are two general PV system options: flat-plate systems (fixed or tracking), and concentrator systems. Both systems offer economic and/or efficiency advantages.

Flat-Plate PV Options

This is the most commonly used design today. Flat plate panels can either be fixed in place or designed to track the movement of the sun. While the former is economically less intensive, the latter provides the most efficient capture of solar radiation. Both respond to direct or diffuse sunlight. A typical flat-plate module design has been presented in **Figure 13**. (Department of Energy)

Fixed flat-plate panels are the simplest of the PV arrays. They are lightweight and lack mechanical moving parts making them easy to install and inexpensive to maintain. These main characteristics of a fixed flat-plate panel make them suitable for installation in most locations, i.e. residential rooftops. For best performance, each fixed flat-plate module is installed south-facing with an incline suited to individual site location's latitude angle. In Grand Junction, fixed flat plate modules would be angled at 39.1° elevation. Collectors inclined at latitude angles absorb maximum solar radiation at midday. This is when the sun's rays strike the solar collectors at right angles. The greater the angle of the sun on the collector the less efficient the collector becomes. Since the sun varies in position throughout the day, fixed flat-plate panels are usually at an angle to the sun that is less than optimal. Despite this, the cost of the system is less than that of a tracking system. (Department of Energy)

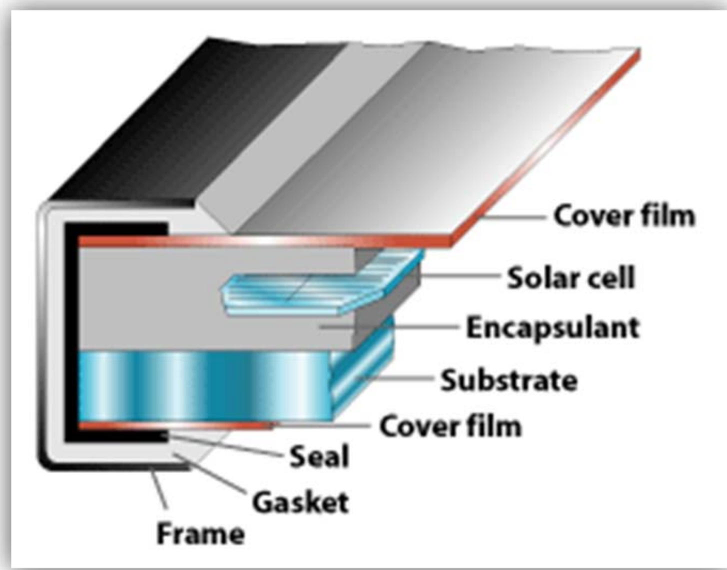


Figure 13. Flat-plate module designs are typically composed of a structural support of metal, glass, or plastic; a material which surrounds the cell providing protection; and a plastic or glass covering (EERE)

Tracking flat-plate panels are designed to follow the sun's movement in the sky during the day. They can move on one or two axes. This creates maximum PV module surface exposure to solar radiation, thus capturing the greatest amount of energy per unit area of array. In turn, this provides a greater electrical output per module than a fixed flat-plate system. With this advantage comes an economical disadvantage. Capital costs will be higher than that for a fixed system. As will operating/maintenance costs due to the more complex mounting system. (Parsons Brinckerhoff)

Concentrator PV Options

This system is used to reduce the net costs of PV cells through the use of mirrors or lenses. Concentrator PV (CPV) systems use less solar cell material which are the most expensive component of a PV system on a per area basis. Plastic lenses and metal housings are used to capture solar energy. This energy is focused onto a solar cell and then converted into usable power. (Department of Energy)

Concentrator PV systems have several advantages over flat-panel systems; 1) Low system cost: Through the use of concentrating optics, power output is increased while the number and size of PV cells needed is reduced providing economical savings. 2) High efficiency: The Solar cells' efficiency increases under concentrated light. The need for fewer solar cells allows for the spending on smaller, more efficient solar cells, such as single-crystalline GaAs thin films, capable of achieving between 26% to 37% efficiencies. 3) Low capital investment: Concentrators can be composed of small individual cells which are easier to produce than large-area, high-efficiency solar cells. Mirrors and lenses are used as an inexpensive, semiconductor substitute, shaving material costs. (National Renewable Energy Lab) A typical PV concentrator unit, depicted in **Figure 14**, consists of a lens to focus solar radiation onto the cell assembly. Within the cell assembly is a secondary concentrator to focus off-center light rays onto the cell and a mechanism to dissipate excess heat produced by concentrated sunlight. These components are protected by a housing element. The module displayed in **Figure 14** is a 12 cell unit in a 2x6 matrix, but can be configured as necessary to achieve the desired module. (Department of Energy)

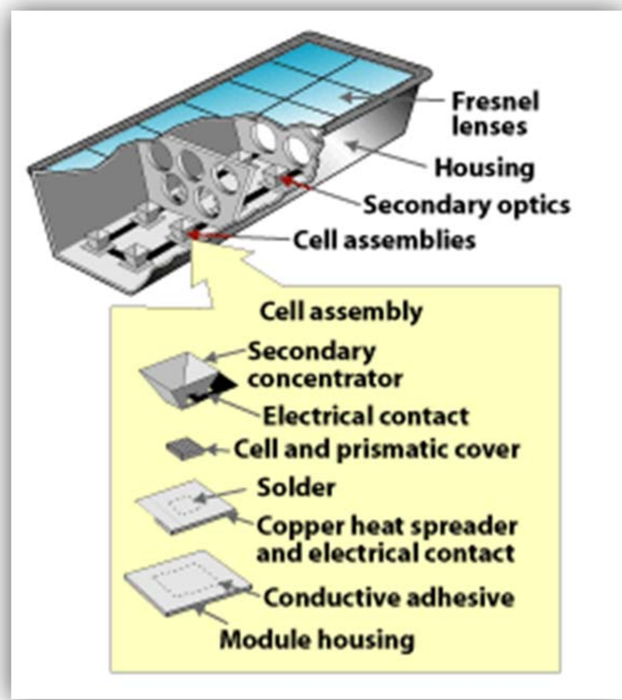


Figure 14. Typical PV concentrator unit. (Department of Energy)

As a relatively new technology, CPV systems face several challenges. Although concentrating optics reduce the number of PV cells needed – the most expensive component of a PV system – the concentrating optics used to focus the energy onto the solar cells are more expensive than the simple covers used for flat-plate systems. Concentration PV systems are extremely efficient and achieve high absorptive rates, but to do so they must track the sun and use precise controls for concentrating sunlight. This requires the employment of expensive tracking mechanisms and technical mounting structures. Additionally, concentrators cannot make use of diffuse sunlight, light that is reflected off of clouds, the ground, or other objects. Diffuse sunlight comprises approximately 20% of the solar radiation available on a clear day. Concentrated PV systems concentrate heat as well as solar radiation, creating over heat problems. The efficiencies of solar cells decrease as their temperature increases which reduces power output and can negatively affect the long-term stability of solar cells. Therefore, it is important to keep solar cells cool in a concentrator system, possibly resulting in additional capital costs. Finally, in designing such a system it is essential to consider and minimize electrical resistance. This generally occurs where the external electrical contacts carry off the current generated by the cell. Contemporary methods require exceptionally good-quality, high-value silicon material. (Department of Energy)

2.1.3 Comparison of PV System Options

In 2005, the NREL performed a cost comparison of building power plants from various solar technologies. The construction of a concentrator PV electrical power plant was determined to cost less than production facilities using silicon or thin-filmed PV systems. (National Renewable Energy Lab) This comparison is illustrated in **Figure 15** which comes directly from NREL's 2005 study. It compares the construction costs of three 100 megawatt per year (MW/yr) manufacturing plants based on the three major PV technologies, but does not identify whether the two flat-plate systems are tracking or fixed modules. Although the results of this study show concentrating PV to have the lowest capital investment, it does not consider operation and maintenance (O&M) costs which can add considerably to the overall economics. Furthermore, the technology is less mature than both flat-plate PV systems and has not yet been proven reliable. Until this is accomplished, utility companies will not be inclined to invest in concentrator PV technology.

Technology	Cost ($ Million)
Crystalline-silicon PV	150–300
Thin-film PV	150–300
Concentrating PV	30–50

Figure 15. Cost to build 100 MW/yr solar power plants for various technologies (National Renewable Energy Lab)

A pre-feasibility study performed by the company, Parsons Brinckerhoff (PB), compares the capital expenses (Capex) and operational expenses (Opex) between fixed, tracking, and concentrator solar power plants. This comparison is presented in **Table 3** and shows fixed flat-plate PV to have the lowest price option. The purpose of the PB study was to identify the best large-scale solar operating technology for a project sized to produce 80 gigawatt hours per year (GWh/yr). To do so, the study examined various attributes of PV and CSP technologies appropriate for large-scale electrical production. These attributes included cost and performance. The comparison by PB of PV solar as a fixed flat-plate system, tracking flat-plate system, and concentrator system provides insight into costs and land space requirements for each system were a solar power plant of said technology to be implemented in Grand Junction.

Table 3. A comparison of PV options taken from the PB solar power pre-feasibility study. (Parsons Brinckerhoff)

Technology	Capacity (MW)	Energy (GWh/yr)	Plant Capital Cost ($/kWp)	Project Capital ($ million)	Annual O&M ($ million/yr)	Land Area (acres)	Land Area (hectares)
Fixed Flat Panel	56.5	80	6,704	424	1,893	185.25	75
Tracking Flat Panel	47.6	80	9,158	482	3,098	207.48	84
Concentrated	45	80	8,525	427	2,925	138.32	56

Energy Payback Time

Energy payback time (EPBT) provides an approximate calculation of the length of time it will take for a given system to produce the energy (output energy) that went into its manufacture (input energy). It is especially useful for renewable energy technology because the majority of costs are governed by one-time development. There are three factors which determine the EPBT in a photovoltaic system: the amount of insolation received by the PV system, the conversion efficiency from light into electricity of the PV system, and the manufacturing technology used to produce the PV cells. (Department of Energy) Insolation is the incident solar radiation received on a collector and is measured in kilowatt hours per meter squared per year ($kWh/m^2/yr$) (Randolph and Masters) The United States receives an average of about 1800 $kWh/m^2/yr$; however, this value varies widely according to geography and other factors. (Department of Energy) **Table 4** below provides EPBT values for four different PV technologies and is based on the average insolation for southern Europe. A conservative Performance Ratio (PR) of 75% was used to account for shading, snow cover, cloud cover, heat loss, and DC-AC conversion losses. (Fthenakis and Alsema)

Table 4. System EPBT based on 1700kWh/m²/yr insolation and 75% PR for several different PV technologies. (Department of Energy)

Cell Technology	Energy Payback Time (EPBT)[1] (yr)	Energy Used to Produce System Compared to Total Generated Energy[2] (%)	Total Energy Generated by System Divided by Amount of Energy Used to Produce System[2]
Single-crystal silicon	2.7	10.0	10
Non-ribbon multicrystalline silicon	2.2	8.1	12
Ribbon multicrystalline silicon	1.7	6.3	16
Cadmium telluride	1.0	3.7	27

Although concentrating PV solar power is the least mature of the technologies described by this study it illustrates many promising benefits. Costs to build a large-scale concentrated PV system are competitive in price if not less expensive than a fixed or tracking flat-plate system as illustrated in **Figure 15** and **Table 3**. Costs continue to decrease as technology becomes more available, reliable, and utilized. They are also highly efficient at converting solar into energy. Some CPV technologies have achieved 37.3% efficiency. They are able to do so because their concentrating optics focuses incoming sunlight; therefore, solar cells (semiconductors) needed for energy conversion is much smaller than for flat plate systems. Since fewer solar cells are needed, more expensive and efficient semiconductor materials can be utilized, such as GaAs. This also allows for the use of inexpensive mirrors or lenses. As seen in **Table 3**, CPV requires less land to produce almost the same amount of power per year as flat plate systems; because CPV is highly efficient, the number of solar modules decreases. In turn, this reduces the amount of land needed to support a CPV power plant. (National Renewable Energy Lab) Of the PV systems identified, a concentrated PV system appears most advantageous for solar power plants.

Except for fixed flat plate systems, tracking flat plate and CPV are almost always designed for ground systems. However, with continued R&D this is beginning to change. While designs for

[1] V. Fthenakis and E. Alsema, "Photovoltaics energy payback times, greenhouse gas emissions and external costs: 2004-early 2005 status, *Progress in Photovoltaics*, vol. 14, no. 3, pp. 275-280, 2006. (Department of Energy)

[2] Assumes 30-year period of performance and 80% maximum rated power at end of lifetime. (Department of Energy)

rooftop mounted low-concentration CPV are being experimented with, this technology is beyond the scope of this study. Only those proven reliable will be considered in this study. To date, crystalline silicon (c-Si) semiconductor materials still dominate the market; however, thin film materials, particularly amorphous silicon, are making significant in-roads. Of the thin film technologies, amorphous silicon is the most well-developed and is cheaper to manufacture than c-Si. That being said, it is still less-efficient at converting solar to energy than its c-Si competitor. (Solar Buzz "Tech") Companies like SunPower® are achieving efficiencies greater than 20% with c-Si technology. (Sunpower) The onslaught of solar power production and increased efficiency has driven down c-Si production costs. It remains the leading material on the market used in rooftop mounted solar modules; therefore, for this study, fixed flat plate c-Si panels are the best proven reliable option to use for rooftop mounted systems. (Solar Buzz "Tech")

2.2 Concentrating Solar Power

Concentrating solar power (CSP) systems have been employed commercially for the past three decades. Nine solar trough-based CSP plants generating approximately 354 MW of power have been operating in the US since the 1980s. Until recently, no new commercial CSP plants have been built. Due to a renewed interest and awareness sparked by increased fuel costs, an interest to generate low carbon energy, and new financial support mechanisms, CSP technology has again regained momentum. (Parsons Brinckerhoff)

CSP systems are well suited for large, utility-scale applications capable of providing hundreds of MW of electricity for the power grid. A CSP system contains three main components (Parsons Brinckerhoff):

- Solar concentrator, i.e. mirrors to collect and concentrate solar energy
- Solar energy receiver to convert solar energy into useable heat
- Electricity generating plant

Simply described, power is concentrated using mirrors that reflect sunlight onto receivers. The collected solar energy is converted to thermal energy and used to heat a working fluid such as water to produce steam. This high-temperature fluid (steam) is used to drive a Rankine cycle which converts heat into work, as in a conventional thermal electricity generation plant. (DOE)

There are three main CSP technologies classified by how they collect solar power (Department of Energy):

1. Linear concentrator systems (line focus)

2. Dish/Engine systems (point-focus distributed receiver)
3. Power tower systems (point-focus central receiver)

The following sections will elaborate and illustrate basic operations of each as well as CSP systems' distinct advantage over other solar technologies (i.e. PV systems) to store energy.

2.2.1 Linear Concentrator Systems

In a linear CSP system, large, U-shaped mirrors (**Figure 16**) are used to reflect and focus sunlight onto linear receiver tubes which contain a working fluid, typically a synthetic oil, that is heated to about 390 degrees Celsius (°C). (Sandia National Laboratories) For maximum annual solar energy collection, the mirrors are oriented in a north-south direction and track the sun from east to west on a single-axis system. This ensures that the sun reflects continuously onto the receiver tubes. (DOE) As described earlier, the hot oil is used to heat/boil water for use in a conventional steam turbine generator to produce electricity. (Sandia National Laboratories)

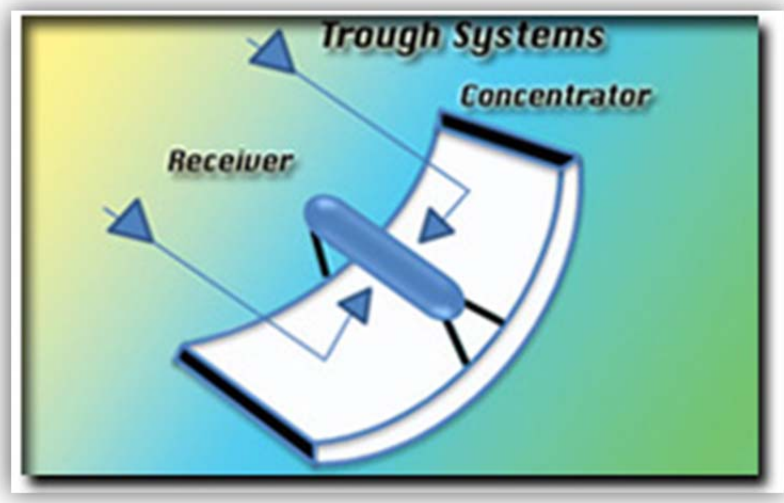


Figure 16. A schematic of a typical mirror for a linear CSP system. (Sandia National Laboratories)

Parabolic Trough Systems

There are two major linear concentrator system architectures: parabolic trough systems; and linear Fresnel reflector systems. Parabolic trough systems are the predominant CSP systems operating in the US and have the most commercial experience of all the main solar thermal technologies. (Parsons Brinckerhoff) The design uses parabola-shaped mirrors or reflectors to reflect and focus solar radiation onto central receiver tubes positioned along the focal line of each mirror. Within the mirrors is a silver layer located on the backside of the glass, described as a second-surface silvered glass mirror. The glass is composed of a high transmittance, four-millimeter (mm) thick, low iron or white glass and is approximately two (2) square meters (m^2) in area. (NREL) A heat-transfer fluid (oil) or water/steam circulates within the receiver tubes. The mirrors concentrate solar radiation onto the receiver tubes to heat the working fluid where it is used to create steam for use in a steam turbine generator or sent directly to the turbine. (DOE) This process is portrayed in **Figure 17**.

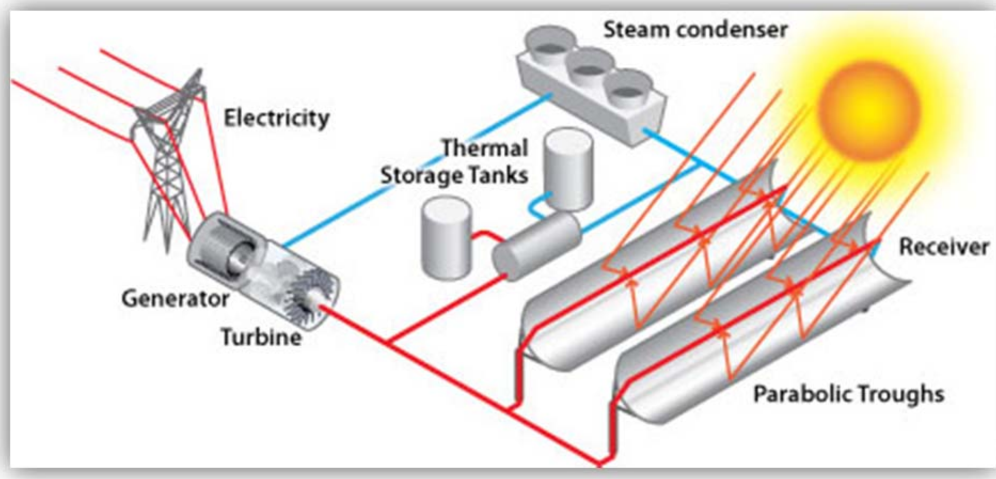


Figure 17. A linear CSP plant using parabolic trough collectors and thermal storage tanks. (DOE)

As shown in **Figure 17**, trough designs can incorporate thermal storage. To do so, the collector field, which consists of parallel rows of reflective parabolic troughs, is oversized in order to heat a storage system during the day. The energy stored in the thermal storage tanks can be used to generate additional steam to produce electricity during the evening or on cloudy days. Parabolic trough plants can also incorporate a natural gas- or coal fired heater, gas-steam boiler/reheater, or combined cycle gas turbine (CCGT) as auxiliary power during periods of low solar radiation. (DOE)

Linear Fresnal Reflector Systems

Originally invented for lighthouses by the French engineer Augustin-Jean Fresnal, this segmented lens is a type of optical system that uses a multiplicity of small, flat optical faces. (Ford) This characteristic makes for a cheaper and lighter optical system. (Parsons Brinckerhoff) The Fresnal technology has since been adopted and adapted into the linear Fresnal reflector (LFR) system representing the second major CSP technology. In this system, a number of discrete mirrors (flat or curved) are mounted on trackers on the ground. Large, linear solar receiver tubes are elevated in a fixed position above the mirrors which are configured to reflect sunlight onto the tubes, as seen in **Figure 18**. (DOE)

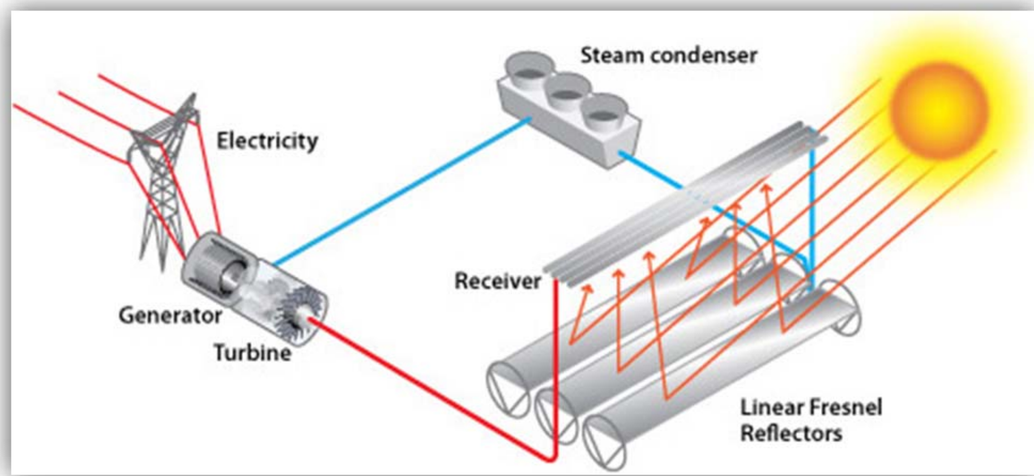


Figure 18. An example of a typical LFR CSP plant. (Department of Energy)

A fixed receiver offers a couple engineering and economic advantages. As a stationary device, LFR receivers lack the mechanical complexity indicative of moveable receivers used with parabolic troughs. Moreover, the flexible connections used between the receivers and the piping systems on parabolic troughs are unnecessary. (Parsons Brinckerhoff) Additional advantages include the structure of LFR mirrors which are composed of thin one (1) to two (2)mm thick ribbons of mirrored float glass or low-iron glass to achieve added efficiency. Unlike parabolic trough mirrors (heliostats) which need precision bent glass reflectors, LFR mirrors are easily procured and are a third of the weight (3 kilograms per square meter) of parabolic mirrors, thus minimizing structural costs. (Ford) In conclusion, though LFR systems may have lower energy conversion efficiency and less optical accuracy in comparison to dish and trough systems, they potentially have lower capital and operating costs and thus produce cheaper energy. (Parsons Brinckerhoff)

2.2.2 Dish/Engine Systems

The dish/engine solar power system resembles a large satellite dish made up of parabolic mirrors designed to direct and concentrate sunlight onto a central power conversion unit (PCU) to produce electricity. The PCU houses the thermal receiver and the engine. The dish/engine system is composed of two major components: the solar concentrator (dish) and the PCU as represented in **Figure 19**.

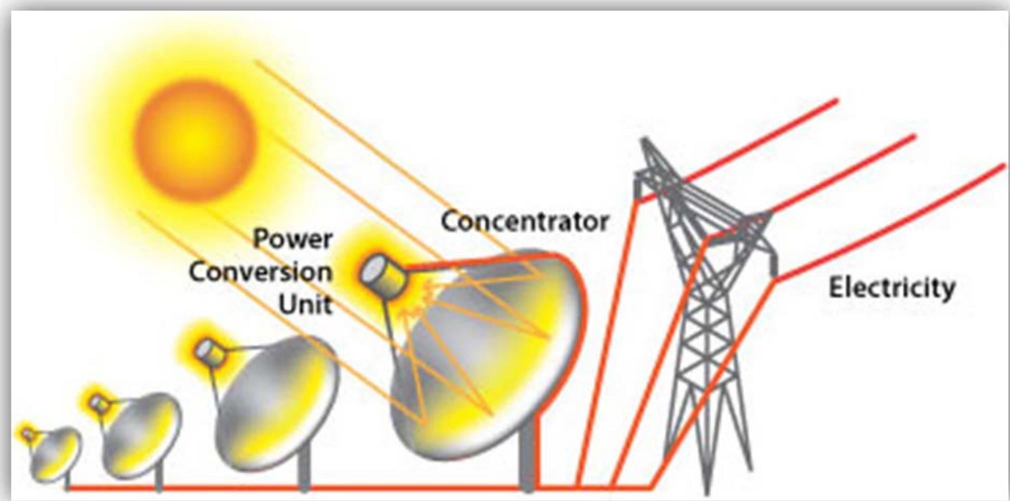


Figure 19. A dish/engine system. (Department of Energy)

As with linear concentrator systems, the dish collects the sun's energy which is then reflected onto a thermal receiver. The thermal receiver is located within the PCU which is fixed as a single point above the dish. The dish is mounted on a dual-axis tracking system allowing it to follow the sun throughout the day to collect and reflect as much solar energy onto the receiver as possible. (DOE)

The thermal receiver acts as the interface between the dish and the engine/generator. A heat-transfer medium made up of a multitude of tubes typically filled with hydrogen or helium run throughout the interior of the receiver. Sunlight is reflected off the dish and concentrated onto the receiver which absorbs the sun's energy converting it into heat. (DOE) The fluid within the tubes of the receiver also create mechnical power to move the pistons within the engine which then turns a generator or alternator to produce electricity. (National Renewable Energy Lab)

Unlike the CSP technology precviously discussed, most dish/engine systems use the Stirling cycle rather than the Rankine cycle to perform work in a heat engine. The Stirling cycle consumes heat from an external source such as the sun in the case of a dish/engine CSP system. Typically, a Stirling engine is coupled with the dish, but some systems employ steam engines. The Stirling engine operates by creating a net conversion of heat energy to mechanical work. This is done through the compression and expansion of gaseous working fluids (i.e. helium or hydrogen) at different temperature levels. (Nice) The mechanical work drives a rotational crank shaft producing rotational kinectic energy which in turn runs a generator or alternator to create electricity. (DOE)

There are several advantages of a dish/engine system. Dish/engine systems are capable of achieving higher temperatures than LFR systems because 92% of the sunlight collected is reflected directly onto one centralized point. (Sandia National Laboratories) Higher temperatures convert heat to electricity more efficiently than at lower temperatures. Working gaseous fluids reach temperatures over 700°C (1,292°F). The Stirling PCU design is typically 90% efficient in delivering solar energy from the dish concentrator to the engine. Dish/engine systems have demonstrated 29.4% solar-to-electric conversion efficiency, highest of the CSP systems. (SolarPaces) They can be used individually in remote locations without a power grid system to pump water or provide electricty. (Sandia National Laboratories) They can be grouped together for distributed generation, grid connected applications, or end-of-line utility applications. Furthermore, they are capable of hybridizing with fossil fuels (i.e. NG, coal) to provide dispatchable power. (SolarPaces)

Operationally, environmental consequences are relateively insignificant. Dish/engine systems have a high profile and may have some visual impacts on the landscape as they extend as much as 15 meters (m) (49.2 feet) above the ground. The engine produces little noise and emissions. Spills and leaks of engine oil, coolant, and/or gearbox grease can occur; however, preventative measures can be taken to avoid such events, such as routine maintenance checks and a well-developed spill prevention, control, and countermeasure (SPCC) plan. (SolarPaces)

2.2.5 Power Tower Systems

Numerous flat mirrors (heliostats) mounted on tracking systems focus sunlight onto a receiver located at the top of a tall tower. Theses mirrors are installed in a circular formation surrounding the power tower. A design example of a power tower plant has been provided in **Figure 20**. The power tower receiver is usually filled with a heat-transfer fluid, such as water, to generate steam; however, more advance technology is now experimenting with molten nitrate salt which has far more efficient heat-transfer and storage capabilities than water. As with all CSP technologies, power tower systems also utilize a conventional turbine generator to produce electricity. Power tower plants can be sized to commercially produce 200 MW of electricity. (DOE)

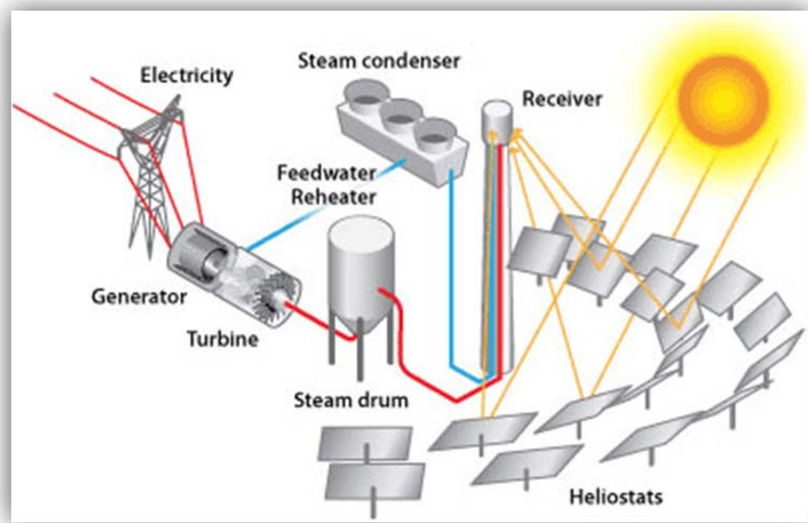


Figure 20. Example of a power tower plant. (DOE)

To date, two large-scale solar power tower plants have been deployed in the US as demonstration projects: Solar One plant and Solar Two plant. Solar One began operations in 1982 and was designed to produce 10 MW. It was located near Barstow, California and was in operation for about six (6) years until 1988. Solar One successfully demonstrated the viability of power tower technology by producing more than 38 million kWh of electricity over its life. Solar Two retrofitted Solar One's receiver with one of molten salt as its heat-transfer fluid to demonstrate its heat-transfer efficiency and thermal storage advantages. These advantages were observed when Solar Two successfully produced and dispatched power to the grid 24 hours a day for nearly seven days straight. (Sargent and Lundy Consulting Group)

2.2.6 Comparison of CSP Operating Systems

In nearly all applications, CSP is used for large-scale operations of 100 MW or larger. All CSP technologies collect solar energy and convert it to heat to be used in a conventional power cycle where heat produces mechanical power to drive a generator. (Sandia National Laboratories) This attribute enables CSP plants to operate as a hybrid system where one part runs on fossil fuels like the Cameo power plant described in Section 1.4. CSP plants are also capable of supporting cost-effective thermal storage techniques (**Figure 17**). Both CSP plant options (hybrid and thermal storage) generate electricity even when the collectors aren't absorbing solar energy, for example during the night or periods of cloud coverage.

A cost comparison of the different available CSP technologies was performed using the System Advisor Model (SAM) Version 2010.10.8 developed by NREL in partnership with the Sandia

National Laboratory (SNL) and the DOE's Solar Energy Technologies Program (SETP). SAM was developed to be employed by various users in the renewable energy industry. It is a simulation model designed to make performance and economic predictions for solar, wind, and geothermal power systems connected to the grid. The model calculates energy output, energy costs, and cash flows based on the interaction between multiple simulation models (i.e. cost, finance, and performance models). The software also accounts for state, utility, and federal incentives. (NREL "SAM")

The figures presented in **Table 5** were calculated using SAM. The nameplate capacity or maximum rated output is 100 MW for each CSP plant. This capacity was determined and described in Section 0. SAM has a variety of locations/climates to choose from for each state. There were six offered locations in Colorado; one of these was Grand Junction. The location/climate information included several key attributes such as direct normal and global horizontal radiation and latitude. The following table is a baseline cost and performance comparison of the three different CSP technologies with 100 MW capacities. Parabolic troughs and power towers are capable of supporting thermal storage while dish systems are not. Incorporating thermal storage increases the capital cost of a system; therefore, to perform a relatively fair comparison thermal storage was not taken into account. Each CSP plant was simulated as a utility project owned by an independent power producer. This option was chosen because 1) currently, CSP technology is designed for large-scale (utility-sized) production of energy, and 2) it was the only option provided for a power tower system. To maintain consistency, all CSP systems needed to be compared using relatively the same inputs. These figures provided in **Table 5** are only representative and not exact figures. Costs are dependent on many factors such as plant size, the addition of thermal energy storage and size of storage, and if the solar field (modular array) is expanded to increase annual production capacity.

Table 5. Cost and performance comparison of different CSP technologies.

Technology	Nameplate Capacity (MW)	Cost ($ million)	Land Area (acres)	Energy Output (kWh/yr)	LCOE (¢/kWh)
Parabolic Trough	100	636.7	910	223,624,633	20.97
Dish	100	301.5	600	165,177,300	15.63
Power Tower	100	591	1,284	123,060,862	35.72

According to SAM, a CSP plant using dish/engine technology has the lowest capital cost and cost to consumer which is represented as LCOE in **Table 5**. The Levelized Cost of Electricity (LCOE) is the minimum price at which electricity must be generated from a specific source to create enough revenue to pay off all the utilities' costs and make a sufficient return to investors. (CBO) Of the three, a power tower plant has the least energy output per year. Although a parabolic trough plant has the highest capital cost, it produces the most energy per year at a lower LCOE price than that of a power tower. From the choices described in **Table 5** it would appear that a dish/engine system would be the most economical option to building a CSP plant. It is also the most environmentally efficient as it requires the least amount of land and it does not require water for production. (Clarke) Parabolic trough and power tower systems use water as a mechanism for cooling. This method is known as wet cooling and typically requires around 500 – 800 gallons per MWh, the same as a coal-fired or nuclear power plant. At some point all solar collectors of any system must be cleaned of debris (i.e. dust) to maintain optimal performance. This requires water, approximately 20 gallons per MWh. (SEIA "Water") The table provided below displays an estimated amount of water use for each CSP system (parabolic trough, dish, and power tower). Wet cooling and total usage are given as a range for a parabolic trough and power tower system based on the typical water requirement for wet cooling stated above.

Table 6. Estimated water usage per year for each type of CSP system.

Technology	Nameplate Capacity (MW)	Wet Cooling (million gal/yr)	Cleaning (million gal/yr)	Total Usage (million gal/yr)
Parabolic Trough	100	111.8 - 179	4.47	116.3 - 183.5
Dish	100	N/A	3.3	3.3
Power Tower	100	61.5 - 98.4	2.46	64 - 101

Water cooling is the most efficient and cost effective technique available; however, many CSP plants designed today are implementing dry cooling. Dry cooling utilizes outside air which must be significantly cooler than the exhaust steam produced by the plant to create an adequate heat exchange. This is performed by using fans and the ambient air to reject heat from the condenser. Performance becomes limited as the ambient outside air temperatures increase during the summer season. Dry cooling systems are higher in capital costs, but drastically reduce the overall use of water. (SEIA "Water")

Of the three CSP technologies described, parabolic troughs are the most commercially mature and many power plants using this technology have been in operation since the early 1980's. Nearly 30 years of operation have allowed for close observations which have benefited the technology by improving both economic and performance efficiency. The reliability of this technology is so trusted that this year (2010) Solar Millennium, LLC plans on building the world's largest solar power plant, a 1000 MW (1 gigawatt) CSP plant designed with parabolic troughs estimated to service almost 800,000 California homes. It is known as the Blythe Solar Power Project and is the first of its kind to be granted federal approval to begin construction on public lands. (BLM "Blythe")

3. Solar Resource Potential

Solar insolation, a measure of solar radiation, is the total solar radiation energy (encompassing ultraviolet, visible, and infrared radiation) received by a specific geographical location at a given time. (EPLAB) The earth's surface receives solar radiation as direct and diffuse insolation. Direct radiation is that which passes through the atmosphere directly to the surface of the earth. The remaining solar radiation that isn't absorbed or received directly is scattered by molecules of air, water vapor, or dust particles and reaches the earth's surface as diffuse radiation. Both direct and diffuse forms of solar radiation make up the total radiation absorbed by any horizontal surface. This is referred to as global radiation. (EERE)

Concentrating solar collectors are designed to track the sun, but only absorb direct beam radiation which is converted into heat and used in a thermal power station. Flat-plate PV collectors are capable of absorbing global radiation (direct and diffuse beam radiation) as well as radiation reflected from the ground in front of the collector. Different solar conversion energy technologies are further explained in Chapter 2. (Marion, Riordan and Renne)

The distribution of solar radiation across the entire earth's surface varies on a daily and annual basis. Changing atmospheric conditions (i.e. the accumulation of clouds) largely determines the amount of solar radiation that reaches the earth. Increasing cloud cover scatters the sun's rays and decreases the amount of available solar radiation. Desert climates such as those found in the southwestern US typically receive more solar radiation than mountainous or coastal regions where geographical features influence the formations of clouds. Air pollution, forest fires, and volcanic activity also disperse sunlight and affect the amount of solar radiation received by different regions on the earth. (Marion, Riordan and Renne)

The variation in position of the sun throughout the day and year (seasonal positioning) also impacts the variability of solar radiation. More direct solar radiation reaches the earth's surface during midday when the positioning of the sun is directly overhead and the angle from the zenith direction is 0°. Zenith is the point directly overhead. In **Figure 21**, when the sun "A" is directly over point "X", the zenith angle is equal to 0°. The zenith angle is the angle from the zenith to the sun's position. (Stickler) When sun "B" is lower on the horizon, the zenith angle is 60° (**Figure 21**). The angle of the sun relative to zenith determines the air mass. Solar radiation must travel through the atmosphere before it reaches the surface of the earth. The air mass is a measure of this distance travelled by radiation. (Sukhatme) Therefore, air mass 1 corresponds when the sun is directly above zenith, thus creating “the path of least resistance” for direct beam radiation through earth’s atmosphere (**Figure 21**). (Marion, Riordan and Renne)

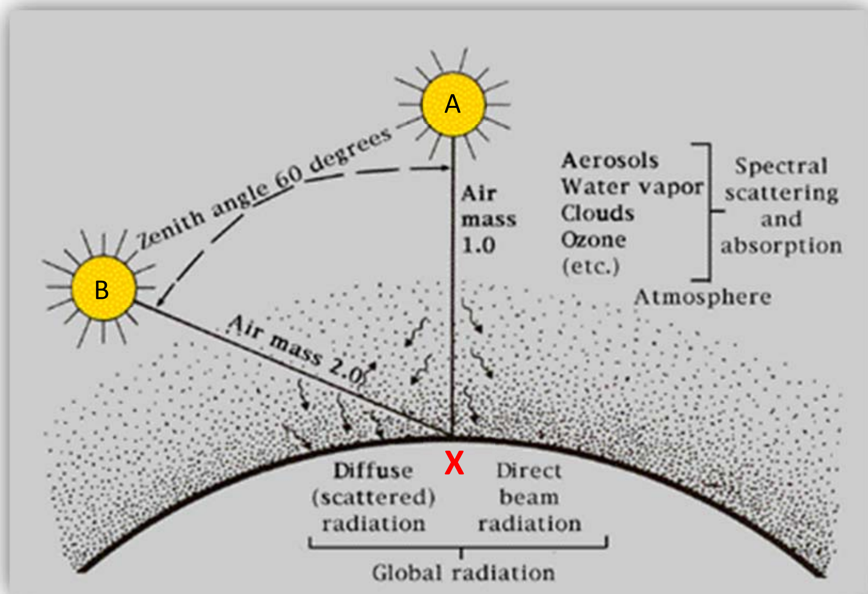


Figure 21. “X” represents zenith. Sun “A” is directly above zenith. Sun “B” is closer to the horizon at a 60° angle to zenith. (Marion, Riordan and Renne)

In order to determine the performance, size, and economics of solar conversion technologies it is important to characterize the solar radiation potential associated with a site that is to be considered for solar generation. Solar radiation data for a site can also be used to optimize energy production in cells used in PV modules. From this designers and engineers can then optimize design and determine potential for energy production. For example, to determine hour-by-hour energy production throughout the year for a solar power plant, hour-by-hour solar radiation data is needed. This is normally calculated with a computer simulation program. This kind of information allows utility engineers to effectively evaluate if a solar power plant will reliably and economically meet the daytime electrical demand of an area. (Marion, Riordan and Renne)

3.1 Solar Resource in Grand Junction, CO

The solar power implementation options described in this study are for distributed generation. Distributed generation is power generation at or close to the point of consumption. This reduces the amount of energy lost in transmission and reduces the size and number of power lines that must be constructed. Grid reliability increases, because DG does not connect directly into the bulk transmission system. This also eliminates the need to update existing transmission/distribution lines. (Solar Buzz)

The solar energy resource data for Grand Junction is taken from NREL. National solar resource potential for PV and CSP technologies were assessed by NREL for the US at a resolution of 40 km by 40 km. These solar radiation data are displayed in maps on the following pages. A solar radiation data chart and meteorological data for Grand Junction has been provided in **Appendix II**. The NREL solar radiation data maps (**Figures 18 – 21**) are based off of 30 years of data collection for each site. Solar radiation values were derived from data collected from 1961 – 1990. (NREL "Radiation Data") They illustrate potential values for various PV and CSP technology installed with and without latitude tilt and a tracking mechanism that follows the sun's position in the sky throughout various times of the day.

For optimum solar radiation absorption from a PV system, panels on a 2-axis tracking system that constantly hold their receiving surface perpendicular to the sun's rays at its current position in the sky will produce 7 – 8 kWh/m^2/day in Grand Junction (**Figure 22**). (Utah Geological Survey)

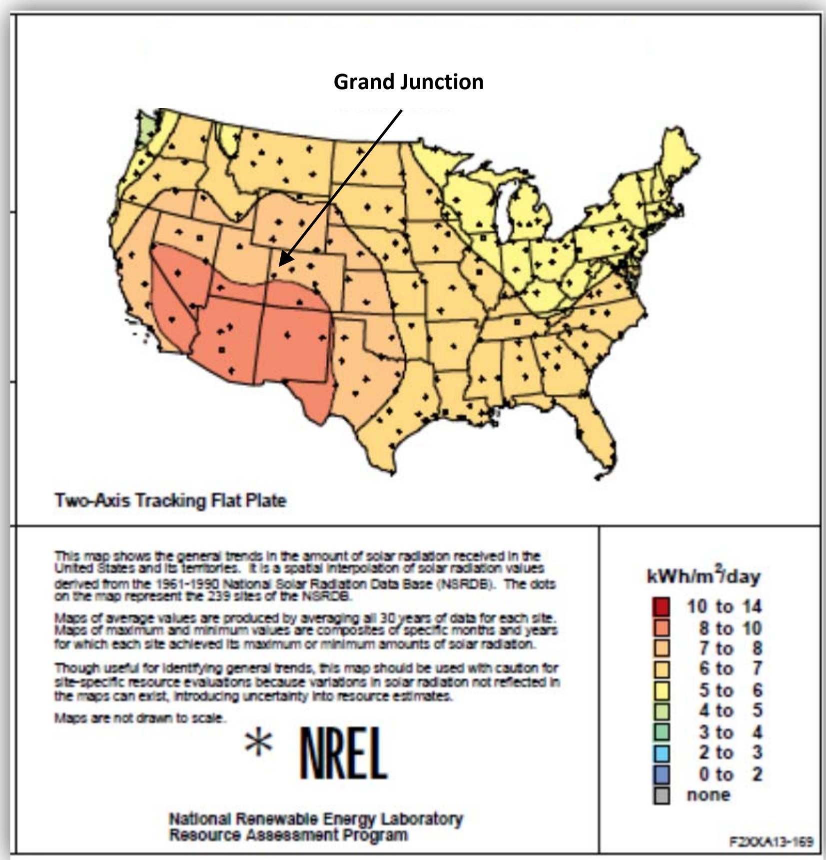


Figure 22. Annual average daily solar radiation data for a two-axis tracking PV flat plate. (NREL "Radiation Data")

This next figure, **Figure 23**, represents the annual average solar radiation for a south-facing, flat-plate PV collector with fixed tilt at latitude. For a fixed flat-plate collector, maximum solar absorption is achieved by using a tilt angle equal to that of the site's latitude. To achieve optimal performance in the winter time, the collector is tilted 15° greater than the latitude. For optimal summer performance, the tilt is 15° less than the site's latitude. Using this technology, Grand Junction (39°03'53"N) receives as an average between 5 – 6 kWh/m^2/day. (NREL "Radiation Data")

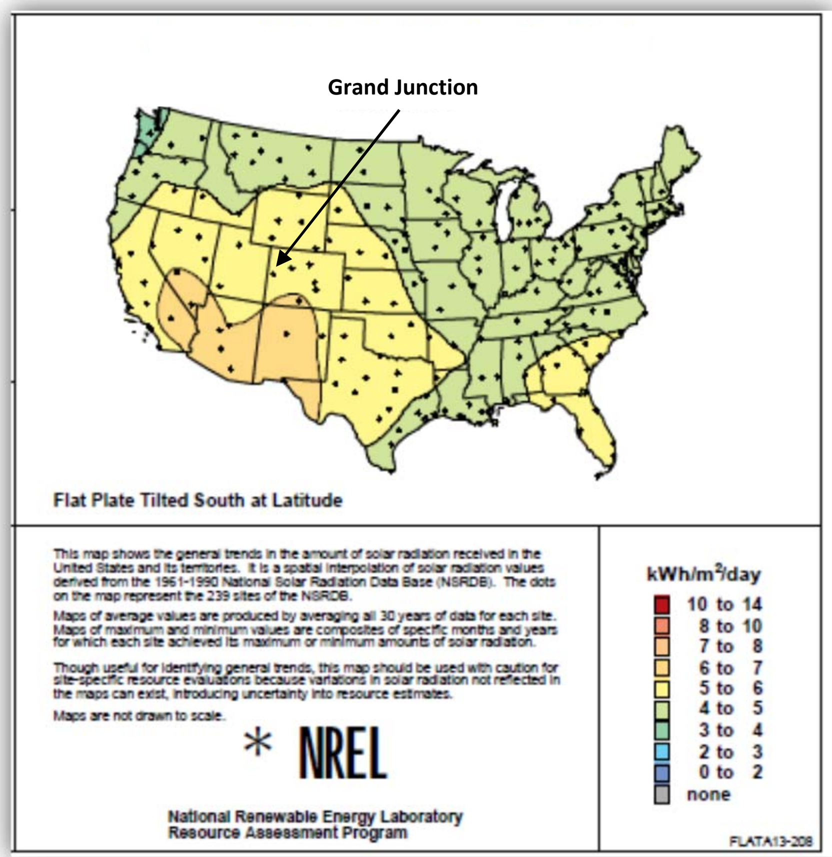


Figure 23. Annual average daily solar radiation data for a fixed PV flat-plate tilted south at latitude. (NREL "Radiation Data")

The Cameo solar-coal hybrid power station discussed in Section 1.4 utilizes single-axis tracking parabolic troughs with a horizontal east-west axis. The axis of the concentrator runs north-south allowing the collectors to track the sun throughout the day from the east to west horizons. In Grand Junction, the annual average solar radiation received by this technology is between 4 – 6 $kWh/m^2/day$ as displayed in **Figure 24** below. (NREL "Radiation Data")

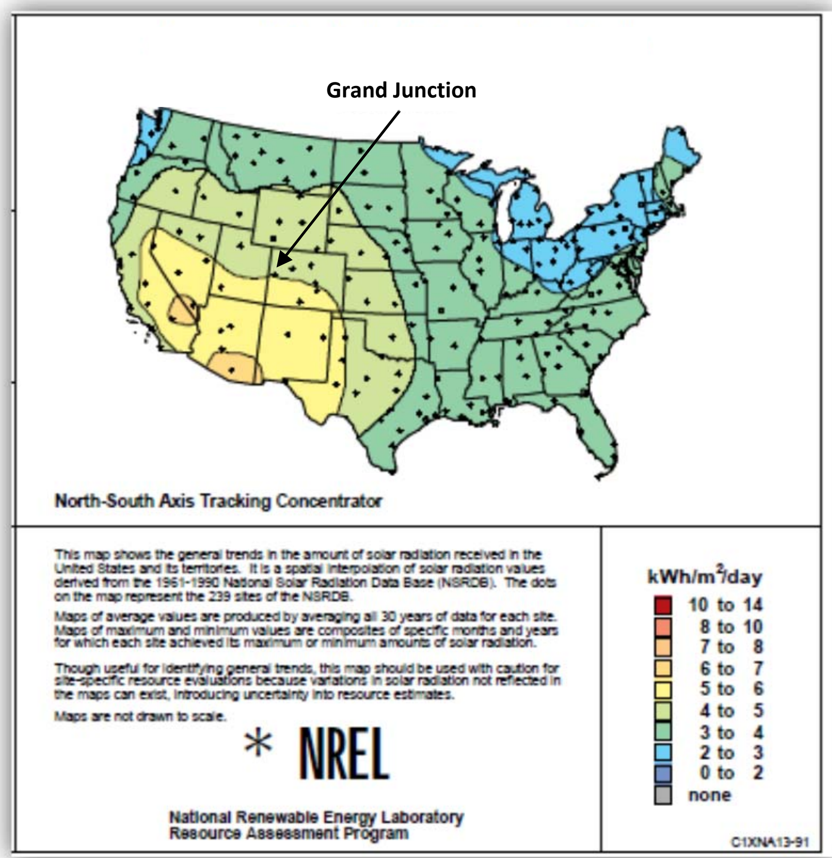


Figure 24. Annual average daily solar radiation data for a north-south axis tracking concentrator. (NREL "Radiation Data")

A two-axis concentrating system allows for greater solar radiation absorption than the one-axis tracking system. Parabolic dish systems are only able to absorb direct beam radiation from the sun. Direct beam radiation comes in a direct line from the sun. The parabolic dish concentrates solar energy onto a small area by tracking the sun in both azimuth (angle from due north in a clockwise direction) and elevation. A two-axis tracking system keeps the surface of the collector perpendicular to the sun's rays all day, thus maximizing energy production from a solar energy generating system. Grand Junction's annual average daily total resource using this technology is between 5 – 6 kWh/m^2/day (**Figure 25**). (NREL "Radiation Data")

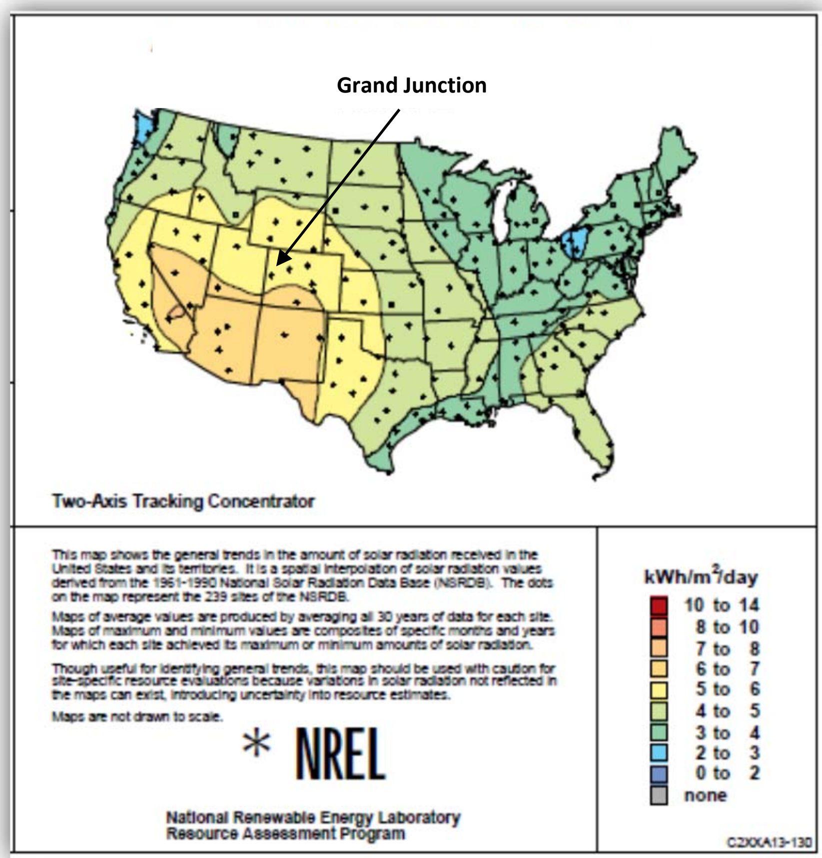


Figure 25. Annual average daily solar radiation data for a two-axis tracking concentrator. (NREL "Radiation Data")

4. Option 1: Solar Power Plant

Grand Junction is surrounded by prime real estate capable of supporting a large-scale, utility-sized solar power plant as seen in **Figure 26**. Approximately 41 mi^2 (106.2 km^2) of Mesa County is developed. The city of Grand Junction, 33 mi^2 (85.5 km^2) in area, contributes to well over half of this development. The remaining 3,268 mi^2 (8,464 km^2) is unincorporated land, of which nearly 71% has been designated as public lands and is managed by federal and state agencies, such as the Bureau of Land Management (BLM) and Colorado State Parks. (Mesa County)

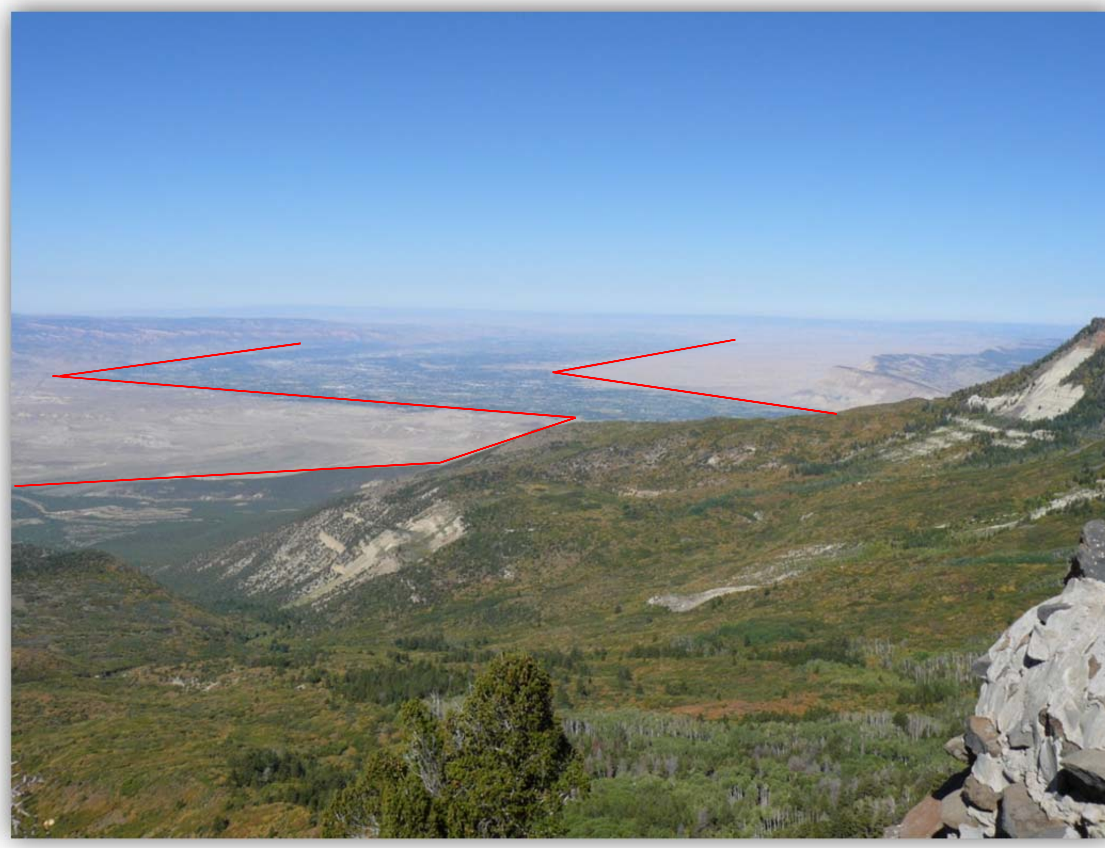


Figure 26. Personal picture of the Grand Junction valley. Lighter-colored areas outlined in red are unincorporated BLM lands available for possible large-scale solar power

Most public land in the western US is managed by the BLM and has been identified as having potential to support renewable energy projects such as solar power plants. As Federal land managers, the BLM receives, reviews, and authorizes permits and licenses submitted for the exploration, development, and production of both renewable and non-renewable forms of energy. They are responsible for designing ecologically sound development strategies that meet applicable environmental laws and regulations. (BLM) These are known as Programmatic Environmental Impact Statements (PEIS) and undergo several public reviews.

At present, the BLM, in cooperation with the DOE, is preparing a PEIS for solar development on public lands. The PEIS will address several subject matters associated with environmental, social, and economic impacts. Such subject matters include the assessment of environmental impacts associated with agency-specific programs developed to establish environmental policies and mitigation strategies for solar projects; the revision and amendment of relevant land use plans in six (6) western US states including Colorado; and the designation of tracts of western public lands for use as utility-scale solar energy zones. The solar energy development PEIS proposes that action be taken to establish programs focused on the environmentally responsible development of utility-scale solar energy projects. Through this PEIS, the BLM expects to identify lands within their jurisdiction that are environmentally capable of supporting solar energy development and those lands that would not. The BLM will also determine if "additional electricity transmission corridors" are necessary to support the growth of utility-scale solar energy development. Likewise, through this PEIS, the DOE is considering policies and mitigation strategies as guidance for the deployment of DOE-funded solar energy projects. Such policies and mitigation measures would help to identify the best practices for deploying solar energy projects with the least environmental impact. The draft PEIS is expected to be released for public review and comment late summer or early fall of this year (2010). To date, there are no utility-scale solar power plants operating on Colorado BLM land. (BLM)

4.1 Policies and Regulations

The following sections have been provided as a brief introduction into the development process of a solar power plant. Before construction of a solar power plant can take place on public lands managed by the BLM several conditions established through policies and regulations must be met. These processes can often take more than a year to complete and have been described below to offer a basic understanding of their purpose.

4.1.1 Solar Energy Policy

The BLM's existing Solar Energy Policy, released 4 April, 2007, is used to process applications for solar energy projects on public lands. The goal of the policy is to facilitate environmental responsibility in the development of commercial solar energy projects such as solar power plants. The Solar Energy Policy defines and addresses several aspects.

In summation, the Solar Energy Policy provides guidelines for the development of solar energy facilities by designing and reviewing appropriate land use strategies and describes the steps to be taken by individuals/companies in order to receive authorization to use a specific piece of public land. This is achieved by applying for a right-of-way (ROW) grant. The grant is then processed on a first-come, first-served basis under Title V of the Federal Land Policy and Management Act (FLPMA) and Title 43, Part 2804 of the Code of Federal Regulations (CFR). Upon approval, the successful party is expected to pay an annual rent in conformance with 43 CFR 2806.10(a). If a particular piece of land has been deemed particularly valuable to the support of solar energy development, the BLM will initiate a competitive bidding process for solar energy ROW authorizations. Successful applicants will be expected to practice due diligence. They will not hold ROW authorizations for the purpose of hindering solar energy development in any way. Also in accordance with due diligence, applicants will be required to include information of their technical and financial capability to construct, operate, maintain, and terminate the solar energy facility. This must be consistent with the approved Plan of Development (POD). An environmental analysis will be performed by the applicant in accordance with the National Environmental Policy Act (NEPA). It will address all direct, indirect, and cumulative effects of the proposed action. (BLM)

4.1.2 Solar Energy Plan of Development

The solar energy Plan of Development (POD) is a living document in that during the NEPA review and analysis process the POD may require additional information. The POD is to be submitted before the NEPA procedure (analysis and review) begins. In accordance with the POD's due diligence statement, ROW applicants are required to submit a carefully completed POD no later than 90 days after the BLM's letter of request. The POD will speak to six (6) main points: project description, construction of facilities, related facilities and systems, O&M, environmental considerations, and maps and drawings. Within these points, applicants will expand on details associated with each according to the initial outline provided by the BLM. (BLM) An outline describing the details expected to be presented in a POD has been provided in **Appendix III**.

4.1.3 NEPA/EIS

Once the POD has been submitted to the BLM, it is in the interest of the applicant to begin composition of an Environmental Impact Statement (EIS) in accordance with regulations promulgated by NEPA. This process can often take up to a year or more to complete.

NEPA was designed with the profundity of the varying impacts that human activities have on the quality and health of the environment. The purpose of NEPA is to ensure the protection of the natural environment and future resources while meeting social, economic, and other requirements of present and future generations. The procedures within NEPA require that environmental information, of applicable, accurate, and professional quality detail, be available to public officials and citizens for review. (Council on Environmental Quality)

For the development, implementation, and operation of solar energy facilities the BLM, the determining Federal agency, requires applicants draft and submit an EIS. The purpose of an EIS is to provide comprehensive information about a project and elaborates on the potential environmental effects associated with the proposed activity. An EIS document generally contains four main sections. The first chapter addresses the purpose of and the need for the project. This chapter provides the framework in terms of scope, extent and objectives of the project. Here the reasoning behind the proposal of the project is introduced and discussed. The second chapter discusses the character of the proposed action, such as the specific components that comprise the project. Alternatives to the project are introduced to provide decision makers with options from which to deliberate on and choose from. By law, two alternatives are required in an EIS: the original proposed project (Proposed Action) and the No Action Alternative. The third and fourth chapters represent the heart of the EIS document. Chapter 3 describes the current state of the potentially affected environment on three levels: abiotic (physical), biotic (biological), and socio-economic (anthropological) environment. This chapter provides solely a baseline analysis of the current environmental condition. It leads into Chapter 4 which identifies probable positive and negative effects on the three levels of environment described in Chapter 3. Chapter 4 examines the expected environmental impacts over the life of the project and provides a detailed description of a complete environmental analysis. (UNH)

Prior to the preparation of the draft EIS, the public is notified via the Federal Registry, the media, and letters. Project contact information is provided at this time to enable the public to freely send in comments/concerns that may help in issue identification and drafting of the EIS. Upon the completion of the draft EIS, substantive critiques are provided by the public through written comments or public hearings. Public review of the draft EIS lasts between 60 to 90 days. This is a time for individuals affected by the project to come forth and give feedback concerning the adequacy of the data, alternatives, and environmental analyses in the draft EIS. Afterwards, the draft EIS is revised into the final EIS based on public comments and additional studies. At this point, the preferred alternative is announced. Further review and commenting is closed to the public; however, the final EIS is released for 30 to 60 days for public protest before the BLM approves/denies the solar power facility application.

4.1.4 Solar Energy Interim Rental Policy

The Rental Instruction Memorandum issued on 10 June, 2010 addresses base rent and megawatt capacity fee policies associated with the BLM. Rental fees will be administered on all ROW authorizations and are calculated based on real estate appraisals and reviews procured from the Department of Interior (DOI), Appraisals Services Directorate. (BLM) Schedule payment of rent will occur annually and will include the calculated base rent fee and MW capacity fee. (BLM)

The base rent fee shall be paid the same day as issuance of the ROW authorization. Base rent is applied to the entire acreage of public land described in the ROW authorization and is a per acre fee. There is no phase-in period for the base rent fee, meaning that the applicant shall be charged annually the full amount regardless of the stage of development or operations. (BLM)

Unlike the base rent fee, the MW capacity fee will be phased-in over a five (5) year period. This is to allow for a testing and operational period. Payment shall commence upon the start of generation of electricity from the facility and will be implemented as follows:

Yr. 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5+
20%	40%	60%	80%	100%

Subsequent years of operation shall be charged the full MW capacity fee. The MW capacity fee is calculated based on the total MW capacity approved by the BLM for the solar energy facility and the efficiency factors for the various solar technologies. The capacity fees currently established under the Solar Energy Interim Rental Policy is: $5,256/MW for PV; $6,750/MW for concentrated photovoltaics (CPV) and CSP without storage capacity; and $7,884/MW for CSP with storage capacity of three (3) hours or more. Examples are given in **Table 7**.

Table 7. MW capacity fees for the 3 types of solar energy facilities of same MW capacity. (BLM)

Facility	20% ($)	40% ($)	60% ($)	80% ($)	100% ($)
100MW PV	105,120	210,240	315,360	420,480	525,600
100MW CPV/CSP	135,000	270,000	405,000	540,000	675,000
100MW CSP w/ storage	157,680	315,360	473,040	630,720	788,400

The MW capacity fee will be adjusted according to improvements in solar technology efficiency rates. (BLM)

4.2 Environmental Impacts

Although solar power systems do not emit air pollutants during operation, there are environmental impacts associated with solar energy that must be addressed. These are associated with the manufacturing, installation, operation, and disposal of a solar power system. In order to properly understand the full scope of each, a life cycle assessment (LCA) should be performed. The LCA is a method used to identify and analyze each and every impact associated with a product from its conception (cradle) to its death (grave). For example, the mining or source of raw materials, transport of these materials, processing and manufacturing of materials, distribution and installation, operation and maintenance, and finally disposal methods. (Tester) The LCA should also quantify the amount of energy, including emergy (embodied energy), required in each stage. This process is often referred to as a life cycle energy analysis (LCEA). Emergy is the energy needed to make the product, bring it to market, and then eventually dispose of the product. The purpose of emergy is to account for the total energy used for the entire product's lifecycle. All energy inputs associated with the product being evaluated are analyzed, such as the extraction of raw material, transport, manufacture, installation, operation (for solar this is important because it requires outside energy input to bring water to the collectors for cleaning and energy is also consumed for the action of cleaning), disassembly, and decommission. (Odum)

The following provides a simple overview of environmental impacts associated with the life-span of solar power. Solar power plants can utilize either PV or CSP technologies; therefore, the environmental impacts described below are relevant not only to solar power on a whole, but also to solar power plants. Impacts unique to solar power plants have also been identified and described in the following sections.

4.2.1 Manufacturing

Like with conventional energy production and other industrial processes, there are hazards associated with the manufacturing of materials and use of chemicals. Some PV cells use cadmium and arsenic which are toxic to humans, when burned (e.g. fossil fuel combustion, municipal solid waste incineration, cement production, etc), inhaled, or ingested. Nonetheless, this hazard and others differ no more from the innumerable hazards people are exposed to on a daily basis in industrial occupations, such as the use of inorganic arsenic in the manufacturing of microelectronics. (Union of Concerned Scientists) The Occupational Safety and Health Administration (OSHA) regulate and set standards regarding exposure to Cd. One such standard mandates "medically monitoring employees when they are exposed at, or above, the OSHA 8-hour time-weighted average permissible exposure limit for cadmium of 5 micrograms per cubic meter (μg/m^3) for 30 days or more per year." (NTP) A study conducted by First Solar Inc. found no significant exposure to cadmium as defined by OSHA after monitoring their employees for ten years. (NTP) Despite these findings, the US Department of Energy (DOE), Brookhaven National Laboratory, National Renewable Energy Laboratory (NREL), and First Solar Inc themselves have nominated CdTe for further study to the National Toxicology Program (NTP). The NTP evaluates those chemicals of public health concern through the development and application of modern toxicology and molecular biology tools. (NTP)

In addition, each element must be extracted through the process of mining. Mining practices have often resulted in the contamination of drinking water, contribution to air pollution, and destruction of natural habitat. Although mining practices in the US are subject to federal and state regulations (an EIA, reclamation requirements, etc.), the above stated environmental impacts and others still persist.

Another impact that is generally overlooked is the usage of water in the manufacturing of solar power technologies. This is part of the LCA. As previously discussed, PV systems require minerals that must be mined from the earth's crust. This requires water used to mine, process, and transport the element. A free-standing solar field of PV modules involves a supporting structure generally designed with aluminum, steel, plastic, and other such materials. This is known as the balance of system (BOS) and also requires the use of water during the production of its materials. In general, the entire production of a PV module and its supplemental parts requires the input of water. One LCA study found that a PV plant using CdTe panels uses approximately 7.54 gallons/MWh (gals/MWh) produced over the lifetime of the plant. The same was considered for CSP input materials and was found to consume approximately 9.08 gals/MWh of water over the lifetime of the CSP plant. (Montgomery)

4.2.2 Installation

Solar power plants require large amounts of land to generate significant amounts of power. Based on an environmental impact comparison study of a utility-scale PV power plant and CSP plant both located near Las Vegas, Nevada, a solar power plant constructed of PV panels will need more than twice the acreage of a CSP plant. In this study, performed and composed by Zoë Montgomery of Duke University, five (5) acres per GWh per year (ac/GWh/yr) were used for the PV power plant whereby the CSP plant consumed three (3) ac/GWh/yr less. The PV power plant, First Solar El Dorado (FSED), produces a total of 16 GWh/yr, thereby occupying approximately 80 acres of land. The CSP plant, Nevada Solar One, produces a total of 130 GWh/yr, thereby occupying approximately 260 acres. These two plants are the largest of their kind in the nation and were chosen because they provide the best operating examples in the field and for their proximity to one another, thus minimizing variances in solar radiation. (Montgomery)

As with any construction site, the area must first be cleared of vegetation and rock cover, and leveled. Access roads are needed to reach sites that are undeveloped, such as those identified by NREL and the BLM for utility-scale solar power plants. This allows for the unimpeded movement of construction equipment and workers and later for the maintenance of the solar power plant. These processes involve the "scraping" (removal) of sensitive soils.

The Grand Junction area, as described in Section 1.4, is classified as a desert ecosystem. Deserts are arid regions that receive less than 10 in of precipitation annually. This would suggest an environment barren of life. Paradoxically, deserts support a complex and diverse collection of species. Although almost devoid of organic debris, life in the desert is strictly dependent on its soil characteristics. Upon close examination, desert soil teems with small organisms such as cyanobacteria, algae, lichens, mosses, and liverworts. Together they form living microphytic crusts with a multifunctional purpose to provide nutrients to desert plants, fix carbon and nitrogen from the atmosphere, decrease the effects of leaching, minimize surface runoff, retain moisture, and increase soil stability. Damaging these mycrophytic crusts can have severe repercussions on the entire desert ecosystem. Without crusts, there would be a reduction in the already limited water and nutrient reserves, leading to decreased primary productivity, thus reducing plant life and animal life, increasing vulnerability to erosional processes, which in turn may increase the risk of desertification. (Kauffman)

4.2.3 Operation

Although PV solar power plants do not require water in their process to generate electricity, they do require water for cleaning the collectors. CSP plants consume water during production of electricity and for cleaning as described in Section 2.2. According to the DOE, a typical parabolic trough CSP plant requires approximately 800 gals of water/MWh. Of this 780 gal/MWh (≈98%) is consumed during the steam cycle. The remaining 20 gal/MWh (≈2%) is used to keep trough mirrors clean of desert debris (i.e. dust) for maximum solar absorption. (DOE) Although there are alternatives to the traditional wet cooling system (i.e. dry cooling and hybrid wet/dry cooling systems) they suffer disadvantages such as higher capital costs, higher auxiliary operating power requirements, fan noise, and an overall lower plant performance, but can decrease water requirements by 720 gal/MWh. However, water cooling is still preferred over the alternatives to minimize costs and maximize efficiency. (DOE)

Grand Junction receives approximately nine (9) inches of precipitation per year and has a finite groundwater supply. Although the Colorado River flows along the Valley's floor, it is already over allocated for agricultural, urban and commercial uses. When building a CSP plant, one must consider location in terms of proximity to a water source in order to minimize the costs of developing water transport infrastructure to the CSP plant site. BLM land borders the Colorado River to the North of Grand Junction easing access to water from the Colorado River. This will add to the ever increasing pressure of demand on the already over-exploited Colorado River. Water is a scarce resource, especially so in desert ecosystems such as Grand Junction.

4.2.4 Disposal

The expected life of most solar technologies is somewhere between 20 and 40 years. (Hope) Solar technology employed today will eventually be future refuse; however, because of solar technologies' longevity there is little experience or information concerning decommissioning of large plants, disposal processes of old systems, and potential environmental effects involved. With the onset of solar power generation it is critical that this aspect of solar power be studied.

Chemicals used in the production of PV panels are generally treated off-site by a variety of methods: Publicly Owned Treatment Works (POTW), metals recovery systems, solvents/organics recovery systems, and energy recovery systems. Those chemicals that are disposed of are either landfilled or incinerated. A major concern is the leaching of these chemicals (i.e. cadmium, selenium, sulfur hexafluoride, etc.) from old PV solar panels that have reached the end of their life. Although not a new concept, recycling is a favorable practice that many companies are looking to facilitate in the solar industry. Many, if not most, materials contained in both PV and CSP modules can be recycled and reused, from the chemicals and metals to the glass and plastics. This approach reduces the potential of hazardous materials leaching into the environment and the need for extraction of new resources. (Hope)

4.2.5 Additional Impacts

Other impacts associated with utility-scale power plants involve competing land uses. This includes recreational activities such as hiking, mountain biking, camping, climbing, use of off-road vehicles (i.e. motorcycles, four-wheelers, etc.) This also includes ranching activities such as cattle grazing. Were a solar power plant installed North of Grand Junction adjacent to the Colorado River it would be highly visible to those traveling along Interstate 70 (I-70) which at times parallels the river and follows the base of the Bookcliffs (BLM managed land) into Utah. For residents especially, this could prove to be an unwelcome aesthetic disturbance of the landscape. High-voltage transmission lines are necessary for the transport of electricity between places of generation to consumption. Sites suited for the development of utility-scale solar power plants are generally far from any transmission lines. Similar impacts such as those discussed in the Section 4.2.2 will be associated with the development and expansion of transmission lines to remote areas.

4.3 Advantages

The advantages associated with solar power plants will be the same for all forms of solar power generating options. It is a renewable form of energy that, during energy production, does not emit GHG's into the earth's atmosphere which contributes to climate change. Despite the impact to the environment caused during the manufacturing and installation of solar power, it maintains an overall smaller environmental footprint when compared to fossil-fueled energy production plants. For example, solar power plants derive their energy from the sun, an on-going source of free energy, where-by a coal-fired power plant must have a constant input of coal, its energy source, which must be mined and transported at monetary and environmental cost. For an in-depth analysis of the impacts from a coal-fired power plant refer to the 1999 NREL study *Life Cycle Assessment of Coal-Fired Power Production*. For an in-depth analysis of the impacts from solar power refer to Columbia University's Center for Life Cycle Analysis which has performed several LCA's for PV[3] and two European studies that describe the results of LCAs performed for a power tower plant[4] and PV[5]. Links for these studies have been provided below as footnotes. Comparing solar power to a fossil-fuel based power supply is warranted a comprehensive study, but is outside the scope of the objectives proposed by this study.

[3] http://www.clca.columbia.edu/publications.html
[4] http://www.aidic.it/escape20/webpapers/496Piemonte.pdf
[5] http://www.worldenergy.org/documents/lca2.pdf

By increasing the amount of energy produced from solar, it no longer becomes necessary to produce as much energy from fossil fuels as today. This reduces dependency on a fuel source that not only contributes to climate change throughout its life-cycle, among other environmentally damaging effects, but also reduces our reliance on foreign supply. It must also be noted that solar power has the uncanny ability to directly offset peak demand during the summer season in hot climates, thereby reducing grid load during these crucial times. While homes and businesses are turning down thermostats to battle midday heat, solar panels are at their optimal performance. This replaces some, if not all, of the highest-cost electricity used during peak demand when conventional fuel power plants would otherwise need to use auxiliary natural gas boilers, a costly approach.

4.4 Disadvantages

On the other hand, solar power plants will not generate power during the night or during periods when the sun is concealed by clouds. Their capacity to produce power will diminish throughout the day. To compensate for this loss in production, solar power plants will need to be substituted by conventional power plants which cannot be turned up and down as needed without acquiring high expenses. The cost of the technology itself is expensive. Utility-scale solar power plants must also bear costs imposed by the BLM: i.e. an annual property lease, a MW capacity fee, fees associated with the POD and EIS as discussed in Section 4.1. A considerable amount of land is also required that not only comes at a monetary cost, but also at several environmental costs. Perhaps the most profound effect will be on Grand Junction's water resource. Once the solar power station is assembled, how will the power generated get to the consumer? The most likely location for a utility-scale solar power plant will be in an isolated area far from any transmission lines, thus necessitating the need to erect new power lines.

5 Option 2: Solar Rooftop Leasing Program

Solar power generating systems, specifically PV technologies, are versatile in that they have the ability to mount on various structures. As the county seat for Mesa County, Grand Junction is the largest city on the western slope. It is also the most developed in terms of infrastructure offering prime rooftop real estate for solar PV installation. Local owners of warehouses, shopping centers and other large buildings have the advantage of leasing their unused roof space to utility companies. The renting of vacant rooftops has quickly come to practice in many locations around the US, Canada, and Europe. The concept is known as a solar rooftop leasing program.

A synopsis of how this generally works is presented: A utility company, for instance an IOU such as Xcel, leases commercial rooftop space. Like in the case of conventional leases, the utility company will enter into a rental agreement with the property owner. The utility company owns, installs, maintains, and removes the system over the lifetime of the lease. The owner benefits from the long-term, monthly/annual (depending on agreement) excess income generated from renting their available rooftop space to the IOU for the installation of PV panels. A more detailed description of a solar rooftop leasing program has been provided in the following sections (Section 5.1 and Section 5.2).

This thesis study assumes Xcel Energy, the IOU for Grand Junction, will install, operate, and maintain solar PV arrays mounted atop leased commercial and/or industrial roofs. Property owners can be compensated either by receiving a percentage of revenue generated from the system or paid a flat annual fee relative to the amount of rooftop space used. The PV systems would be tied directly into the existing grid-system on the IOU side of the meter so that the power generated from this type of system would be used to supply electricity to the city of Grand Junction.

5.1 Existing Program

Southern California Edison (SCE) has developed the largest solar rooftop leasing program in the nation. In June 2009, the SCE IOU obtained permission to utilize 64 million square feet (ft^2) of available commercial rooftops in Southern California. The projected 250 MW capacity generated from this solar program will generate enough power to supply approximately 162,000 homes. In 2008, SCE began their pilot program, a smaller, preliminary study to test the design of the full-scale experiment, installing three rooftop systems totaling approximately 5 MW using the latest PV technology. In 2009, SCE began their second installation that would generate 1 MW, thus meeting the demand of 650 homes in Chino, CA. Over the next five years, SCE plans to add a total of 250 MW, 50 MW each year. The utility expects to lease between 100 and 150 roofs for the entire project. (SCE)

The SCE plan identifies areas where power demand is growing. The idea is to then place solar PV modules atop unused commercial rooftops located in/proximate to these areas. Commercial/industrial buildings (i.e. warehouses) are ideal because they tend to offer enough space to install a 1 MW system including the large inverter. Under the SCE program, size requirement must be no less than 200,000 ft^2 to support a 1 MW system. SCE purchases the system and incurs all costs associated with installation, maintenance and removal of the solar system while leasing the rooftop space from the building owner. To eliminate the need for new long-distance transmission lines, SCE will connect the panels directly to the neighborhood power delivery circuits. Therefore, the electricity produced by the systems will flow directly into the electrical grid to supply SCE customers with solar generated power. The total expected cost of SCE's solar rooftop leasing program is approximately $875 million. (SCE)

In implementing this program, SCE hopes to benefit its customers and the State of California. Their goal is to decrease the installed cost of solar PV power through economies of scale. By increased purchasing of solar modules, SCE hopes to succeed in reducing installed costs from about $7.00 to $3.50/kW, thereby extending purchasing power of solar PV systems to a broader range of customers. The SCE solar program will also boost California's Solar Initiative. (SCE)

5.2 Requirements and Considerations

Not all roofs are suitable to support an array of PV panels. Certain structural requirements are needed to ensure safety and optimal system performance. For commercial installation the ideal roof is relatively new or has been recently rebuilt, is between 30,000 and 200,000 ft^2, reasonably flat, and is free from obstructions. (Cornett) Panels vary in size and power output; therefore, the amount of rooftop space needed will vary according to the solar panel.

New or rebuilt roofs tend to have the necessary structural support needed to accommodate a PV array. By using roofs with 20+ years of remaining life, the need for any significant repairs or overhauls is minimized. Since the roof provides the foundational support, it is imperative that it be able to sustain the total weight of the system, including BOS, external and internal loads on the exterior and interior of the roof, and uplift loads imposed by wind passing under the panels. (Zizzo

Allan) Physically, flat roofs negate the need for proper building orientation. Panels can be easily and properly mounted and angled to absorb maximum radiation from the southern sun. To ensure optimal performance, roofs must be clear of any obstructions (i.e. other current and future structures either on-site or neighboring sites) that might cast shadows on the arrays throughout the day and inhibit solar performance. (Cornett) Another requirement specific to the SCE program includes ground space availability to house inverters and transformers for the solar system. For the first MW, they require approximately 900 ft^2 and 600 ft^2 for each additional MW thereafter. (SCE)

When negotiating a rental contract several factors must be taken into consideration. These include, but are not limited to: (Cornett)

- Situations that may cause early termination of contract and compensation for the solar operator or building owner should said situations occur;
- Future plans for the building that may impact the operator's use of rooftop;
- Unlimited operator access to the roof to install, maintain, repair, and replace equipment as necessary;
- Length of lease (this is generally negotiated for the lifetime of the solar system which is 20+ years);
- Rent (several payment options are available and include fixed gross rent paid annually calculated on the square footage of rooftop space utilized, percentage of revenue generated by the wattage produced by the system, or a hybrid method that combines elements of both the area and revenue formulas);
- Roof repairs/replacement (the lease should clearly define the financially responsible party in the event roofs acquire any damage during the installation, life, and removal of the solar system. Any loss in roofing structural integrity can cause, at minimum, leaks which may interrupt daily operations and potentially effect revenue generated by the business occupying the building. The lease should also include discussions concerning written notice of roof damage to responsible party, the relocation of solar PV equipment during repairs, estimated time to repair, and compensation to either party if required);

- Access to tenant's plans and specifications should building owners want the right to inspect and approve of the solar installation plans and any alterations, repairs, or replacements made subsequent to installation;
- Insurance (all equipment associated with the solar PV system is sole property of the tenant (utility company) and therefore insured separate from the building. Both parties are responsible for proper and adequate insurance of their property as defined by the lease); and
- Sale of property or loan defaults on part of building owner (the landlord may be required to obtain agreement from mortgage lender to permit tenant continued possession of rooftop space and honor lease as written).

5.3 Environmental Impacts

As described in Section 4.2, most environmental impacts associated with solar power production result from the manufacture, installation, and disposal of the system. Most of the impacts characterized earlier with solar power plants are also identified with solar panels used for a rooftop leasing program; however, the biggest divergence between the two is their installation process. Unlike a solar power plant, the rooftop leasing program uses existing building infrastructure which does not require large amounts of undeveloped land for installation. This eliminates environmental impacts associated with land development, such as "scraping", construction of access roads, and installation of new transmission lines. By utilizing available rooftop space, this potentially eliminates the use of sensitive desert ecosystems for the production of energy from solar and therefore further reduces the environmental footprint of solar power.

There still remains the issue of transportation. During the installation process the solar equipment are transported from manufacturer or retailer to the site of operation. This requires vehicles. Vehicles are not only major contributors' to climate change, but are also a main source of air pollution, i.e. carbon monoxide (CO), hydrocarbons, nitrogen oxides (NO_x), and particulate matter (PM). The following figure, **Figure 27**, illustrates the percentage of contribution to these air pollutants from on-road mobile sources. On-road mobile sources include light gasoline trucks, heavy gasoline vehicles, diesel vehicles, cars, and motorcycles. Non-road mobile sources include diesel equipment, aircraft, boats, and trains.

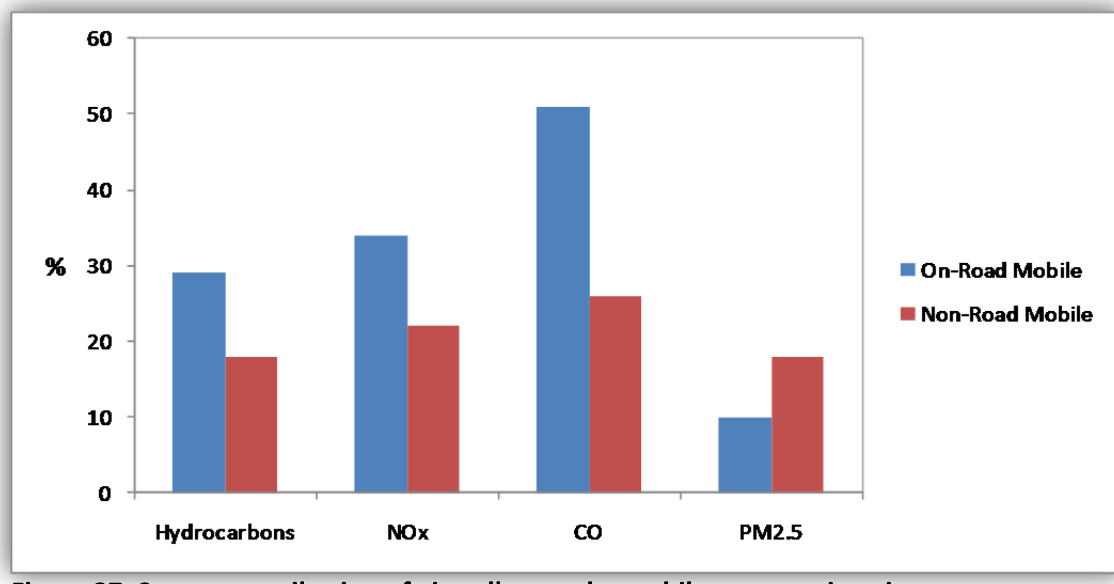


Figure 27. Source contribution of air pollutants by mobile sources given in percentage. (EPA "Pollutants")

These pollutants cause significant health problems, i.e. Chronic obstructive pulmonary disease (COPD), cancer, and others. (EPA) To reduce these impacts, it is highly advisable that solar equipment be bought locally and installed by local professionals. The same should be practiced for decommissioning. Have the system dismantled by local professionals and disposed of properly in appropriate, certified local facilities. If these businesses/facilities are not available locally, then the next closest location should be chosen.

Despite the impacts previously stated above and in Section 4.2, solar power generation is a relatively clean form of energy. Solar power panels are built for longevity with a lifespan of 20+ years. No adverse environmental impacts have been identified during their lifetime of operation. With the increasing ability to recycle more materials used to build solar panels this helps to abate the need for newly mined resources, thus reducing their environmental footprint.

5.4 Advantages

There are inherent advantages to using solar power as discussed in Section 4.3. Others associated with a solar rooftop leasing program are as follows:

- Few regulatory impediments
- No new land space required
- Placed within the population center; i.e., close to demand
- Close to transmission lines

- Will help meet Colorado's RPS
- Creates reliable, long-term source of extra income
- Companies can benefit from positive press coverage and gain recognition for their commitment to environmental sustainability
- If so interested, rooftop solar will help businesses obtain Leadership in Energy and Environmental Design (LEED) certification. This will ultimately strengthen social responsibility.
- Benefit their community with renewable energy without investing in the solar power equipment
- Creates local jobs
- Highest energy production occurs during peak consumption times
- Reduce commercial/industrial building cooling requirements. Many commercial buildings have to cool all year long due to large internal loads from lighting and the operation of industrial equipment.
- PV systems mounted on commercial/industrial roofs are secure and less susceptible to intentional damage (vandalism). This is because they are 1) out of reach and 2) usually located on buildings that are occupied most, if not all, of the time.

5.6 Disadvantages

The disadvantages associated with this option are similar to those discussed in Section 4.4. This includes the inability to operate during the night or on cloudy days, a continuous diminishing capacity to produce power throughout the day, and the challenge of adequately compensating for loss in production during these times without incurring added expenses. Not all rooftops can structurally accommodate an array of solar panels. For those companies wishing to participate in such a program, they will need to make sure their building meets certain structural requirements as described in Section 5.2. In Grand Junction, it is required that buildings be inspected by the building department of Mesa County to obtain a building permit before solar panels are installed. This involves assessing structural and electrical characteristics of the building to be used for the installation of solar PV panels. If the building does not pass structural requirements, owners will need to properly re-structure the roof to withstand solar modules, including BOS, and the inverter. Depending on renovation costs, potential leasers could eventually earn back more than the cost of re-designing the roof.

6. Option 3: Third Party Power Purchase Agreement

This next option utilizes residential rooftop space as well as commercial/industrial rooftops. It involves an outside party other than the utility company or home/building owner. Usually the outside, or in this case third party, is a business that specializes in the installation and operation of solar electric systems on properties. Much like the rooftop leasing program, third party operators, also known as solar service providers (SSP), own, install, operate, and maintain the solar system mounted atop host customer rooftops. Rather than lease rooftop space, property owners who participate buy the power produced by the solar system from the SSP. The idea is to free home/business owners from the initial investment burden of solar power generation systems.

This model is quickly becoming a popular financial alternative providing convenient installation for end users unable to afford initial capital costs.

6.1 Key Players

There are several entities involved that participate in what is known as the “solar services” model: the host customer, solar services provider, financial investor, installer and manufacturer. (EPA) The role of each is described in the narrative below. A diagram of a typical solar service model has also been provided to assist in clarification.

A “host customer”, as referred to by the EPA under their Green Power Partnership program, is someone who agrees to have a solar power system installed on their property without having to cover the capital costs of the system. Similar to a rooftop leasing program, host customers enter into an agreement with the SSP. Instead of leasing their available roof space, host customers agree to purchase the power generated by the system for a predetermined period. This is a solar power purchase agreement (SPPA). The price for the solar power purchased is often equal to or slightly lower than market electric rates paid to the utility provider. These rates can be fixed and will often include an “annual price escalator”, a yearly percentage increase ranging between one and five percent to account for energy inflation and depreciation of the solar system. (EPA)

The entity responsible for developing and implementing the SPPA is the SSP. They are accountable for managing the logistics for the entire project. This means the SSP owns, installs, operates, and maintains the system until the SPPA expires and other arrangements are made. Host customers are bound by a SPPA for approximately six to 20 years depending upon the SSP. Upon natural termination of the SPPA, host customers usually have the option to buy the system, renew the SPPA, or opt to have the system removed entirely.

As owner of the system, the SSP is responsible for designing and financing the solar system. The latter often involves a separate institution known as the investor. In some cases, the SSP is capable of designing and installing the system themselves. If the SSP does not provide this service through their company, one is contracted by the SSP. The installer develops an appropriate design system for the building using the system and provides maintenance during the life of the contract between the SSP and host customer.

The investor supplies capital funding for the construction and operation of the PV system. As such, they receive the state and federal incentives applicable to the project and own the system until it is paid off by the SSP.

Upon design finalization, SSPs purchase the necessary solar power equipment through a manufacturer. Manufacturers are companies specialized in making solar equipment, i.e. solar PV panels and inverters. They receive revenue from the sales of their equipment and provide warranties to ensure efficient and proper operation of their equipment. (EPA)

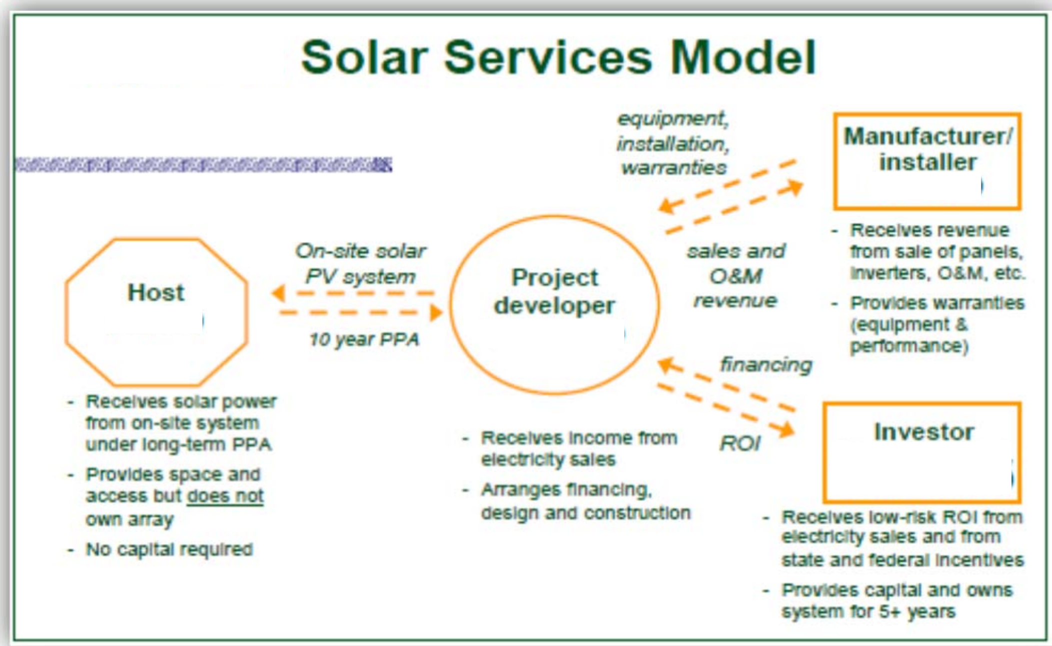


Figure 28. 3rd Party Solar Service Model depicting key players and their role. SPPA term length will vary between 6 and 25 years. (The Green Power Group)

6.2 ADVANTAGES

The third party design provides the necessary principal to overcome daunting cost barriers associated with solar power using companies equipped to absorb the up-front costs. This approach creates greater access to solar technology by individuals (residential, commercial, and industrial) willing to adopt such systems. This stimulates growth in PV equipment purchases and PV installations which in turn drives solar technology market prices down. (Kollins, Speer and Cory)

During the summer season, PV systems will generally meet the electrical demands of the end user. This means consumers who take advantage of this model will not be pulling electricity through the transmission-grid from conventional power plants. This helps alleviate overload burdens (brown-/blackouts) experienced during critical peak periods in summertime. It also creates increased transmission-grid capacity during the day since the renewable electricity produced is immediately absorbed onsite and any net excess generated becomes "community property". (Allen)

Xcel provides net metering, the difference between energy input and energy output, for residential and business customers with solar power systems connected to the grid. Host customers that generate more than they consume receive credit towards their bill or "bank" excess energy for future use when needed. (Solar Power Authority) The Energy Security Act 2005 Section 1251 requires utilities to supply net metering upon customer request provided they are eligible under the State's standards. (Holtberg) While this is not an integral part of the third party business model, it provides an additional incentive for host customers considering the third party model as an option for going solar.

Competitive, stable electricity rates provide predictable energy prices and certainty for host end users, because the value of their electricity will not change with volatile conventional/fossil fuel energy prices. Host customers are able to easily monitor and adjust business or home operations accordingly to reduce expenditures. (Kollins, Speer and Cory)

Entities that are tax exempt such as schools and non-profit organizations are not eligible for federal and state solar tax incentives. This model benefits such entities enabling an affordable, risk-free option to installing solar power. When partnering with a third-party a tax-paying entity is introduced. Tax credits can then be leveraged thereby significantly reducing the cost of the system paid by the SSP and electrical prices paid by the tax exempt entity. (Brandt, Devine and Lamb)

While state and federal tax incentives belong to the financier of the solar system, in some cases host customers have the option of buying the Renewable Energy Certificates (REC) from their SSP. Although, it is more likely for SSPs to sell the RECs to utility providers (i.e. Xcel) who would benefit from their environmental attributes as verification of working towards meeting state RPS's. Sale of RECs also creates some revenue stream for the SSP. RECs and other federal and state incentives received by the system owner (either the SSP or financier) are applied to reduce capital costs. These savings are passed on to host customers as lower electrical rates. (Kollins, Speer and Cory)

The purpose of REC's is to demonstrate that renewable energy was produced to meet electrical demand. In the case of a third party SPPA, the SSP owns the RECs. One REC represents one MWh of energy produced from an eligible renewable energy resource such as solar. Host customers have the option of buying the RECs generated by the system installed on their property. By purchasing the RECs the host customer retains the right to claim environmental sustainability through the use of renewable electricity. Without ownership of RECs, the host customers would not be able to do so. Once RECs are claimed, they are no longer eligible for sale and are considered "retired". (EPA)

6.3 Disadvantages

Many of the disadvantages with this option are similar to those of a rooftop leasing program as discussed in the previous chapter. These include proper building orientation and sound roofing structure clear of obstructions that may inhibit solar absorption by the PV panels. Those individuals interested in participating in third party SPPA may find they will need to remodel or update their roof in some capacity. This could be cost prohibitive, but also may prove beneficial. Older roofs often contribute to heat loss during the winter and gain heat during the summer which increases energy use. Remodeling provides property owners a chance to upgrade and use better insulation to increase energy efficiency and lower heating bills. In the long run, money spent could be equal to or less than money saved. With more effective insulation and onsite third party solar energy generation, host customers could see a quick return on investments.

As for building orientation, south-facing roofs are essential unless rooftops are flat. Orientation is a critical aspect when installing PV panels unless buildings have a flat roof. For those unable to meet these criteria, there are other alternatives. If property owners have land available that receives direct sunlight for most the day, this could be utilized in lieu of a roof.

It is the SSP's responsibility to care for and maintain the system for the life of the contract. In order to keep the system operating at optimum efficiency the SSP or the entity contracted to perform these duties will need unimpeded access to the host customer's property. For some, this may be an inconvenience. Ongoing site access should be addressed in the contract, outlining specific requirements that both parties involved can agree upon. In most cases, maintenance and upkeep activities will not require entrance into residents' homes or businesses. (Berwind)

Other third party SPPA attributes that might be considered a disadvantage:

- It is absolutely pertinent that host customers understand the contract they will be signing. This may require hiring a lawyer to properly translate the SPPA;
- If the SSP does not decide to sell RECs to host customers willing to buy them they will not be able to claim any environmental attributes associated with the solar power system;
- If electricity rates decline then host customers will be paying above-market rates; however, historical price trends indicate that the likely-hood of this is marginal. In which case, host customers will be enjoying the benefits of lower electrical rates. (Brandt, Devine and Lamb) The following figure (**Figure 29**) illustrates a rising trend in electricity prices from fossil fuel sources for the past ten years. With incentives in place, cost per kWh from solar electricity is competitive with that from conventional electricity production. According to SAM, the LCOE for a third party owned five kW PV system is approximately 14.62 cents/kWh. This is the amount a third party must receive to cover financing, installing, and operating costs; however, this price is usually negotiated by the project developer (third party) and the electricity purchaser (host customer) and often times is determined at a flat-rate equal to or less than current electrical prices. Current electrical prices for the various end-use sectors are as follows:
    - Residential: 11.14 cents/kWh;
    - Commercial: 9.17 cents/kWh;
    - Industrial: 6.80 cents/kWh. (EIA "Avg Retail Elec Price")

  SAM calculated the LCOE based on electricity generated throughout the lifetime of the project, project revenue from electricity sales throughout the lifetime of the project, the time value of money, and inflation rate ("expected price increases over the project life"). (NREL "SAM") This LCOE estimate does not take into account the cost of RECs and net-metering. Project developers who own the PV solar energy system also own the RECs. Xcel pays third party owners \$.07/kWh of actual production on a monthly basis. This provides additional income to third party owners who may choose to apply this to electricity costs in favor of the host customer. Also, as described in Section 6.2 Xcel provides net-metering. The host customer benefits if more energy is generated by the solar system than is used. Xcel will either pay the host customer for the extra generated or “bank” it for the host customer to use at a later date when they are using more than the system is generating. These two benefits just mentioned in combination with decreasing solar energy system capital costs will reduce electricity costs.

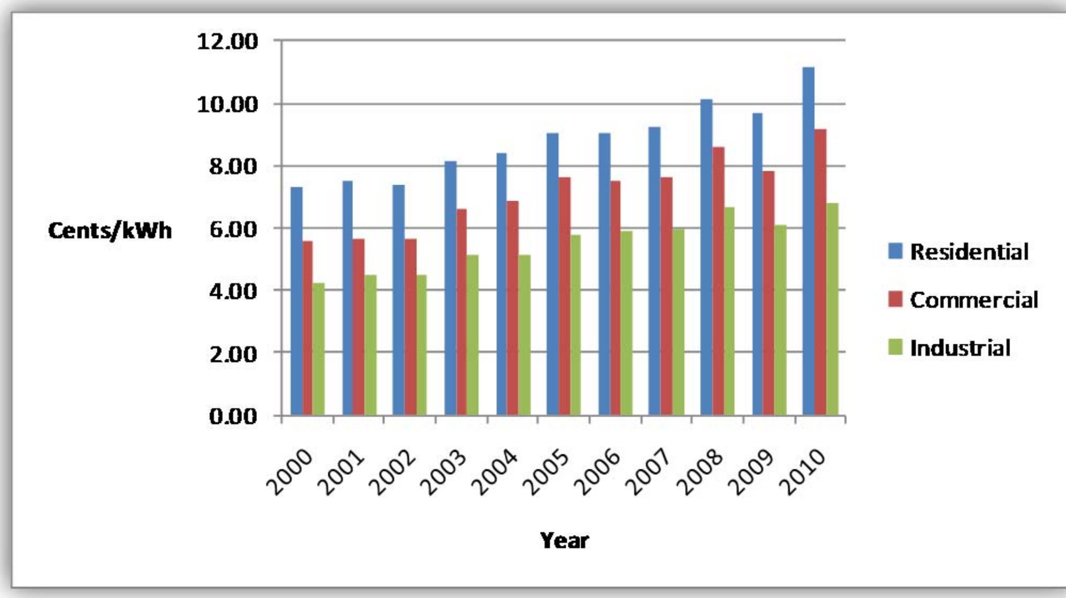


Figure 29. Average retail price of conventional electricity by end-use sector for Colorado. (EIA "Energy Estimates")

What happens if a host customer moves or defaults on their property mortgage during the term of agreement? This is addressed in the written contract. Most contracts allow the transfer of the SPPA to the new owner, but not without first meeting credit qualifications established by the SSP. Since the third party developer is accepting the initial credit risk it is in their interest to protect their assets. New owners will likely have to meet a credit check and other requirements as stated in the contract. This may be a deterrent to potential buyers. (Kollins, Speer and Cory)

7. Analysis of Business Models

This study identified and described three different solar business models that could produce 100 MW of renewable electricity for distributed generation to the city of Grand Junction. The three different solar implementation business model options described in chapters four through six were a solar power plant, a solar rooftop leasing program, and a third party solar power purchase agreement.

It has been predicted by this study that in the year 2020 Grand Junction's population will be about 60,725 and electricity consumption per capita approximately 12,601 kWh. From this, it is expected that Grand Junction's electricity demand will roughly total 765,196,725 kWh for the year 2020. In order to help Colorado meet its RPS goal of generating 30% of their energy from renewable resources with three percent of this deriving from distributed generation, Grand Junction can install 100 MW of solar power either by a solar power plant or rooftop solar business model. Anything larger than 100 MW exceeds the definition of distributed generation and is approaching Colorado's western slope's maximum solar energy capacity predicted by the GE study (**Section 1.6**).

The solar power plant business model option described in Chapter 4 can utilize a variety of solar technologies from PV to CSP. The table provided below provides a comparison of solar technologies used for solar power plant production and are based on Grand Junction's solar resource potential. These figures were provided from SAM as explained in Chapter 2, Section 2.2.6.

Table 8. Comparison of performance and economic results of PV and CSP power plants with 100 MW capacity.

Technology	Nameplate Capacity (MW)	Capital Cost ($ million)	LCOE (¢/kWh)	Annual Energy Output (million kWh/yr)	GJ Electrical Demand Met (%)
PV Two-Axis Tracking	100	540.2	16.83	230.17	30
Parabolic Trough	100	636.7	20.97	223.62	29.2
Dish	100	301.5	15.63	165.18	21.6
Power Tower	100	591	35.72	123.06	19.1

This table illustrates a dish system as being the most economically friendly choice, both in capital costs and in a levelized cost of electricity. Of the four solar power plants, a PV two-axis tracking system provides the most energy output per year followed closely by a parabolic trough system. Both the PV two-axis tracking and parabolic trough system are able to provide Grand Junction with approximately 30% of its energy demand.

Assuming that both a solar rooftop leasing program and third party SPPA business model utilize solar panels from the same manufacturer the performance and economic results will be similar. Fixed flat-plate PV modules were chosen for both rooftop business models as they are the most commonly used for rooftop installation. They are also cheaper to buy, install, and maintain than a single axis or two-axis tracking system. The following table projects the costs (capital and LCOE), annual energy output, and how much of Grand Junction's electrical demand will be met by rooftop solar.

Table 9. Performance and economic results for rooftop PV.

Technology	Installed Capacity (MW)	Capital Cost ($ million)	LCOE (¢/kWh)	Annual Energy Output (million kWh/yr)	GJ Electrical Demand Met (%)
Fixed flat-plate	100	551.4	14.62	151.86	19.8

If 100MW worth of rooftop solar systems were installed they would produce enough energy to meet 19.8% of Grand Junction's electrical demand. Although the capital cost of installing 100 MW of rooftop solar is more expensive then the capital costs associated with two of the four solar power plant options, the economic figures listed in **Table 8** do not account for the costs incurred from BLM land leases. **Table 10** incorporates BLM MW capacity fees discussed in Section 4.1.3 and illustrated in Table 7, but does not include base rent fees as these are decided on by the county and has not yet been established for Mesa County. First year costs include capital costs of the entire system and 20% of the BLM MW capacity fee. Maintenance and labor costs are not included in this analysis.

Table 10. Capital and total costs expended on PV and CSP solar power plants including BLM MW capacity fees phased in over a 5 year period.

Technology	Year 1 20%	Year 2 40%	Year 3 60%	Year 4 80%	Year 5 100%	Life of Project (20 years)
PV 2-Axis	$540,305,120	$210,240	$315,360	$420,480	$525,600	$549,660,800
Parabolic Trough	$636,835,000	$270,000	$405,000	$540,000	$675,000	$648,850,000
Dish	$301,635,000	$270,000	$405,000	$540,000	$675,000	$313,650,000
Power Tower	$591,135,000	$270,000	$405,000	$540,000	$675,000	$603,150,000

Initially, a solar power plant designed with a PV two-axis tracking or dish system is cheaper than the total costs associated with rooftop solar; however, the capital cost presented in **Table 9** does not account for federal or state incentives applied to third party mounted systems. Incentives can reduce the overall cost by nearly 45%. Also, the levelized cost of power produced from rooftop solar is the lowest of the options presented. On the other hand, rooftop solar is one of the lowest producers of electrical energy, but requires the least amount of area for installation.

According to High Noon Solar (HNS), a residential and commercial solar energy system sales and installation company, five kW is typical in size for a residential solar energy system. To generate 100 MW, 20,000 five kW systems would need to be installed. The majority of these panels sold by HNS are 15 square feet (ft^2) with an optimal output of 200Wp per panel.

$$\left(\frac{1panel}{.2kW}\right)x\left(\frac{1000kW}{1MW}\right)x100MW = 500{,}000panels$$

$$500{,}000x15ft^2 = 7{,}500{,}000ft^2$$

From the data above, the amount of rooftop space needed to accommodate 100 MW is approximated to be 7.5 million ft^2 (696,773 m^2). In optimal conditions, i.e. facing south and tilted at an angle of 39.1° to the horizontal, a typical 1 kWp PV system in Grand Junction will generate approximately 1600 kWh per year. (High Noon Solar) Around 500,000 panels with 200 Wp are needed to generate 100 MW. To estimate the amount of rooftop space required per person using the information provided by HSN: 1 kWp = 1600 kWh/yr; 1 panel = .200 kWp; therefore, five panels would be needed to produce 1600 kWh/yr.

$$\left(\frac{5panels}{1600kWh}\right)x\left(\frac{12{,}601kWh}{person}\right) = 39.38\, panels/person$$

$$39.38\ x\ 15ft^2 = 590.67ft^2$$

If by the year 2020 each person in Colorado consumes 12,601 kWh per year (Section 1.5) then from the data previously provided each person would require approximately 590.67 ft^2 (54.88 m^2) of rooftop space for solar installation to accommodate their electrical energy needs. In other words, 590.67 ft^2 is the Colorado "solar electric footprint" per capita. Currently, an estimated 785.77 ft^2 (73 m^2) of rooftop space is available for PV per person in Colorado. (Denholm) To date there are 53,390 people living in Grand Junction. This amounts to a total of 42.4 million ft^2 (3.94 million m^2) of available rooftop space in the city of Grand Junction (this includes residential and commercial roofs) which is more than enough area needed to support 100 MW of solar power. The table provided below compares the amount of area needed to support PV and CSP power plants with 100 MW capacity and rooftop PV. The acreage determined for a parabolic trough and power tower solar power plant was determined through SAM. Of the systems analyzed, rooftop solar utilizes the least amount of area.

Table 11. Comparison of area needed by each option.

	Rooftop System	Solar Power Plant			
Technology	Fixed Flat-Plate	PV 2-Axis[1]	Parabolic	Dish[2]	Power Tower
Land Area (acres)	172	1,000	910	600	1,284

[1] (Abengoa)
[2] (Clarke)

From an emissions analysis standpoint, the generation of electricity from solar power offsets a certain amount of GHG's and air pollutants that threaten to damage human health, such as those expelled into the air from antiquated coal-fired power plants. Mercury is perhaps one of most serious ground-level pollutants of concern. Approximately .023 milligrams per kilowatt hour (mg/kWh) of mercury is released during the generation of electricity from coal. This equates to nearly 50 tons of mercury entering into the ambient air per annum and accounts for almost half of the US's mercury inventory. (NESCAUM) Approximately 2.08 pounds per kilowatt hour (lbs/kWh) of CO_2 is released during the generation of electricity from coal. In 2008, emissions from conventional power and combined-heat and power plants totaled 2,477.2 million metric tons (MMT). This accounted for 42% of the total CO_2 emissions released in the US. (EIA "Environment") Coal generates approximately 82% of Colorado's electricity. (CEA) In 2020, Colorado will consume an estimated 78.2 billion kWh/yr of electricity (Section 1.5) and 64.12 billion kWh will come from coal. This means that approximately 60.5 MMT of CO_2 and 3,253 lbs of mercury will be released. The amount of CO_2 emissions and mercury pollution offset by 100MW of rooftop PV, and PV and CSP power plants is presented in **Table 12**.

Table 12. Amount of CO_2 and mercury emissions offstet by solar implementation options.

	Rooftop System	Solar Power Plant			
Technology	Fixed Flat-Plate	PV 2-Axis	Parabolic	Dish	Power Tower
CO_2 (metric tons)	143,275.68	217,158.98	210,983.61	155,840.18	116,104.49
Mercury (lbs)	7.7	11.7	11.3	8.38	6.34

The Colorado RPS states that IOU's are required to generate 30% of their energy from renewable resources and/or recycled energy by the year 2020. Of this, three percent (3%) must derive from DG. The below table presents how much 100 MW of electricity generated from each solar implementation option will contribute to meeting Colorado's three percent DG standard. This was determined using Colorado's estimated electrical demand of 78.2 billion kWh (Section 1.5).

Table 13. Percent contributed to Colorado's RPS for distributed generation from 100 MW generated by each solar implementation option.

	Rooftop System	Solar Power Plant			
Technology	Fixed flat-plate	PV 2-Axis	Parabolic Trough	Dish	Power Tower
Energy Output (million/yr)	151.86	230.17	223.62	165.18	123.06
% RPS for DG	21.6	32.7	31.8	23.5	17.5

8. Conclusion

Perhaps the most prominent drivers behind the development of renewable solar energy sources are to deliver the United States from the dependency on foreign oil and reduce carbon emissions to combat climate change. However, the pursuit of clean energy resource generation requires the consideration of more than just these two drivers. A LCA will address direct and indirect considerations that take into account such additional factors which include but are not limited to; capital costs, operational costs, social costs, environmental impacts other than emissions, transmission line access, land availability, regulations, and available proven technology.

In the process of describing each solar implementation business model option, the additional factors previously stated were addressed. It is suggested that for a more in depth understanding of these factors and their role in solar power development that a more detailed study be performed for each on an individual basis. Although the figures provided in this study are rough calculations they provide enough background information to formulate a general understanding of how the implementation of solar power can provide for the city of Grand Junction and their effects on the environment.

There were three solar power implementation business model options discussed and analyzed by this study. The solar power plant option has the capability of utilizing several different forms of solar technology (i.e. CSP or PV). The other two options were designed as rooftop systems and utilize PV fixed flat-plate solar technology. All options have been shown capable of providing the city of Grand Junction with renewable energy that will ultimately help to satisfy Colorado's RPS. All three options have also been shown capable of alleviating the risks associated with the installation of a personally owned solar power system by transferring the burden of capital and operational and maintenance costs from the end user to a company with available funding, such as an IOU or third party owner. The table provided below, **Table 14**, lists the attributes previously discussed (Chapter 7) in this study associated with each solar technology employed by the three business model options. The highlighted cells within the table depict which solar technology provides the most desirable value associated with each attribute. Of the systems (rooftop and solar power plant) depicted in Table 14 the PV two-axis solar power plant is the most advantageous of the technologies. A PV two-axis system has the best performance values for five of the eight attributes. While a dish CSP system incurs the least capital costs, a fixed flat-plate system is the least economically burdensome on the end user (LCOE).

Table 14. Attributes and their values generated by each solar technology associated with the options described in this study.

	100 MW Nameplate Capacity				
	Rooftop System	Solar Power Plant			
Technology	Fixed Flat-Plate	PV 2-Axis	Parabolic	Dish	Power Tower
Cost ($ million)	551	552	652	316	606
LCOE (¢/kWh)	15	17	21	16	36
Energy Output (million kWh/yr)	152	230	224	165	123
GJ Electrical Demand Met (%)	20	30	29	22	19
Land Area Consumed (acres)	172	1000	910	600	1284
CO_2 (metric tons)	143,276	217,159	210,984	155,840	116,104
Hg (lbs)	8	12	11	8	6
RPS Contribution for DG (%)	22	33	32	24	18

This table (**Table 14**) does not account for the economic, social, and environmental costs of externalities associated with each system, such as environmental damages and impacts on human health accrued during material extraction (mining) and the manufacturing and installation processes. As discussed in Chapter 4, solar power plants require large amounts of land for installation. The damaging environmental impacts associated with preparing large plots of undeveloped land have not been monetarily quantified. If this can be been accomplished, then the costs of implementing a solar power plant will surely outstrip the costs of a solar rooftop system. However, if these externalities were not a concern then capital expenses would be the only issue of discussion and the cost to build a solar power plant would easily be defeated by the cost to build a coal-fired power plant. Current costs to build a coal-fired power plant are around $2,500/kW. (Power-Gen) A 100 MW coal-fired plant would cost roughly $250 million; this does not include other project costs associated with a coal-fired power plant, such as operation and maintenance costs or mine development costs. Depending on the solar technology used, one to three more 100 MW coal-fired plants could be built for each solar power plant. The capital installed cost of building a 100 MW coal-fired power plant is 17% to 72% cheaper than the capital costs of the solar power plants described by this study. However, construction costs are increasing due to increased regulations and energy demand throughout the nation. Increased energy consumption demands the need for new power stations which is driving up the cost of materials and labor. (Hargreaves) If environmental and human health externalities were accounted for, these costs would likely further increase. Solar power is the conversion of sunlight into electricity; as a result, all three options are pollution free during operation. The sun is the fuel that operates the system; therefore, when operating, neither PV nor CSP generation emits atmospheric (i.e. CO_2) or ground level (i.e. mercury) pollutants. Thus, the implementation of solar in Grand Junction can not only reduce CO_2 emissions by 116 – 217 thousand metric tons per year, but will also remove approximately 6 – 12 pounds of mercury per year. Though this doesn't seem like much when compared to what is released on an annual basis from coal-fired power plants, over the long term installing 100 MW of solar power will not only eliminate one new 60 MW[6] coal-fired power plant from being built, but will offset 30 years of emissions released during a lifetime production from this new coal-fired power plant. This is in addition to the amount of emissions actual solar power production offsets from coal-fired power plants already in place.

Climate changing gases (i.e. CO_2) and air pollutants are important environmental/health impacts with severe long-term consequences, but there other environmental concerns that demand as much attention. This includes the destruction of habitat and contamination of water sources identified with mining for materials, the hazards associated with manufacturing, the destruction of habitat that occurs with "scraping" of sensitive desert ecosystems during installation of a PV or CSP solar power plant, and the consumption of water from a limited supply during energy production by a typical CSP plant (i.e. parabolic trough and power tower systems). These are a few of the externalities associated with the development of solar power. Half of these issues mentioned can be avoided by using rooftop mounted PV solar systems as implemented with a solar rooftop leasing program or a third party SPPA. Also, most materials used in the construction of solar power systems can be recycled and reused. Once the life of the system has been recognized, the recycling of materials can help combat the need for further mining.

In keeping solar power to onsite generation and decentralized there should be no need to develop large solar power facilities in sensitive ecosystems isolated from the populace. Distributed generation may be ill-defined by both location and size, but it is apparent that location provides the best delineation between DG and centralized generation which is commonly used for distributing power from solar power plants. Unfortunately, a 100 MW solar power station is likely still too large to be placed next to or in close proximity to the populace center of Grand Junction to be utilized as distributed generation. This would require the need to build new transmission lines. The US has been operating off the same transmission system for the past 100 years and

[6] According to NREL's SAM, a 60 MW coal-fired power plant will produce approximately the same amount of energy per annum as a 100 MW PV two-axis tracking solar power plant and a 40 MW coal-fired power plant is equivalent to 100 MW of rooftop solar.

while populations have grown and the way the electrical industry does business has changed, the transmission grid has not. (SEIA "Transmission") Although there is need for expanding and upgrading the grid to accommodate new demands and renewable energy this will take time, money, and more research and will only post-pone the implementation of solar power if only large-scale solar power plants are considered. Transmission lines typically span over great distances from the power source to a substation then to the consumer. They therefore suffer a percentage of electricity loss due to voltage fluctuations and other factors. (SunRun) Thus, increasing the amount of electrical energy carried through the transmission lines only creates additional stress on an already overburdened, outdated transmission system. The flexibility in solar technology and design allows solar power generating systems to be installed virtually anywhere, like atop existing infrastructure such as roofs as done in a solar rooftop leasing program and a third party SPPA. This not only brings production of electricity directly to the site of consumption, but also eliminates the need for new transmission lines. A solar rooftop leasing program and/or a third party SPPA virtually knock out the “middle man”, the substation, by connecting directly into the community grid and dramatically decrease the amount of distance travelled to the end-user.

The expansion of transmission lines requires land, as does the construction of a solar power plant. Nearly 1.5 million acres (607,028 ha) of undeveloped land surrounds the city of Grand Junction. Much of this open space is managed by the BLM. The amount of land needed to support a 100 MW solar power plant ranges from 600 to 1,300 acres (243 – 526 ha). This requires “scraping” of sensitive desert ecosystems which could potentially have a negative cascading effect on the desert ecology of that region (Section 4.2.2). This could be avoided through the implementation of a rooftop solar program or third party SPPA. Assuming that there is approximately 42.2 million ft^2 (3.92 million m^2) of available rooftop space in Grand Junction, then theoretically, Grand Junction’s infrastructure could support nearly 500 MW of rooftop solar using current fixed flat-plate systems (Chapter 7). This figure is an extremely rough estimate. It is recommended that a more technically comprehensive analysis be performed assessing the rooftop availability in Grand Junction for more accurate data. However, as solar technology improves, it may be that by the year 2020 solar will be architecturally integrated in a building’s structure as standard practice, for example through roof shingles, south facing walls, or awnings. There are also open spaces within the city, such as parking lots, that could adequately support solar power production. Already, companies are installing carports made of solar panels in parking lots. This serves a dual purpose, shade and power. There are numerous opportunities available using solar PV technologies that could be implemented within the framework of the city, but how will the explosion of DG affect an aged and burdened grid system?

Solar power is a rapidly growing industry in many ways and has been and will likely continue to be widely studied by various government entities and private businesses throughout the world. There are constant improvements being made to already proven solar technology (i.e. efficiency improvements of semi-conductor materials) along with the development of new solar technologies, such as using thermal-chemical technology to release solar energy (AE) or cylindrical solar cells (Bullis). These contributions are changing the face of solar even as we know it today. Discussion and research are pioneering solutions to integrate solar into a building's envelope as an integral structural component, such as flexible solar rooftop shingles. (AE "Solar Shingles") Each attribute of concern associated with solar power (capital costs, operational costs, social costs, environmental impacts, regulations, and infrastructure) deserve a comprehensive analysis so that we, as consumers of electrical energy, can better understand the framework of solar power on a whole.

It is important to keep in mind that no one solution will ever be without its environmental problems. Every form of technology comes from the elements provided by the earth that at some point in time must be extracted. The responsibility therein lies in minimizing any harmful consequences by taking only that which is needed with as little impact as possible. This is done by understanding as fully as possible the LCA of a product. Not all consequences can be avoided, but this approach will help reduce undesirable, unintended consequences naturally associated with complex systems. As recognized in this study, solar power is not without its dark side and its challenges. Increased solar research and development is a vital investment in the US's energy future. An improved understanding of solar technology will better prepare the nation for the handling of future energy crises, health and safety issues, and environmental impacts. More efficient designs will generate more power at lower costs.

Ultimately, it is the responsibility of the public to understand the energy resources we consume. We are the end users that drive demand. Without demand there would be little need for the exploration, development, and production of energy in any form. Enough background information has been provided in this study to give the reader a strong, general understanding about solar power and its attributes. It has identified and analyzed three major solar power implementation options available to the populace of Grand Junction. With knowledge in hand we become a more powerful deciding factor in which direction our future will take.

> *With the exception of preventing war, this is the greatest challenge our country will face during our lifetimes. The energy crisis has not yet overwhelmed us, but it will if we do not act quickly.*
>
> *It is a problem we will not solve in the next few years, and it is likely to get progressively worse through the rest of this century.*
>
> *We must not be selfish or timid if we hope to have a decent world for our children and grandchildren.*
>
> *We simply must balance our demand for energy with our rapidly shrinking resources. By acting now, we can control our future instead of letting the future control us.*[7] Jimmy Carter

[7] President Jimmy Carter's televised speech on April 18, 1977.

Appendix I

List of Colorado State Incentives applicable to solar power generation.

Incentive Type	Applicable Sectors	Amount	Max Incentive	Summary	Available in GJ
Property Assessed Clean Energy (PACE) Financing	Commercial, Industrial, Residential, Multi-Family Residential, Low-Income Residential, Agricultural, Institutional	Not Applicable (N/A)	N/A	Borrowing of money to pay for energy improvements. Repaid via assessment of property over a set time period.	No
Property Tax Incentive	Commercial, Industrial, Residential, General Public/Consumer, Agricultural	Varies	Varies	Local option - Property tax exemption for property owners who install renewable energy systems (RES) on their property.	No
	Residential	100%		RES located on-site are defined as "household furnishings" and are exempt from property taxes.	Yes
	Commercial	Varies	N/A	Renewable energy property tax assessment of utility scale electric generation facilities based on cost of system, revenue generated from electricity sales, and a tax factor multiplier.	Yes
Sales Tax Incentive	Commercial, Industrial, Residential, General Public/Consumer, Agricultural	Varies	Varies	Sales and use tax exemption for property owners who install RES's on their property.	No
	Commercial, Industrial, Residential, General Public/Consumer, Nonprofit, Local Government, State Government, Agricultural, Institutional, Retail Supplier	100%		Sales and use tax exemption for all sales, storage, and use of components used in the production of alternating current (AC) from renewable energy equipment.	Yes
State Grant Program	Commercial, Industrial, Residential	N/A	N/A	From the Federal American Recovery & Reinvestment Act Funds established to stimulate the economy by investing in new energy economic development	Yes
State Rebate Program	Commercial, Nonprofit, Agricultural	$1.50/W for first 10kW		For businesses and organizations who receive ≥50% of income from agricultural production and are paying commercial utility rates and have installed new qualifying RES's on/after April 19, 2010.[1]	No
	Residential	Up to $1.50/W		American Recovery and Reinvestment Act of 2009 funds rebates to Colorado residents who purchase and install qualifying RES's.[2]	No
Utility Rebate Program	Commercial, Residential, Nonprofit, Installer/Contractor, Systems Integrator	Varies	$200,000	Xcel Energy's Solar*Rewards Program[3]	Yes

1) PV: Max size 25kW. Xcel Energy and Black Hills customers do not qualify for PV rebates due to existing incentives. Most businesses/organizations are Xcel customers

2) Xcel Energy and Black Hills customers do not qualify for PV rebates due to existing incentives. Most residents of GJ are Xcel customers.

3) See following page for details concerning this incentive.

Appendix I (Con't)

Solar*Rewards Program

Amount:	*Rebates:* Systems 0.5 kW - 500.0 kW DC: $2/W DC with a maximum rebate of $200,000 Systems >500.1 kW DC: Determined through request for proposal (RFP) process with a maximum rebate of $200,000 *Renewable Energy Credit (REC) Purchases as of 9/16/10:* Customer-owned systems 0.5 kW - 10.0 kW DC: $0.45/W DC up-front, one-time payment Third-party-owned systems 0.5 kW - 10.0 kW DC: $0.07/kWh of actual production (paid monthly) Systems 10.1 kW - 100.0 kW DC: $0.045/kWh of actual production (paid monthly) Systems 100.1 kW - 500.0 kW DC: $0.055/kWh of actual production (paid monthly) Systems 500.1 kW DC and larger: Determined through RFP process *REC payments will step down over time as certain MW levels are reached for each system classification.*
Eligible System Size:	Minimum of .5 kW Limited to 120% of average annual consumption of the site
Summary:	Two incentives are provided for grid connected solar systems: upfront rebate payment and a separate payment for REC's produced by the system. All REC purchases are good for 20 years. REC payment is dependent upon size and owner of system as defined above. These payments vary through time and are updated daily on Xcel's Solar*Rewards webpage.[8]

[8] http://www.xcelenergy.com/Colorado/Residential/RenewableEnergy/Solar_Rewards/Pages/home.aspx

Appendix II

Meteorological and Solar Resource Data for Grand Junction, CO

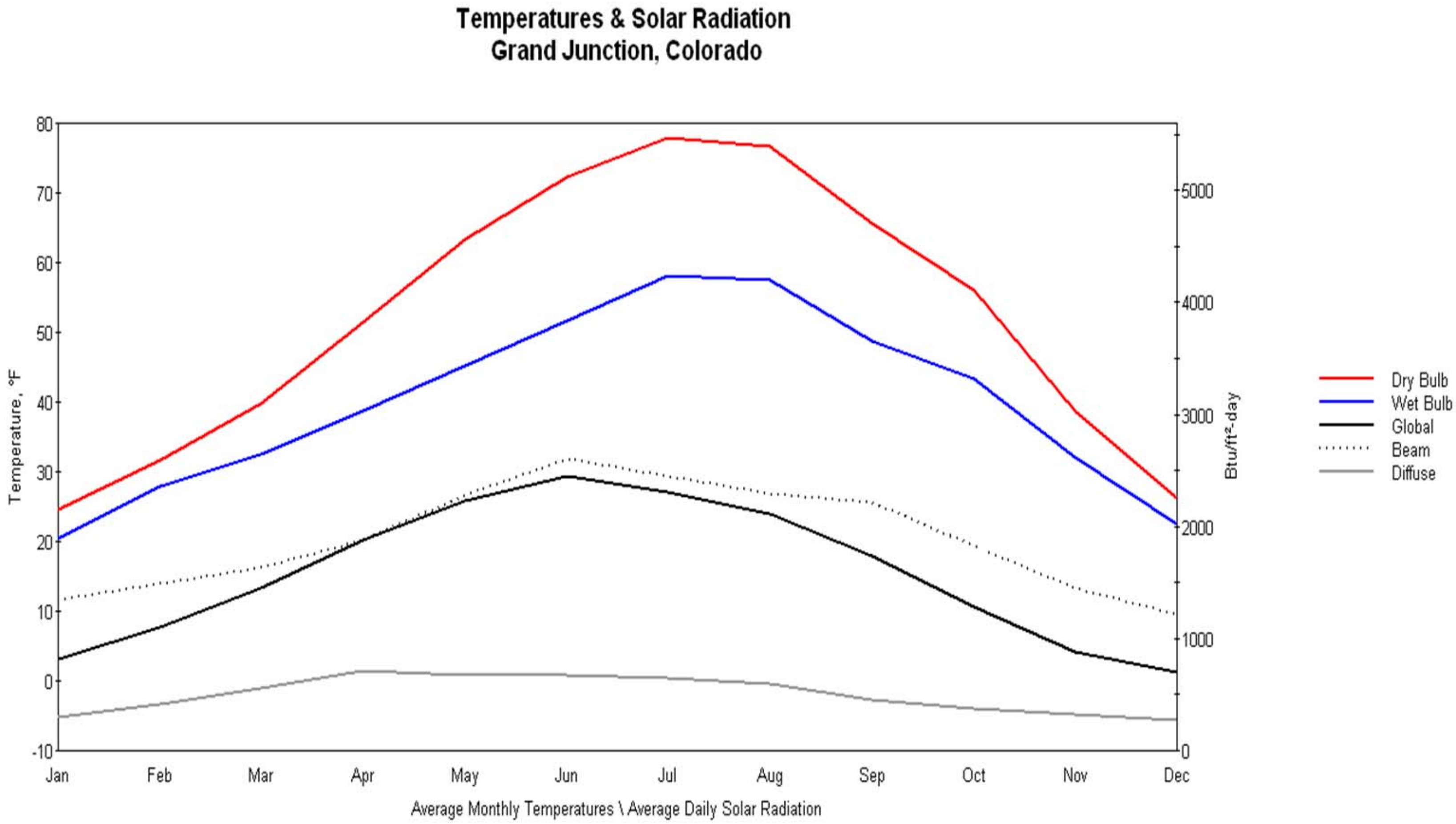
Weather File Summary
Grand Junction, Colorado

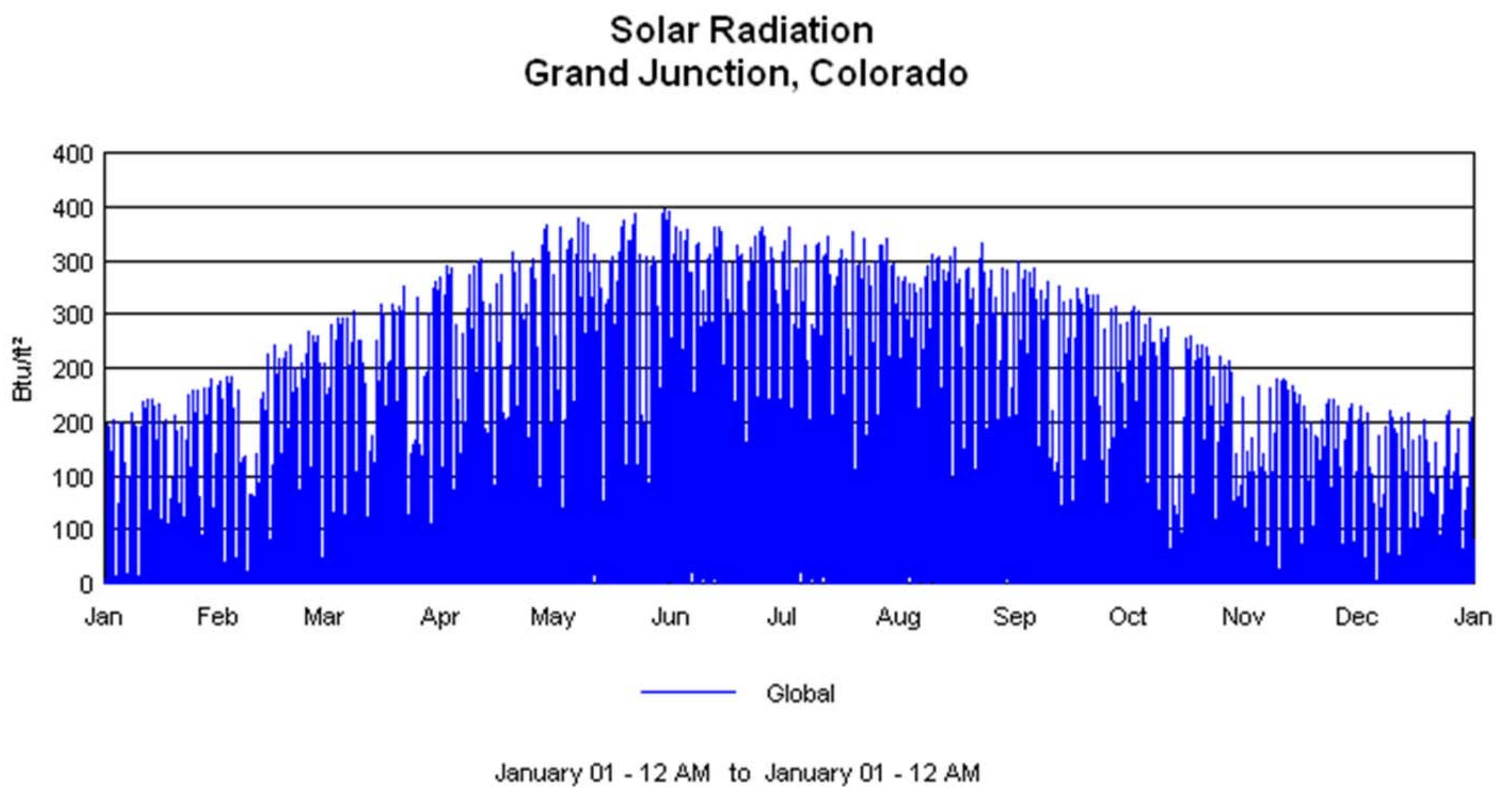
Source:	Weather Maker, Version 1.0.5, Jun 7, 2006, National Renewable Energy Laboratory	
Latitude:	39.117	
Longitude:	-108.53	
Elevation:	4839 ft	
Design Day Dry Bulb (Winter 99.0%):		2.0 °F
Design Day Dry Bulb (Winter 97.5%):		7.0 °F
Design Day Dry Bulb (Summer 2.5%):		94.0 °F
Design Day Wet Bulb (Summer 2.5%):		59.0 °F

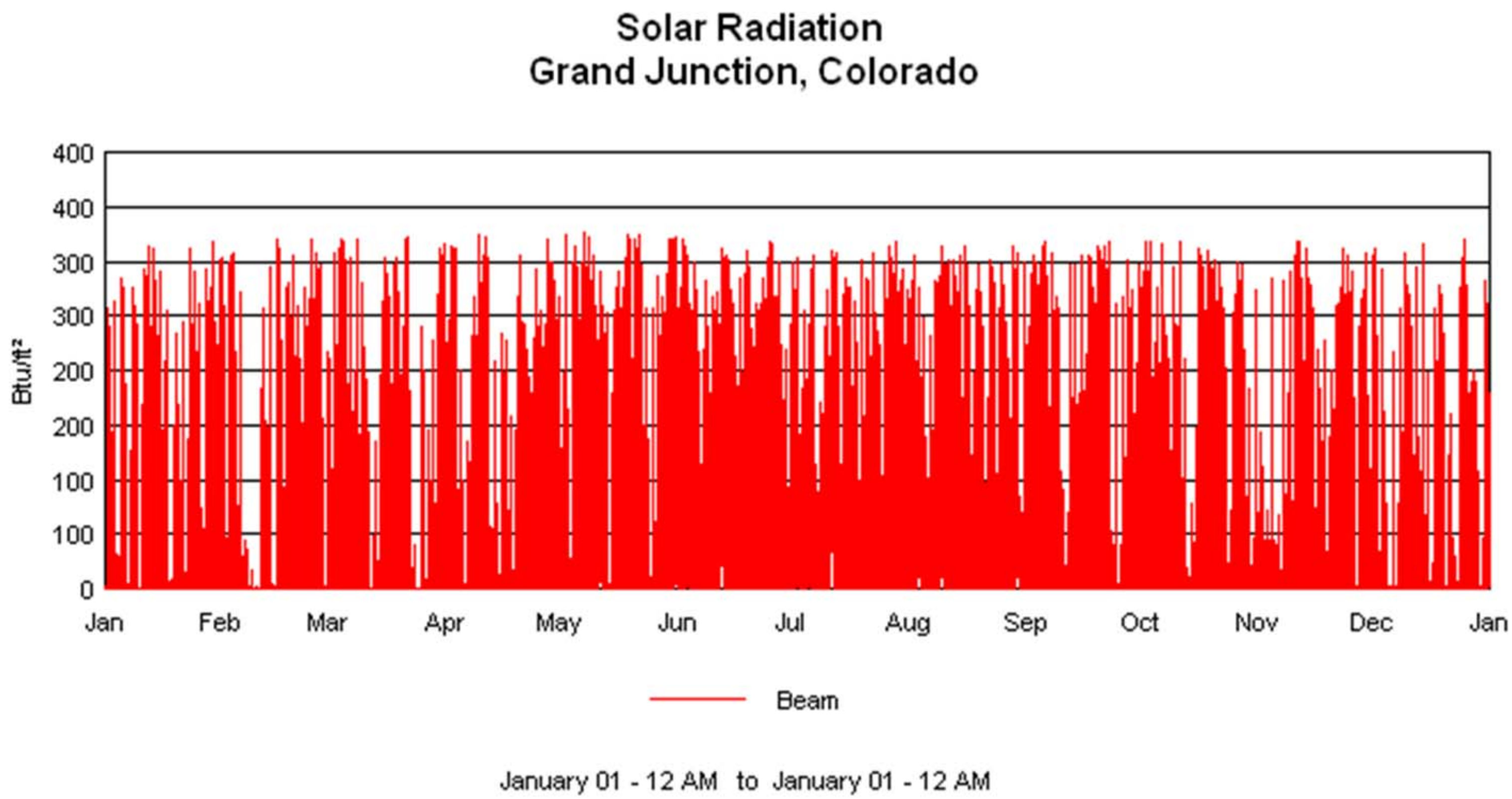
Month	TAA	TMXA	TMNA	TMX	TMN	TWBA	RH	WSA	HS	HDD	CDD
January	24.6	36.1	15.3	54.0	0.0	20.4	54.7	4.8	812	1219	0
February	31.7	41.1	24.3	56.0	6.0	27.8	68.6	6.0	1105	905	0
March	39.8	49.8	31.1	73.0	13.0	32.4	49.5	7.3	1452	762	0
April	51.4	63.3	39.7	76.0	26.0	38.8	36.4	8.9	1880	406	0
May	63.3	75.7	50.3	90.0	35.0	45.1	27.0	10.1	2232	111	50
June	72.4	84.7	59.9	92.0	50.0	51.6	27.3	10.0	2454	5	224
July	77.9	90.8	64.8	100.0	58.0	58.1	36.1	9.6	2314	0	396
August	76.7	89.5	65.0	96.0	58.0	57.5	35.8	10.7	2107	0	379
September	65.6	78.7	52.9	89.0	41.0	48.8	34.5	9.2	1742	72	95
October	56.0	70.1	43.6	83.0	33.0	43.3	43.1	7.4	1287	256	2
November	38.7	50.4	28.5	62.0	11.0	32.0	54.9	7.3	888	767	0
December	26.3	35.4	18.7	45.0	4.0	22.4	62.5	4.6	699	1176	0
Year	52.0	63.8	41.2	100.0	0.0	39.9	44.2	8.0	1581	5676	1145

TAA Average Dry Bulb Temperature, °F
TMXA Average Daily Maximum Dry Bulb Temperature, °F
TMNA Average Daily Minimum Dry Bulb Temperature, °F
TMX Maximum Dry Bulb Temperature, °F
TMN Minimum Dry Bulb Temperature, °F
TWBA Average Wet Bulb Temperature, °F
WSA Average Wind Speed, MPH
HS Average Daily Horizontal Solar Radiation, Btu/ft^2

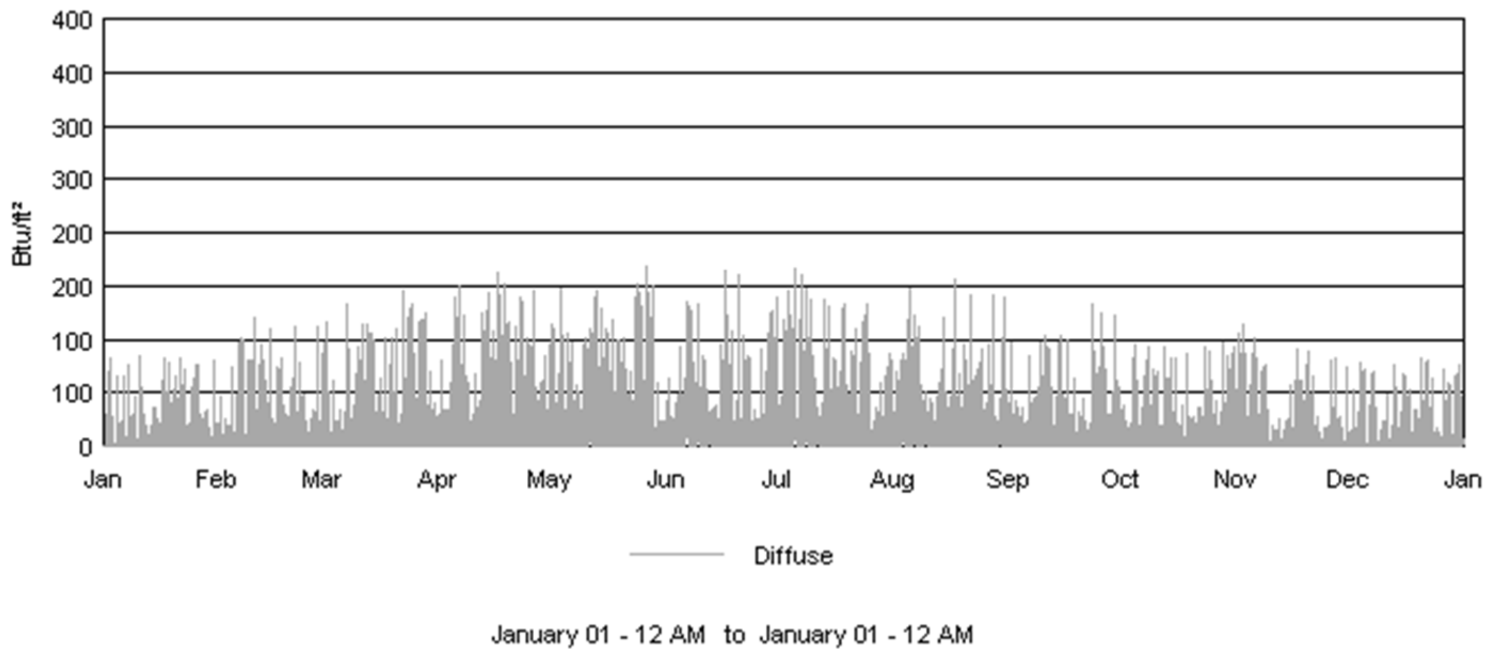
RH Relative Humidity, %
HDD Heating Degree Days, Base 65.0 °F
CDD Cooling Degree Days, Base 65.0 °F




Solar Radiation
Grand Junction, Colorado
400
400
300
300
200
200
100
100
0
Btu/ft²
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Global
January 01 - 12 AM to January 01 - 12 AM

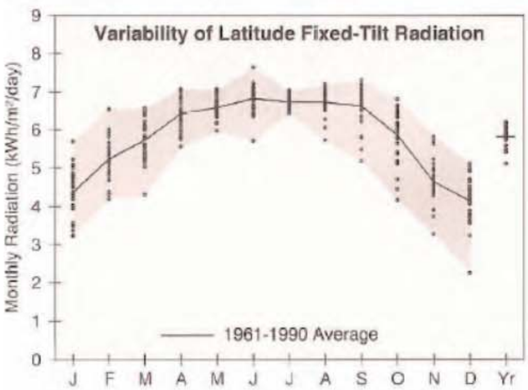

Solar Radiation
Grand Junction, Colorado
Btu/ft²
400
400
300
300
200
200
100
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Beam
January 01 - 12 AM to January 01 - 12 AM

Solar Radiation
Grand Junction, Colorado



Appendix II (Con't)

Solar Resource Chart[9]



Grand Junction, CO

WBAN NO. 23066

LATITUDE: 39.12° N
LONGITUDE: 108.53° W
ELEVATION: 1475 meters
MEAN PRESSURE: 853 millibars

STATION TYPE: Primary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.5	3.5	4.6	6.0	7.0	7.7	7.4	6.6	5.5	4.1	2.7	2.2	5.0
	Min/Max	2.1/2.9	3.0/4.1	3.8/5.1	5.3/6.5	6.3/7.5	6.4/8.7	7.1/7.7	5.7/7.1	4.5/6.0	3.1/4.5	2.2/3.2	1.5/2.5	4.6/5.2
Latitude -15	Average	3.8	4.7	5.5	6.5	7.0	7.5	7.3	7.0	6.5	5.4	4.1	3.6	5.7
	Min/Max	2.9/4.8	3.9/5.8	4.3/6.3	5.7/7.2	6.3/7.5	6.2/8.4	7.0/7.6	6.0/7.5	5.2/7.2	3.9/6.2	3.0/5.0	2.0/4.3	5.1/6.1
Latitude	Average	4.4	5.2	5.7	6.4	6.6	6.8	6.7	6.7	6.6	5.9	4.6	4.1	5.8
	Min/Max	3.2/5.7	4.2/6.6	4.3/6.6	5.6/7.1	6.0/7.1	5.7/7.6	6.4/7.0	5.7/7.2	5.2/7.3	4.2/6.8	3.3/5.8	2.3/5.1	5.1/6.2
Latitude +15	Average	4.7	5.4	5.6	6.0	5.8	5.8	5.8	6.1	6.4	6.0	4.9	4.5	5.6
	Min/Max	3.4/6.2	4.3/6.9	4.2/6.5	5.1/6.6	5.3/6.2	4.9/6.5	5.6/6.1	5.2/6.5	4.9/7.0	4.2/6.9	3.4/6.2	2.4/5.6	4.8/6.0
90	Average	4.4	4.7	4.2	3.7	3.0	2.7	2.8	3.5	4.4	4.8	4.4	4.3	3.9
	Min/Max	3.0/5.8	3.5/6.4	3.0/4.8	3.2/4.0	2.9/3.2	2.4/2.9	2.7/2.9	3.0/3.7	3.4/4.8	3.3/5.6	3.0/5.7	2.2/5.3	3.3/4.3

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.7	5.1	6.4	8.2	9.5	10.6	10.1	9.2	8.1	6.1	4.2	3.4	7.0
	Min/Max	2.7/4.8	3.9/6.5	4.4/7.5	7.0/9.4	7.7/10.5	8.3/12.4	9.3/10.7	7.6/10.2	6.0/9.0	4._/7.1	2.8/5.2	1.9/4.2	6.0/7.5
Latitude -15	Average	4.7	6.0	7.1	8.7	9.6	10.6	10.1	9.5	8.9	7.1	5.1	4.4	7.7
	Min/Max	3.4/6.2	4.6/7.8	4.9/8.4	7.3/10.0	7.9/10.7	8.3/12.3	9.4/10.7	7.9/10.6	6.5/9.9	4.8/8.4	3.4/6.6	2.3/5.5	6.4/8.2
Latitude	Average	5.2	6.4	7.3	8.7	9.3	10.1	9.8	9.4	9.0	7.5	5.6	4.9	7.8
	Min/Max	3.7/6.9	4.8/8.4	4.9/8.7	7.2/9.9	7.6/10.4	7.9/11.9	9.0/10.4	7.7/10.4	6.6/10.0	5.0/8.8	3.7/7.2	2.5/6.1	6.4/8.3
Latitude +15	Average	5.4	6.6	7.2	8.3	8.8	9.5	9.2	8.9	8.8	7.5	5.8	5.2	7.6
	Min/Max	3.8/7.3	4.9/8.6	4.8/8.6	6.9/9.6	7.2/9.8	7.4/11.1	8.4/9.7	7.4/10.0	6.4/9.8	5.0/8.9	3.8/7.5	2.6/6.5	6.3/8.2

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	5.5	6.6	7.3	8.8	9.7	10.8	10.3	9.6	9.0	7.6	5.8	5.2	8.0
	Min/Max	3.8/7.4	4.9/8.6	5.0/8.7	7.3/10.0	8.0/10.9	8.4/12.7	9.5/10.9	7.9/10.7	6.6/10.0	5.0/8.9	3.8/7.5	2.6/6.6	6.7/8.6

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W	Average	3.3	3.7	3.7	4.3	5.0	5.9	5.5	5.1	4.9	4.5	3.6	3.4	4.4
Horiz Axis	Min/Max	1.9/5.3	2.3/5.2	1.8/4.9	3.2/5.4	3.5/6.0	4.3/7.6	4.8/6.2	3.7/5.8	3.0/5.9	2.6/5.6	2.1/5.2	1.2/4.7	3.3/4.9
1-Axis, N-S	Average	2.5	3.4	4.3	5.7	6.7	7.9	7.4	6.7	6.2	4.6	2.9	2.3	5.1
Horiz Axis	Min/Max	1.5/4.0	2.0/4.9	1.9/5.7	4.0/7.2	4.5/8.2	5.6/10.2	6.3/8.2	4.7/7.9	3.7/7.3	2.5/5.8	1.6/4.2	0.8/3.3	3.7/5.6
1-Axis, N-S	Average	3.6	4.5	5.0	6.0	6.5	7.5	7.0	6.9	6.9	5.8	4.1	3.6	5.6
Tilt=Latitude	Min/Max	2.2/5.8	2.7/6.4	2.3/6.6	4.3/7.5	4.4/8.0	5.3/9.6	6.0/7.8	4.8/8.0	4.1/8.1	3.2/7.2	2.3/5.9	1.2/5.0	4.1/6.2
2-Axis	Average	3.9	4.7	5.0	6.1	6.9	8.1	7.6	7.1	6.9	5.8	4.4	3.9	5.9
	Min/Max	2.3/6.3	2.8/6.5	2.3/6.6	4.3/7.7	4.6/8.4	5.8/10.4	6.4/8.4	4.9/8.3	4.1/8.2	3.2/7.3	2.4/6.3	1.3/5.5	4.3/6.5

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-3.9	1.4	6.3	11.2	16.7	22.4	26.0	24.7	19.4	12.6	4.7	-1.8	11.7
Daily Minimum Temp	-9.7	-4.7	-0.4	3.6	8.8	13.9	17.7	16.8	11.6	5.3	-1.4	-7.4	4.5
Daily Maximum Temp	1.9	7.4	13.1	18.8	24.4	30.9	34.2	32.5	27.3	19.8	10.8	3.7	18.8
Record Minimum Temp	-30.6	-27.8	-15.0	-11.7	-3.3	1.1	7.8	6.1	-1.7	-7.8	-18.9	-27.2	-30.6
Record Maximum Temp	15.6	20.0	27.2	29.4	35.0	40.6	40.6	39.4	36.7	31.1	23.9	17.8	40.6
HDD, Base 18.3°C	689	474	372	216	73	7	0	0	31	184	410	625	3082
CDD, Base 18.3°C	0	0	0	0	22	131	238	196	64	7	0	0	657
Relative Humidity (%)	70	60	50	40	36	29	34	37	39	46	58	68	47
Wind Speed (m/s)	2.5	2.9	3.6	4.1	4.2	4.2	4.1	3.9	3.8	3.4	3.0	2.5	3.5

[9] (Utah Geological Survey)

Appendix III

Solar POD Outline 7/3/2008

Solar Energy Plan of Development Outline:

1. Project Description

a. Introduction

- Describe type of facility, planned uses, generation output
- Applicants schedule for project, including anticipated timelines for permitting, construction and operation, and any phased development as appropriate

b. Proponents Purpose and Need for the Project

c. General Facility Description, Design and Operation

-Project location, land ownership and jurisdiction
-Legal land description of facility (federal and non-federal lands)
-Total acreage and general dimensions of all facilities and components
-Power plant facilities, thermal conversion process
-Numbers and general dimensions of solar array, power generation units (wet or dry cooling), towers, substations, transmission lines, access roads, buildings, parking areas
-Temporary construction workspace, yards, staging areas
-Geotechnical studies and data needs, including solar insolation testing
-Ancillary facilities (administrative and maintenance facilities and storage sites)
-Water usage, amounts, sources (during construction and operations)
-Erosion control and stormwater drainage
-Vegetation treatment and weed management
-Waste and hazardous materials management
-Fire protection
-Site security and fencing (during construction and operations)
-Electrical components, new equipment and existing system upgrades
-Interconnection to electrical grid
-Spill prevention and containment for construction and operation of facility
-Health and safety program

d. Other Federal, State and Local Agency Permit Requirements

-Identify required permits (entire project area on both federal and non-federal lands)
-Status of permits

e. Financial and Technical Capability of Applicant

2. Construction of Facilities

a. Solar field design, layout, installation and construction processes including timetable and sequence of construction
b. Phased projects, describe approach to construction and operations
c. Access and transportation system, component delivery, worker access
d. Construction work force numbers, vehicles, equipment, timeframes
e. Site preparation, surveying and staking
f. Site preparation, vegetation removal and treatment
g. Site clearing, grading and excavation
h. Solar array assembly and construction
i. Power plant construction

j. Gravel, aggregate, concrete needs and sources
k. Electrical construction activities
l. Aviation lighting (power towers, transmission)
m. Site stabilization, protection, and reclamation practices

3. Related Facilities and Systems

a. Transmission System Interconnect
- -Existing and proposed transmission system
- -Ancillary facilities and substations
- -Status of Power Purchase Agreements
- -Status of Interconnect Agreement
- -General design and construction standards

b. Gas Supply Systems (as appropriate)
- -Backup natural gas generation requirements
- -Pipeline routing considerations and construction standards
- -Metering stations

c. Other Related Systems
- -Communications system requirements (microwave, fiber optics, hard wire, wireless) during construction and operation

4. Operations and Maintenance

a. Operation and facility maintenance needs
b. Maintenance activities, including mirror washing and road maintenance
c. Operations workforce and equipment

5. Environmental Considerations

a. General description of site characteristics and potential environmental issues (existing information)
- -Special or sensitive species and habitats
- -Special land use designations
- -Cultural and historic resource sites and values
- -Native American Tribal concerns
- -Recreation and OHV conflicts
- -Other environmental considerations

b. Mitigation measures proposed by applicant and included in POD Solar POD Outline

6. Maps and Drawings

a. Maps with footprint of solar facility (7.5 min topographic maps or equivalent to include references to Public Land Survey system)
b. Initial design drawings of solar facility layout and installation, thermal power conversion facilities, electrical facilities and ancillary facilities. These initial design drawings will typically be a 30% Engineering and Civil Design package to adequately describe the proposed project and evaluate the design considerations for soils, drainage and watershed management.
c. Initial site grading plan
d. Maps with transmission facilities, substations, distribution, communications

e. Access and transportation maps

SUPPLEMENTARY INFORMATION

Additional Supplementary Information will be required from the applicant in order to prepare the NEPA analysis and complete the review process, but is not required to be submitted with the initial POD. This information may be filed after the publication of a Notice of Intent to prepare an EIS, but is required before the BLM can complete the environmental analysis. This information is developed as further data is gathered on-site and as alternative designs and mitigation measures are incorporated into a final POD. Other environmental data and inventory information (including but not limited to cultural resources, sensitive species and other biological data) will also be required to be collected by the applicant in order to prepare the NEPA analysis.

1. Engineering and Civil Design
    - a. Facility survey and design drawing standards
    - b. Final engineering and civil design packages for all solar facilities, thermal power conversion facilities, electrical facilities and ancillary facilities that incorporate all mitigation measures developed in the NEPA analysis and incorporated into the final POD
    - c. Watershed and drainage analysis and calculations
    - d. Watershed protection and erosion control design drawings
    - e. Final site grading plans

2. Alternatives Considered by the Applicant
    - a. Alternative site evaluation criteria
    - b. Alternatives considered but not carried forward by proponent
    - c. Comparative analysis of proponents alternatives
    - d. Alternative site configurations

3. Facility Management Plans
    - a. Stormwater Pollution Prevention and Protection Plan
    - b. Hazardous Materials Management Plan
    - c. Waste Management Plan
    - d. Invasive Species and Noxious Weed Management Plan
    - e. Health and Safety Plan (meeting OSHA requirements)
    - f. Environmental Inspection and Compliance Monitoring Plan

4. Facility Decommissioning
    - a. Reclamation and site stabilization planning
    - b. Temporary reclamation of disturbed areas
    - c. Removal of power generation and substation facilities
    - d. Removal of heliostats/panels
    - e. Removal of other ancillary facilities

Bibliography

Abengoa. Photovoltaic Concentration Plants. 2008. November 2010 <http://www.abengoasolar.com/corp/web/en/technologies/photovoltaic/concentration/index.html>.

AE "Solar Shingles". Flexible Solar Powered Rooftop Shingles. 14 June 2009. November 2010 <http://www.alternative-energy-news.info/flexible-solar-powered-rooftop-shingles/>.

AE. MIT Breakthrough: Thermo-Chemical Solar Power. 3 November 2010. November 2010 <http://www.alternative-energy-news.info/mit-thermo-chemical-solar-power/>.

Allen, Bruce. Leasing America's Rooftop for Solar Energy. 27 January 2009. October 2010 <http://www.miller-mccune.com/business-economics/leasing-america-s-rooftops-for-solar-energy-3987/>.

American Coal Foundation. FAQs About Coal. 2010. October 2010 <http://www.teachcoal.org/aboutcoal/articles/faqs.html>.

Berwind, Joseph. Investing in Solar Stocks: An Investor's Guide to Winning in the Global Renewable Energy Market. Columbus: McGraw Hill, 2009.

BLM "Blythe". Blythe Solar Power Project. 21 October 2010. October 2010 <http://www.blm.gov/ca/st/en/fo/palmsprings/Solar_Projects/Blythe_Solar_Power_Project.html>.

BLM. Colorado Renewable Energy. 1 July 2009. August 2010 <http://www.blm.gov/co/st/en/BLM_Programs/energy/renewable_energy.html>.

—. EMS Transmission of Instruction Memorandum No. 2007-097. 04 April 2007. August 2010 <http://www.blm.gov/pgdata/etc/medialib/blm/wo/Communications_Directorate/public_affairs.Par.20041.File.dat/IM2007-097.pdf>.

—. EMS Transmission of Instruction Memorandum No. 2010-141. 10 June 2010. August 2010 <http://www.blm.gov/wo/st/en/info/regulations/Instruction_Memos_and_Bulletins/national_instruction/2010/IM_2010-141.html>.

—. New Energy for America. 23 July 2010. August 2010 <http://www.blm.gov/wo/st/en/prog/energy.html>.

—. Solar Energy Plan of Development. 03 July 2008. August 2010 <http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/cost_recovery.Par.96285.File.dat/Solar_POD.pdf>.

Brandt, Patrick, Jared Devine and Jeffery Lamb. Leveraging Stimulus Funds: Options for Financing Renewable Energy & Energy Efficiency Projects. White Paper. Washington D.C.: ACORE, 2010.

Bullis, Kevin. Better Solar for Big Buildings. 7 October 2008. November 2010 <http://www.technologyreview.com/energy/21473/>.

CBO. Nuclear Power's Role in Generating Electricity. May 2008. October 2010 <http://www.cbo.gov/ftpdocs/91xx/doc9133/toc.htm>.

CEA. Colorado Coal. 2009. November 2010 <http://www.cleanenergyaction.org/colorado-coal>.

Center for Regulatory Effectiveness. US Code Collection: 42 USC Sec. 7371 Renewable Energy Resources Act of 1980. October 2010 <http://www.thecre.com/fedlaw/legal12q/uscode42-7371.htm>.

Clarke, Emma. Stirling Dish Industry: Not all hot air. 18 Febraury 2010. October 2010 <http://social.csptoday.com/industry-insight/stirling-dish-technology-not-all-hot-air>.

Cornett, Lloyd. Rooftop Solar Leases - Knowledge is Power. 30 July 2010. September 2010 <http://www.thefreelibrary.com/Rooftop+Solar+Leases+-+Knowledge+is+Power-a0233071575>.

Council on Environmental Quality. Part 1500: Purpose, Policy, and Mandate . 28 November 1978. August 2010 <http://ceq.hss.doe.gov/nepa/regs/ceq/1500.htm>.

CRS. Energy Policy Act of 2005: Summary and Analysis of Enacted Provisions. Report for Congress. Washington D.C.: Library of Congress, 2006.

Denholm, P. and Margolis R. The Regional Per Capita Solar Electric Footprint for the United States. Technical. Golden: NREL, 2007.

Department of Energy. Energy Basics: Photovoltaics. 06 July 2010. June 2010 <http://www.eere.energy.gov/basics/renewable_energy/photovoltaics.html>.

—. Solar Energy Technologies Program. 28 October 2008. June 2010 <http://www1.eere.energy.gov/solar/photovoltaics.html>.

Devlin, Lee. How Much Does it Cost to Install Solar on an Average US House? 30 January 2008. October 2010 <http://solarpowerauthority.com/how-much-does-it-cost-to-install-solar-on-an-average-us-house/>.

DOE. Energy Basics: Concentrating Solar Power. 17 August 2010. June 2010 <http://www.eere.energy.gov/basics/renewable_energy/csp.html>.

—. Energy Timeline: From 1971 to 1980. October 2010 <http://www.energy.gov/about/timeline1971-1980.htm>.

—. "Information Resources." 2001. Energy Efficiency and Renewable Energy. September 2010 <http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf>.

—. National Transmission Grid Study. Washington D.C.: U.S. Government, 2002.

DOE/BLM. Assessing The Potential For Renewable Energy On Public Lands. Oak Ridge: DOE, 2003.

EERE "About". "About the office of EERE." 3 September 2010 . US DOE EERE. October 2010 <http://www1.eere.energy.gov/office_eere/>.

EERE "CO Stats". "Colorado: Electric Power and Renewable Energy in Colorado." 25 June 2008. US DOE: Energy Efficiency and Renewable Energy. October 2010 <http://apps1.eere.energy.gov/states/electricity.cfm/state=CO#total>.

EERE. Technologies. 22 May 2008. July 2010 <http://www1.eere.energy.gov/solar/pv_cell_light.html>.

EIA "Avg Retail Elec Price". Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State. 14 October 2010. October 2010 <http://www.eia.doe.gov/electricity/epm/table5_6_a.html>.

EIA "Electricity Report". US Household Electricity Report. 14 July 2005. October 2010 <http://www.eia.doe.gov/emeu/reps/enduse/er01_us.html>.

EIA "Energy Estimates". State Energy Consumption Estimates. Washington D.C.: EIA, 2008.

EIA "Energy In Brief". How Dependent Are We On Foreign Oil. 10 December 2009. October 2010 <http://www.eia.doe.gov/energy_in_brief/foreign_oil_dependence.cfm>.

EIA "Energy Outlook". International Energy Outlook 2010. 27 July 2010. October 2010 <http://www.eia.doe.gov/oiaf/ieo/graphic_data_emissions.html>.

EIA "Environment". Frequently Asked Questions – Environment. 19 August 201. November 2010 <http://www.eia.doe.gov/ask/environment_faqs.asp#electricity_fossil_fuels>.

EIA "FAQS". Frequently Asked Questions: Electricity. 3 September 2010. October 2010 <http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_cooling>.

EIA "Iraq". Iraq Energy Profile. 1 August 2010. October 2010 <http://www.eia.doe.gov/country/country_energy_data.cfm?fips=IZ>.

EIA. Coal Explained: How Much Coal Is Left. 19 February 2010. October 2010 <http://www.eia.doe.gov/energyexplained/index.cfm?page=coal_reserves>.

EPA "Climate Change". Climate Change: Basic Information. 20 May 2010. October 2010 <http://www.epa.gov/climatechange/basicinfo.html>.

EPA. "EPA's Green Power Partnership: Renewable Energy Certificates." July 2008. EPA. October 2010 <http://www.epa.gov/greenpower/documents/gpp_basics-recs.pdf>.

—. Greenhouse Gas Emissions. 14 July 2010. October 2010 <http://www.epa.gov/climatechange/emissions/index.html>.

—. Mercury: Controlling Power Plant Emissions: Overview. 01 October 2010. October 2010 <http://www.epa.gov/hg/control_emissions/index.htm>.

—. Solar Power Purchase Agreements. 24 March 2010. September 2010 <http://www.epa.gov/greenpower/buygp/solarpower.htm>.

—. Technology Transfer Network Air Toxics Web Site. 6 June 2007. September 2010 <http://www.epa.gov/ttn/atw/3_90_022.html>.

EPLAB. Discover Solar Energy. 7 July 2008. July 2010 <http://www.discoversolarenergy.com/solar/radiation.htm>.

Ford, Graham. "CSP: bright future for linear fresnal technology?" Renwable Energy Focus September/October 2008: 48-51.

Fthenakis, Vasilis and Erik Alsema. Photovoltaics Energy Payback Times, Greenhouse Gas Emissions and External Costs: 2004 - Early 2005 Status. Online: Wiley Interscience, 2006.

GE Energy. Western Wind and Solar Integration Study. Study. Golden: NREL, 2010.

Google. Google Maps. 2010. July 2010 <http://maps.google.com/maps?f=q&source=s_q&hl=en&geocode=&q=Grand+Junction,+CO&vps=1&sll =37.0625,-
95.677068&sspn=25.068921,56.513672&ie=UTF8&hq=&hnear=Grand+Junction,+Mesa,+Colorado>.

Hargreaves, Steve. CNN Money: Power prices set to surge. 12 September 2007. November 2010 <http://money.cnn.com/2007/09/11/news/economy/power_prices/index.htm>.

High Noon Solar. High Noon Solar. 2010. November 2010 <http://highnoonsolar.com/>.

Holtberg, Paul. EPACT2005 Summary. 2006. October 2010 <http://www.eia.doe.gov/oiaf/aeo/otheranalysis/aeo_2006analysispapers/epa2005_summary.html>.

Hope, L and Ladwig, K. Potential Health and Environmental Impacts Associated with the Manufacture and Use of PV Cells. Technical. Concord: Electric Power Research Institute, Inc., 2003.

IEA. World Energy Outlook. Paris: OECD/IEA, 2009.

Inflation Data. Historical Oil Prices. July 2010. September 2010 <http://www.inflationdata.com/inflation/inflation_rate/historical_oil_prices_table.asp>.

Institute for Energy Research. Fossil Fuels. 2010. August 2010 <http://www.instituteforenergyresearch.org/energy-overview/fossil-fuels/>.

Kauffman, Christopher. Human Impact on Biotic Soil Crusts. 2 May 1999. September 2010 <http://www.earlham.edu/~biol/desert/crust.htm>.

Keuchel, Edward F. and O'Sullivan, John. American Economic History: From Abundance to Constraint. New York: Markus Wiener Publishing, Inc., 1989.

Kollins, Katharine, Bethany Speer and Karlynn Cory. Solar PV Project Financing: Regulatory and Legislative Challenges for Third-Party PPA System Owners. Technical. Golden: National Renewable Energy Lab, 2010.

Marion, Bill, Carol Riordan and David Renne. Shining On: A Primer On Solar Radiation Data. July 2010 <http://rredc.nrel.gov/solar/pubs/shining/shining_index.html>.

Mesa County. Mesa County. 2009. July 2010 <http://www.mesacounty.us/template.aspx?id=360&linkidentifier=id&itemid=360&ekfxmensel=e9f6449b4_18_50>.

Mignogna, Richard. DSIRE: Database of State Incentives for Renwables & Efficiency. 23 March 2010. June 2010 <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CO24R&re=1&ee=1>.

Minkel, J.R. "Scientific American." The 2003 Northeast Blackout - Five Years Later 13 August 2008.

Montgomery, Zoë. Environmental Impact Study: CSP vs. CdTe thin film photovoltaics. Master's Thesis. Durham: Duke University, 2009.

Mule'Stagno, Luciano. Photovoltaics: New Technologies and Developments. Msida: University of Malta, 2009.

National Renewable Energy Lab. PV Faqs. Golden: DOE/GO-102005-2027, 2005.

NESCAUM. Mercury Emissions From Coal-Fired Power Plants: The Case for Regulatory Action. Boston: NESCAUM, 2003.

Newton, David E. "Oil Embargo." 2005. BookRags. October 2010 <http://www.bookrags.com/research/oil-embargo-enve-02/>.

Nice, Karim. How Stirling Engines Work. 1998-2010. July 2010 <http://auto.howstuffworks.com/stirling-engine4.htm>.

NOAA. Climatography of the United States No. 20 1971-2000. 200. July 2010 <http://cdo.ncdc.noaa.gov/climatenormals/clim20/co/053489.pdf>.

NRDC. Contaminate Coal Waste. 12 March 2009. October 2010 <http://www.nrdc.org/energy/coalwaste/methodology.asp>.

NREL "Maps". "Dynamic Maps, GIS Data, & Analysis Tools." 15 June 2010. National Renewable Energy Laboratory. June 2010 <http://www.nrel.gov/gis/solar.html>.

NREL "Radiation Data". U.S. Solar Radiation Resource Maps: Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors. December 29 2009. October 2010 <http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/>.

NREL "SAM". About SAM. 2010. October 2010 <https://www.nrel.gov/analysis/sam/>.

NREL. Troughnet: Parabolic Trough Solar Power Network. 28 January 2010. July 2010 <http://www.nrel.gov/csp/troughnet/solar_field.html>.

NTP. "Nomination of Cadmium Telluride to the National Toxicology Program." 2003. National Toxicology Program. October 2010 <http://ntp.niehs.nih.gov/ntp/htdocs/Chem_Background/ExSumPdf/CdTe.pdf>.

NY Times. "Mercury and Power Plants." The New York Times 24 July 2009: A22.

O'Connell, Ric. anAEconomic Efficiency and Non-Market Failure: An Analysis of the RPS for Colorado's Energy Market. Boulder: Colorado University, 2003.

Odum, H.T. Environmental Accounting: Emergy and Environmental Policy Making . New York: John Wiley and Sons, 1996.

Office of Air and Radiation. Climate Change and Society. Washington D.C.: EPA, 2010.

Parsons Brinckerhoff. Solar Power Plant Pre-feasibility Study. Brisbane: Parsons Brinckerhoff Australia Pty Limited, 2008.

Patterson, Thom. U.S. Electricity Blackouts Skyrocketing. 15 October 2010. 20 October 2010 <http://www.cnn.com/2010/TECH/innovation/08/09/smart.grid/index.html>.

PBS. The California Crisis: California Timeline. 1995-2010. October 2010 <http://www.pbs.org/wgbh/pages/frontline/shows/blackout/california/timeline.html>.

Power-Gen. Coal-fired power plant to see costs capped at $4.0 billion. 26 July 2010. November 2010 <http://www.powergenworldwide.com/index/display/articledisplay/3207722348/articles/powergenworldwide/coal-generation/new-projects/2010/07/prairie-state-cost.html>.

Proctor, Cathy. "Xcel switches on hybrid solar-coal power plant." Denver Business Journal (2010).

Randolph, John and Gilbert M. Masters. Energy for Sustainability: Technology, Planning, Policy. Washington, D.C.: Island Press, 2008.

Randolph, John and Gilbery M. Masters. Energy for Sustainability: Technology, Planning, Policy. Washington D.C.: Island Press, 2008.

Recession.org. 1970's Oil Crisis. 1999-2010. October 2010 <http://recession.org/history/1970s-oil-crisis>.

Rowe, Marnie. The Energy Crisis. 24 March 2003. October 2010 <http://www.harwich.edu/depts/history/HHJ/rowe.html>.

Sanders, B. Summary of the Ten Million Solar Roofs Act of 2010 (S.3460). July 2010. August 2010 <http://sanders.senate.gov/newsroom/news/?id=818d405d-b23e-4067-944c-dc224410624a>.

Sanders, Bernard. The Hill's Congress Blog: Introducing the Ten Million Solar Roofs Act. 10 March 2010. August 2010 <http://thehill.com/blogs/congress-blog/energy-a-environment/85941-introducing-the-ten-million-solar-roofs-act-sen-bernard-sanders?page=2#comments>.

Sandia National Laboratories. Concentrating Solar Power. 2009. June 2010 <http://www.sandia.gov/csp/cspoverview.html>.

SCE. Solar Rooftop Program. 2010. September 2010 <http://www.sce.com/solarleadership/solar-rooftop-program/>.

SEIA "Transmission". "Transmission Policy for Solar Generation: Green Power Superhighways: A 21st Century Solution." 15 May 2010 . Solar Energy Industries Association. November 2010 <http://www.seia.org/galleries/FactSheets/Factsheet_Transmission.pdf>.

SEIA "Water". "Utility-Scale Solar Power: Responsible Water Resource Management." 18 March 2010. Solar Energy Industries Association. October 2010 <http://www.seia.org/galleries/FactSheets/Factsheet_Water_Use.pdf>.

Smith, S.E. What are rolling blackouts? 9 September 2010. October 2010 <http://www.wisegeek.com/what-are-rolling-blackouts.htm>.

SNL. Concentrating Solar Power. 2009. October 2010 <http://www.sandia.gov/csp/cspoverview.html>.

Solar Buzz "Tech". Solar Cell Technologies. 2010. October 2010 <http://www.solarbuzz.com/Technologies.htm>.

Solar Buzz. Distributed Generation. 2010. October 2010 <http://www.solarbuzz.com/DistributedGeneration.htm>.

Solar Power Authority. Colorado Solar Incentives. January 2008. October 2010 <http://solarpowerauthority.com/colorado/>.

SolarPaces. CSP- How it Works. July 2010 <http://www.solarpaces.org/CSP_Technology/docs/solar_dish.pdf>.

Stickler, Greg. Solar Radiation and the Earth System. October 2010 <http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/science-briefs/ed-stickler/ed-irradiance.html>.

Sukhatme, S.P. Solar Energy: principles of thermal collectiona and storage. West Patel Nagar: Tata McGraw-Hill Publishing Company Limited, 1996.

Sunpower. SUNPOWER ANNOUNCES NEW WORLD RECORD SOLAR CELL EFFICIENCY. 23 June 2010. October 2010 <http://investors.sunpowercorp.com/releasedetail.cfm?ReleaseID=482133>.

SunRun. Lost in Transmission: Why does our electricity grid lose energy? 13 January 2010. November 2010 <http://www.sunrunhome.com/blog/2010/01/transmission/>.

SWEEP. "Colorado Fact Sheet: Energy Efficiency and Energy Consumption." July 2009. Southwest Energy Efficiency Project. October 2010 <http://www.swenergy.org/publications/factsheets/CO-Factsheet.pdf>.

Tester, Jefferson W. Energy Systems and Sustainable Metrics. Cambridge: MIT, 2005.

Therein, Scott. Distributed Generation: Issues Concerning a Changing Power Grid Paradigm. Master's Thesis. San Luis Obispo: California Polytechnic State University`, 2010.

Time. Business: Oil Squeeze. 5 February 1979. October 2010 <http://www.time.com/time/magazine/article/0,9171,946222-1,00.html>.

U.S. Census Bureau. Fact Finder. 2008. July 2010 <http://factfinder.census.gov/servlet/ACSSAFFFacts?_event=Search&geo_id=&_geoContext=&_street=&_county=Grand+Junction&_cityTown=Grand+Junction&_state=04000US08&_zip=&_lang=en&_sse=on&pctxt=fph&pgsl=010>.

U.S. EIA. Petroleum. 29 July 2010. August 2010 <http://www.eia.gov/oil_gas/petroleum/info_glance/petroleum.html>.

U.S. Government. "Major Orders and Regulations." 3 January 1992. Federal Energy Regulatory Commission. October 2010 <http://www.ferc.gov/legal/maj-ord-reg/epa.pdf>.

U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations." 2004.

UNH. University of New Hampshire Cooperative Extension: Environmental Impact Statements: An Introduction. February 2003. August 2010 <http://extension.unh.edu/CommDev/articles/IntrEIS.pdf>.

Union of Concerned Scientists. Environmental Impacts of Renewable Energy Technologies. 1992. August 2010 <http://www.ucsusa.org/clean_energy/technology_and_impacts/impacts/environmental-impacts-of.html>.

USAid. "EPAct of 1992 Subtitle F - Federal Agency Energy Management." 1992. USAid. October 2010 <http://www.usaid.gov/policy/ads/500/epactof1992_subtitlef.pdf>.

USGS. Mercury in the Environment. 19 February 2009. October 2010 <http://www.usgs.gov/themes/factsheet/146-00/>.

Utah Geological Survey. "Solar Radiation Data." 2010. Utah.gov. September 2010 <http://geology.utah.gov/sep/renewable_energy/solar/radiation.htm>.

Weather Channel. Averages & Records for Grand Junction, CO. 2010. July 2010 <http://www.weather.com/weather/climatology/monthly/USCO0166>.

Williams, James L. WTRG Economics: Oil Price History and Analysis (Updating). 2009. October 2010 <http://www.wtrg.com/prices.htm>.

Wiser, Wendell H. Energy Resources: Occurrence, Production, Conversion, Use. New York: Springer-Verlag New York, Inc., 2000.

Xcel Energy. About Xcel Energy. 2009. July 2010 <http://www.xcelenergy.com/Colorado/Company/AboutUs/Pages/Temp.aspx>.

—. Cameo Station. July 2010 <http://www.xcelenergy.com/Colorado/Company/About_Energy_and_Rates/Power%20Generation/ColoradoPlants/Pages/CameoStation.aspx>.

—. Colorado Integrated Solar Project. 2010. July 2010 <http://www.xcelenergy.com/Colorado/Company/Environment/CO-Innovative-Clean-Technology/Pages/ColoradoIntegratedSolarProject.aspx>.

—. Solar*Rewards. 31 October 2009. July 2010 <http://www.xcelenergy.com/Colorado/Residential/RenewableEnergy/Solar_Rewards/Pages/home.aspx>.

Zizzo Allan. Rooftop Solar Program: Barriers & Opportunities with Rooftop Solar in the Pearson Eco-Business Zone. Toronto, 2010.