Rooftop Solar Photovoltaics: The Untapped Potential of Commercial and Industrial Buildings

An exploration of resource capacity, financial feasibility, and policy for increased implementation in Minneapolis and Minnesota

MURP and MPP Capstone Paper

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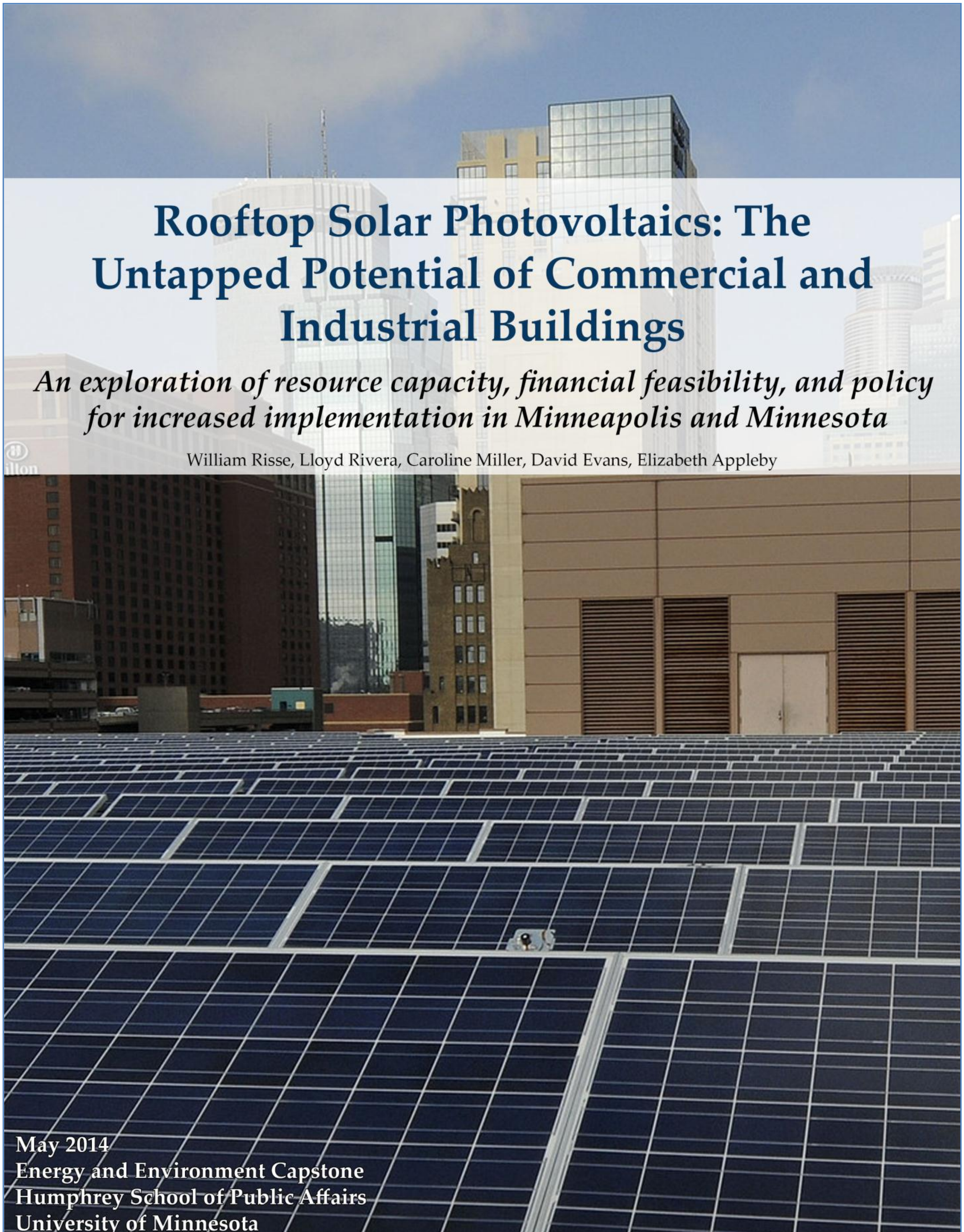

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Cover Photo Source: Richard Sennot, *Star Tribune*. May, 2014.

Abbreviations

C&I = commercial and industrial

EIA = U.S. Energy Information Administration

kW = kilowatt

kWh = kilowatt hour

MACRS = Modified Accelerated Cost Recovery System

MW = megawatt

PPA = power purchase agreement

NPV = net present value

PUC = Minnesota Public Utilities Commission

PV = photovoltaic

VOS = value of solar

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1 Introduction

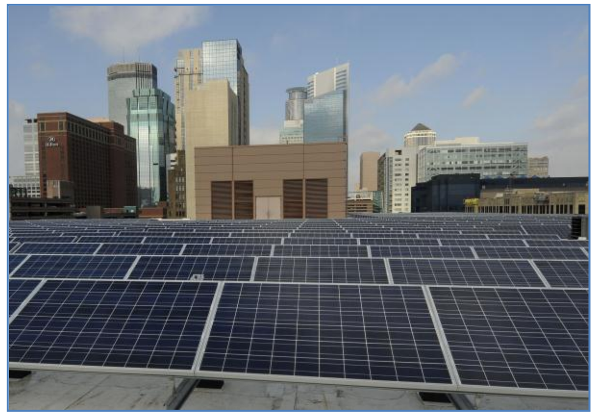


Figure 1. The Minneapolis Convention Center is one example of Minneapolis efforts to transition towards renewable energy. Source: *Star Tribune*

Local and state governments are transitioning to cleaner, renewable forms of energy through policy changes and incentives in the absence of comprehensive federal legislation. The City of Minneapolis is no exception, encouraging increased renewable energy through the Minneapolis Comprehensive Plan (2009), functional Climate Action Plan (2013) and in commissioning the recent report "Minneapolis Energy Pathways: A Framework for Local Energy Action," hereafter referred to as the Energy Pathways Report (Bull et al., 2014). In the Climate Action Plan (2013), Minneapolis set goals to produce 10% of its electricity from directly purchased or local renewable energy sources by 2025, and to achieve a 30% reduction in greenhouse gas emissions by 2025 (from 2006 levels). One of the ways that Minneapolis can reach these goals is by utilizing the untapped resource of commercial and industrial (C&I) rooftops for solar photovoltaic (PV) arrays. Figure 2 shows a diagram of how solar PV panels convert energy from the sun, and the distribution path of that energy to electric utilities and consumers.

This report focuses on how Minneapolis can encourage rooftop solar PV installations on C&I buildings. The report assesses the profitability of large scale solar PV installations in Minneapolis (over 40 kW), and their application to greater Minnesota. The report is divided into four major sections. The first section contains a brief overview on solar PV in the context of Minnesota, discussing the policies and incentives that have spurred recent and renewed solar interest with special attention to the current energy and regulatory environment in Minneapolis. Section two analyzes the solar insolation of Minneapolis to assess the potential capacity of rooftops in the city. Section three analyzes the financial feasibility of these large scale solar systems through an analysis of existing net metering and multiple value of solar rate structures. The fourth section applies the solar insolation and financial feasibility results to land use planning contexts through site specific case studies that identify priority C&I solar installation areas in Minneapolis. Finally, the last section offers recommendations for how the State of Minnesota and the City of Minneapolis can increase solar

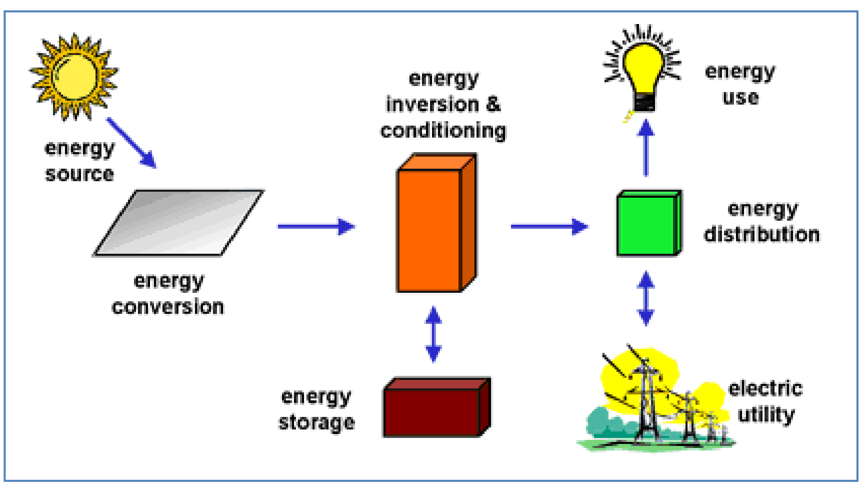


Figure 2. Solar PV technology converts solar energy to electricity available for use by consumers.
Source: Florida Solar Energy Center, www.fsec.ucf.edu

implementation through policies and incentives.

This report is intended to provide policy makers, business owners, solar installers, planners, and other stakeholders with a better understanding of how C&I solar installations can increase solar generation in Minneapolis and the greater state area. The report identifies solar capacity, analyzes profitability on installations in a changing market, and suggests policy changes and incentives to increase the uptake of solar PV by the C&I customer class. Ultimately, the results provide another pathway to help the City of Minneapolis achieve its energy goals.

Electricity market analysts identify solar photovoltaic technology (PV) as a viable local renewable energy resource with great potential. Module prices "fell by $2.6/W from 2008 through 2012 (based on average annual selling prices)", and non-module related installation costs have also declined significantly since 1998 (Barbose, Darghouth, Weaver, & Wiser, 2013 p.1). Figure 3 shows this price reduction trend. The Minnesota Public Utilities Commission (PUC) has also publicly supported the myriad of benefits that solar energy offers. In a landmark ruling in January 2014, Judge Eric Lipman found that a solar energy proposal by Geronimo Energy had sufficient advantages to win out competing natural gas proposals (Shaffer, 2014). The case came about when Xcel Energy reviewed multiple proposals for a utility scale project. The solar energy proposal from Geronimo Energy was found to have competitive advantages when compared to competing proposals powered by natural gas. In late March 2014, the PUC approved Geronimo's project to build $250 million in solar arrays in Xcel's service territory throughout the state (Doyle, 2013).

Despite the decreasing costs of solar, federal and state incentives play a significant role in solar implementation. The already low cost of electricity in the Minneapolis market reduces cost savings motivations for installing solar panels. The residential charge from June to September is currently $0.08671 per kWh, while the non-residential general service energy charge is $0.02981 per kWh, and demand charge is $12.86 per Month per kW from June to September (Xcel 2013b).

It is not surprising that Minneapolis only has 2.12 MW of solar PV installations as of 2012 (Energy Pathways 2014). Financial incentives for solar PV implementation exist at the federal and statewide (or Xcel service territory) levels. The federal Solar

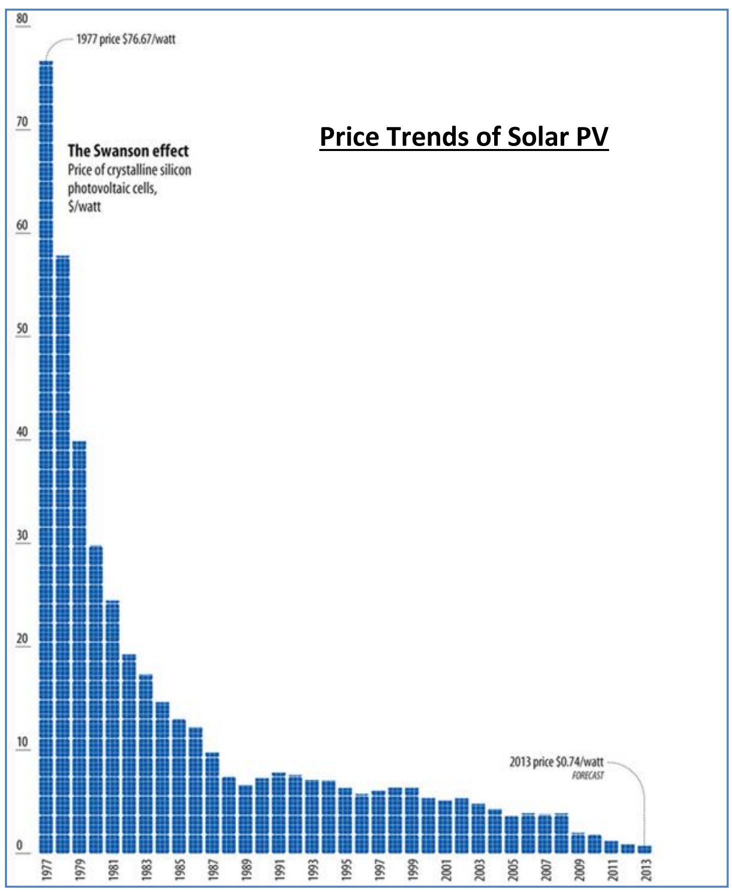


Figure 3. The price of solar PV has dropped over time, and this trend will likely continue.
Source: Bloomberg New Energy Finance

Investment Tax Credit (ITC) has no cap, but statewide incentives Made in Minnesota and Minnesota Solar*Rewards are capped at 20kW and 40kW, respectively. Small installations are an important addition to the energy mix, but the continued focus on these solar systems has overshadowed the potential for much larger capacity, higher producing solar installations on C&I buildings (see Chapter 3 for a more detailed discussion of the Minneapolis context) and done little to address the market barriers faced by larger installations (Abbey & Ross, 2013). C&I customers have some of the largest areas of contiguous rooftop, consume a bulk of the City's electricity, and have traditionally led the way in solar PV adoption in other states (EIA, 2014a). Rooftops of C&I buildings are an underutilized and financially profitable resource that could help Minneapolis to increase its solar capacity.

This report focuses on the technical issues, and to some extent political issues, of the evolving solar PV industry. While social considerations that are inherently connected with how we produce and consume electricity are important, they were intentionally left out of this technical analysis. This report assumes that increased C&I solar PV adoption within the City of Minneapolis is decidedly good, an assumption that is not universal to all parties.

Figure 4. Solar panels on the roof of IKEA in Bloomington, Minnesota.
Source: inhabitat.com

2 Minnesota Solar PV Context

While the City of Minneapolis has set ambitious renewable energy goals, it operates under recent statewide mandates for increased renewable energy. Minnesota passed the Next Generation Energy Act in 2007, establishing itself as a leader in the United States for the promotion and adoption of renewable energy. Wind energy has produced the bulk of this clean energy transition, but recent statewide legislative and policy decisions have focused on solar PV technologies. Figure 5 shows the spike in Minnesota solar PV. Pursuant to Minn. Stat. 216B.1691, all utilities must produce 1.5% of their electricity from solar energy sources by 2020. The state also passed new rate structure legislation in 2014 that encourages solar production, and mandated that Xcel Energy develop plans for community funded solar gardens. The sections that follow provide an overview of federal, state, and city legislation pertinent to solar PV promotion.

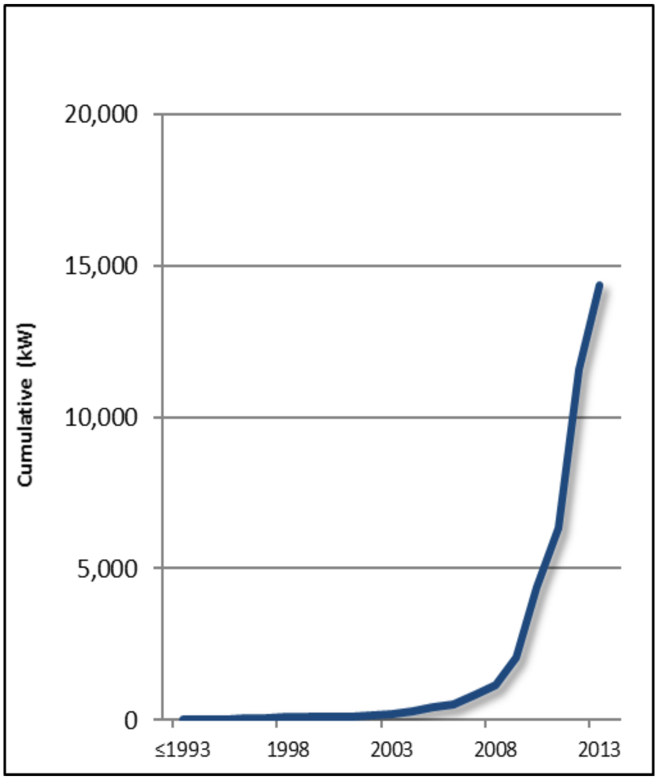


Figure 5. Cumulative PV (kW) in Minnesota.
Source: Minnesota Department of Commerce, Division of Energy Resources 2014

2.1 Federal Legislation for Solar PV

Federal tax breaks and incentives are important to Minnesota solar PV implementation because they can significantly increase the profitability of a solar installation. The Solar Investment Tax Credit gives a credit up to 30% of the cost for solar installations on residential and commercial properties. There is no capacity limit on the credit, and it remains in effect until 2016. In lieu of taking the tax credit, property owners may elect to receive a tax deduction called a Modified Accelerated Cost Recovery System (MACRS) for infrastructure investment depreciation.

2.2 State Legislation for Solar PV

State incentives and legislation have historically focused on small solar installations under 40kW. In order to understand incentives that can be applied to large installations, it is key to also grasp these small-scale incentives. It is possible that small-scale incentives, or some variant of them, could be expanded to larger installations in the future.

Minnesota enacted a statewide renewable portfolio standard in 2007 as part of the Next Generation Renewable Energy Act. The act plays a huge role for the future of solar, and lays out specific legislation and standards that affect solar installations. The legislation mandated 20% of public utility electricity sales to come from renewable energy sources by 2020, and 25% from renewable energy sources by 2025 (Eleff, 2013). Xcel Energy is required to obtain 30% of its electricity from renewable sources by 2020. Solar energy is a sub-category of renewable energy. Table 1 on p.5 summarizes state solar PV legislation.

Table 1. Legislative statutes for solar PV and renewable energy in Minnesota.

Law Component	**Capacity Limits**	**Applies To**	**Timeframe**	**State Statute**
20% from renewable energy by 2020, 25% from renewable energy by 2025	-	Public utilities except for Xcel	Deadlines of 2020 and 2025	State of MN Renewable Energy Standard
30% from renewable energy by 2020	-	Xcel Energy	Deadline of 2020	State of MN Renewable Energy Standard
1.5% of electricity sales from solar energy by 2020 (Separate and above MN's existing RES)	At least 10% must be generated by facilities with capacity 20 kW or less	Public utilities. Excludes retail sales to mining, paper, wood product industries	Deadline of 2020	Minn. Stat. 216B.1691
"Made in Minnesota" Solar Incentives	Must be 20 kW DC or less	Evenly split between residential and commercial properties	2014 thru 2023	Minn. Stat. 216C.422 to 216C.415
Xcel Energy Solar Incentive Program	Must be 40 kW DC or less and generate less than 120% of customer's electricity	Xcel service area	2014 thru 2018	Minn. Stat. 116C.7792
Xcel Energy Community Solar Garden	1 MW limit; subscriptions must be at least 200 watts and not exceed 120% of subscriber's electricity	Xcel Energy	Xcel Energy must submit plan for community solar garden by 9/ 30/2013	Minn. Stat. 216B.1641

In 2013, additional state legislation created a 1.5% solar energy standard for investor owned utilities (*MN 216B.1691 Renewable Energy Objectives*, 2013), who generate about two-thirds of electricity sales in Minnesota. Facilities with a capacity of 20 kW or less must generate at least 10% of the solar electricity. The 2013 state solar legislation also allows utilities to pay solar power generators at a rate equating to their "value of solar," which takes into account additional criteria like the avoided cost of fuel for utilities and decreased emissions. Prior to this law, the PUC set the reimbursement rate set based upon the average retail electricity rate (Eleff 2013).

2.2.1 Financial Incentives: Solar Rewards

In addition, Xcel Energy is required to fund a Solar Rewards program, which sets aside incentives of $5 million annually for the next five years, to be paid out over the next ten years. The incentives encourage solar installations within Xcel Energy's service area. Eligible systems must be 20 kW DC or less, and generate less than 120% of the customer's electricity (Xcel Energy, 2014b).

2.2.2 Financial Incentives: Made in Minnesota

The state legislature also passed incentive legislation and requirements specifically for Xcel Energy. The "Made in Minnesota" component of the 2013 state legislation sets aside incentive funding for owners who buy solar devices manufactured in Minnesota. Solar devices must be less than 20 kW in capacity. The program budgets $15 million per year for the next ten years.

The state of Minnesota has two solar panel manufacturers, tenKsolar in Bloomington and Silicon Energy in Mountain Iron. Both companies look to benefit from the "Made in MN" legislation.

2.2.3 Community Solar Gardens

In 2013 additional legislation was passed that required Xcel Energy to develop plans for community solar garden projects up to one MW (*MN 216B.1691*). Minnesota joins eight other states with community solar legislation (Hoyem 2013). Minnesota law states that a solar garden is, "a facility that generates electricity by means of a ground mounted or roof mounted solar photovoltaic device whereby subscribers receive a bill credit for the electricity generated in proportion to the size of their subscription" (*MN 216B.1691*, 2013).

Community solar projects are a way for customers to buy into solar energy production without installing their own panels. It is an especially appealing option to renters and property owners with rooftops that are not in the best location for solar installations. Community solar is also less expensive than traditional onsite installations since subscribers because you can subscribe to smaller increments of a of project and also can benefit from the economies of scale created by larger community solar projects.

The first announced community solar garden in Xcel's service territory will be on the roof of Northern Sun Merchandising in Minneapolis. Subscriptions for the Northern Sun project have sold out, and the panels will be placed later in 2014 (Shaffer 2014). The array will have a capacity of 39 kilowatts. Northern Sun is a commercial property, and may be a model for other commercial buildings in Minneapolis.

2.2.4 Tax Breaks

The State of Minnesota has enacted tax exemptions for solar energy. Since 2005, solar PV system purchasers do not have to pay sales tax (*MN 297A.67, Subd. 29*). The sales tax exemption has no expiration date. Solar installations on commercial, industrial, and residential properties are also exempt from property taxes (*MN 272.02*). The exclusion of solar PV from property tax calculations have been in effect since 1992.

2.3 Commercial and Industrial Solar PV Market Context

The incentives listed above continue to promote solar PV adoption in Minnesota, but their focus on smaller installations often fails to motivate larger C&I customers to invest in solar arrays. These unused C&I rooftops provide an overlooked opportunity for solar generation. C&I buildings typically have large parcel sites, are one to two stories tall, and provide large contiguous rooftop spaces ideal for solar installations. In the United States, C&I customers are responsible for about 40% energy use, and make up much of the profit to energy utilities (EIA 2014b). These customers can capitalize on the economies of scale that are available for larger installations. Companies such as Costco, Kohl's, Walmart, Apple, IKEA, Macy's, Staples, U.S. Foods, Johnson & Johnson and Target have developed PV projects in California, Arizona, North Carolina, and several other states. The installed capacity of these ten organizations is about 310 MW nation-wide (Schneider, Burr, & Ouzts, 2014).

There is a significant disparity in PV energy adoption among customer classes and sizes of arrays. In 2013, Minnesota had 1,553 solar installations connected to the grid, only seven of which were larger than 100 kW. Solar PV arrays larger than 100kW represent less than 1% of the total installations in Minnesota (Trudeau 2014).

To successfully encourage C&I customers to install solar PV, policy makers can benefit from understanding their motivations as compared to other customers. Technology adoption in the consumer market (residential energy consumers), is led by word of mouth and social recognition (Fishbein & Ajzen, 1975; Lee & Connor, 2003). Alternatively, solar PV implementation by the C&I sector is pushed by reductions in energy costs (Mills *et al.* 2008) and responses to regulatory and market incentives (Suzi and Newefll, 2003). Since low energy costs in Minnesota do not encourage solar energy adoption in the C&I sector, corporate sustainability, green building goals, corporate image, long-term hedging against increasing utility rates, and marketing differentiation have thus far been the primary drivers to solar implementation (Abbey & Ross, 2013). Not surprisingly, Minneapolis C&I customers have been timid on their solar PV investments.

2.4 Challenges to Solar Implementation in Minnesota

Commercial, industrial, mixed use, and institutional rooftops compose approximately 3.3 square miles of the City of Minneapolis. This accounts for nearly 6% of the City's area. These rooftops are mostly flat and open.

Minnesota has climate, policy, and market challenges to solar PV implementation. Solar panels only produce electricity when the sun shines, leading to lower levels of electricity production during shorter winter days. Snow also blocks solar panels, and requires removal for the panels to continue generating electricity in winter. Minnesota's climate is an environmental obstacle, but some locations receiving similar levels of sun exposure and snow (e.g. Germany, New Jersey, and Massachusetts) currently have more installed solar capacity than Minnesota (EIA 2014a).

Minnesota also faces policy challenges to solar energy. The state has legislation preventing the creation of large scale solar leasing businesses. Solar leasing and power purchase agreements (PPA) are the preferred scheme to implement PV systems by many customers, including the C&I sector (Mills et al. 2008).

In addition, there are few incentives to decrease the high up-front investment costs to install a large solar PV array. Most existing incentives are for smaller, residential-scale solar PV. The C&I sector, which usually has larger PV arrays, has fewer options to offset high installation costs.

Furthermore, electricity in Minnesota is comparatively cheap than in many other states where solar has been more prolific. Minnesota's average price per kWh across all customer classes in 2013 was $.0915. Compare that with California's rate of $0.133 or Massachusetts's rate of $0.140 per kWh (EIA 2014b). Minnesota's lower electricity prices decrease the comparative costs savings advantage offered by solar PV generated electricity that exists in many other states. Notwithstanding other incentives, the higher electricity prices in other states lead to higher rates of solar deployment.

3 Minneapolis Solar PV Context

The City of Minneapolis recognizes the short-term and long-term benefits of renewable electricity generation, and has adopted aggressive climate action goals. Two goals are particularly relevant to our study: (1) Reducing GHG emissions 15% by 2015 and 30% by 2025 from 2006 levels, and (2) Produce 10% of its energy from local or directly purchased renewable energy sources by 2025 (Climate Action Plan, 2009).

Two reports provided important insight into the City's future energy goals that we will continue to revisit throughout this report: (1) The Minneapolis Climate Action Plan that encourages increased renewable energy adoption, and (2) the Energy Pathways Study (2014), which provides recommendations for Minneapolis's future energy options as it renegotiates its franchise agreement with Xcel Energy over the next year. Table 2 summarizes key goals from these documents pertinent to this study.

Table 2. Existing strategies for renewable energy in Minneapolis

Climate Action Plan Strategies (2013)	Energy Pathways Study Next Steps (2014)
1. Support efforts to align utility practices with City and State renewable energy policy.	1. Renew the City's utility franchise agreement with targeted enhancements.
2. Implement small to mid-sized business renewable and on-site renewable incentive programs.	2. Pursue additional, broader clean energy agreements with utilities.
3. Investigate the feasibility of large-scale renewable energy purchasing for municipal government and/or residents.	3. Develop programs in partnership with the utilities to meet the City's energy sustainability goals.
4. Encourage "net-zero" energy buildings.	4. Continue state energy policy engagement that can improve the City's ability to meet its goals.
5. Support new financing and ownership models for developing Minneapolis' solar resource.	5. Pursue mid- and long-term options for increasing the City's control over its energy future.

3.1 Energy Consumption and Production

In 2012, Minneapolis utility customers consumed approximately 4.25 million MWh of electricity with total costs to customers totaling approximately $373 million (Minneapolis Energy Pathways 2014). Solar PV installations within Minneapolis accounted for 2,118 kW of capacity or 2,700 MWh (0.06% of total energy consumption) consumed annually given average production rates (Minneapolis Energy Pathways, 2014). In comparison, a total of 56,913 MWh (1.34%) of all electricity consumed came from Xcel's Windsource® program. According to the 2012 energy statistics provided in the Minneapolis Energy Pathways report, solar PV installations make up the smallest share of renewable energy sources in the city providing 0.3% of the renewable energy mix (2014).

3.2 C&I Existing Conditions

The sheer size of the C&I customer class by energy use make them a key component in the shift to renewable energy sources such as solar PV. According to the Minneapolis Energy Pathways Study (2014, p.19), "In 2012, the top ten percent of Xcel Energy's commercial and industrial customers in Minneapolis, a total of 1,650 premises, accounted for two-thirds of total electricity use in the city – and 87 percent of all commercial and industrial use." C&I customers also produced 61% of all local renewable energy in 2012, even though there were fewer individual installations compared to residential customers (Minneapolis Energy Pathways Study 2014, p. 66) (see Figure 6). These C&I customers, in spite of low adoption rates and lackluster incentives, still managed to outperform residential customers in renewable electricity production levels. The largely untapped resource of C&I properties warrants more attention from solar advocates if Minneapolis wants produce more local, renewable electricity.

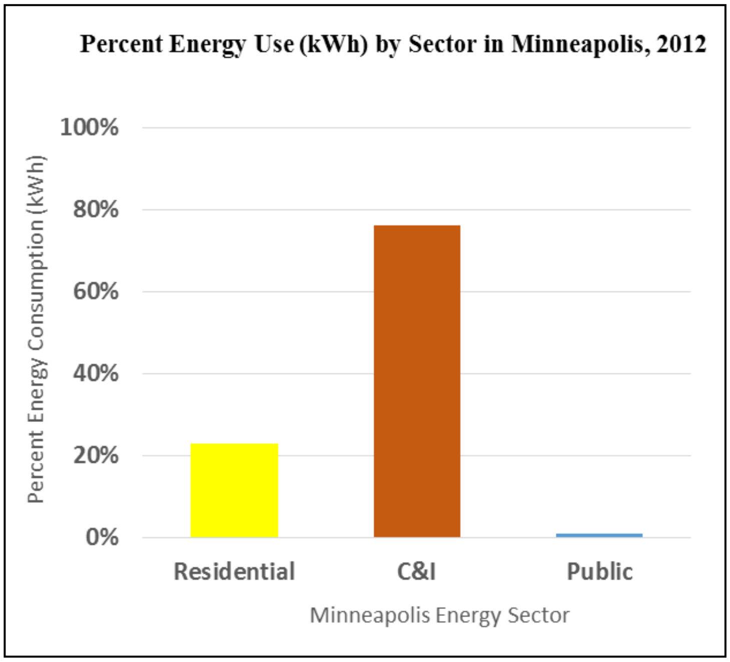


Figure 6. Percent energy use by major sector in Minneapolis

Source: City of Minneapolis Energy Use Data, 2012

3.3 Minneapolis Solar PV Regulatory Structure

The City of Minneapolis has enacted ordinances specific to solar energy (*MN 535.820 - 535.870 Minneapolis Code of Ordinances*, 2014). They are summarized in Table 3. The ordinances specifically allow all districts to permit solar energy systems, as long as they comply with minimum yard requirements. The ordinances also give some guidelines for installations—building-mounted systems cannot be over three feet above the roof, and must be one foot from the edge of the roof. Flat roofs or sheds can have mounted solar systems up to ten feet. Freestanding solar systems may not be more than 20 feet, or higher than the principal building structure.

In addition, the City of Minneapolis has adopted an expedited permitting process for solar energy systems. The City has fifteen days to review permits, and has a permit checklist to make the process easier for applicants. While the expedited permit process is a best practice for encouraging solar implementation, it is one of many strategies that could be used to reduce the soft costs and market barriers for solar PV installations.

The City has taken steps to protect solar resources through the voluntary purchase of solar access easements. This policy allows any property owner to purchase easement access across nearby properties to protect sunlight access. Easements may apply to buildings, trees, or other structures that would block solar access. This easement type has been underutilized, but may become more important in the future when there are a greater numbers of installed solar arrays.

Table 3. Solar energy statutes for the City of Minneapolis.

Law Component (Minneapolis Chap. 535.829 to 535.870)	**Details**	**Eligibility requirements**
Solar energy systems permitted in all zoning districts	Building-mounted systems cannot be over 3 feet above the roof (over 10 feet if a flat or shed roof), and must be at least 1 feet from the edge of the roof. Freestanding solar systems cannot be higher than 20 feet or larger than the principal structure.	Must comply with minimum yard requirements of districts. Screening of solar collector surfaces may not be required.
15 days to review solar energy system permit applications	Based on a model standard to incentivize solar installation.	
Solar access easements may be filed	Applies to building, trees, other structures that would block access to solar.	Any property owner can purchase easement across nearby properties to protect sunlight access.

4 Spatial Analysis of C&I Solar PV Capacity

One of the first steps to understanding the extent to which C&I rooftops can contribute to increased local renewable energy is to calculate their total solar PV capacity. Using a Geographic Information System (GIS) based analysis, we mapped solar capacity using LiDAR, aerial imagery, building footprints, and a solar insolation modeling tool. We then calibrated the model output data using kWh data from the Minneapolis Convention Center, which currently has a solar rooftop PV installation. This methodology has the potential of being used in other cities, and technical details of the analysis are outlined in the Appendix.

Data from this project is available by request. Email hhhsolar2014@umn.edu to access GIS datasets and models of analysis steps.

An ArcGIS online map showing the top 2000 buildings for solar PV is available at http://bit.ly/1kBZCBT

4.1 Spatial Analysis Methodology

Step 1: Create Insolation Model

We created a model of the "surface" of Minneapolis using LiDAR data. In LiDAR, a laser from an airplane rebounds off whatever material it hits first (e.g. the ground, a tree, or a building rooftop). After rebounding, the plane picks up the returning signal and records the elevation. The image resulting from this process is known as a digital surface model, and it shows the highest elevation above ground level.

Interested in doing a similar analysis?
U-Spatial is creating a statewide insolation model. This will eliminate the need for all processes in Step 1 of this report.

ArcGIS has an "area solar radiation" tool that can be used to identify areas of sunlight and shade and the energy those areas produce using inputs from the digital surface model. The "area solar radiation" tool creates what we will refer to as a "solar insolation model". The tool uses the input from the digital surface model, as well as other inputs to display amount of sunlight penetration. The digital surface model accounts for elevation differences, and shows more shaded regions as receiving less solar energy. A subset of the final solar insolation model is shown in Figure 7. It represents the total amount of energy that could be produced per unit of area if all of the sun's energy could be harnessed for electricity use in one year for Minneapolis.

To assess the accuracy of the solar insolation model, we compared our results for Minneapolis with NREL data. The average kWh/m^2/day for the yearly insolation model was 1.97. The NREL calculation estimated between 4.5-5 kWh/m^2/day (see Figure 8). This difference is because NREL only accounted for atmospheric variation. However, the digital surface model accounts for shadowing and surface obstacles of adjacent pixels. Additionally, only direct sunlight is measured using the Area Solar Insolation tool. This means that shadowed areas have lower values than NREL data, and decrease the average across the surface of Minneapolis. Variation can also be seen across months. For July, the highest average insolation was 3.65 kWh/m^2/day, and December had a high of only 0.28 kWh/m^2/day. July matches more closely with the NREL model than December. This is due to the higher sun angle reaching areas that are heavily shadowed during winter months. More detailed information on these calculations can be found in the Appendix.

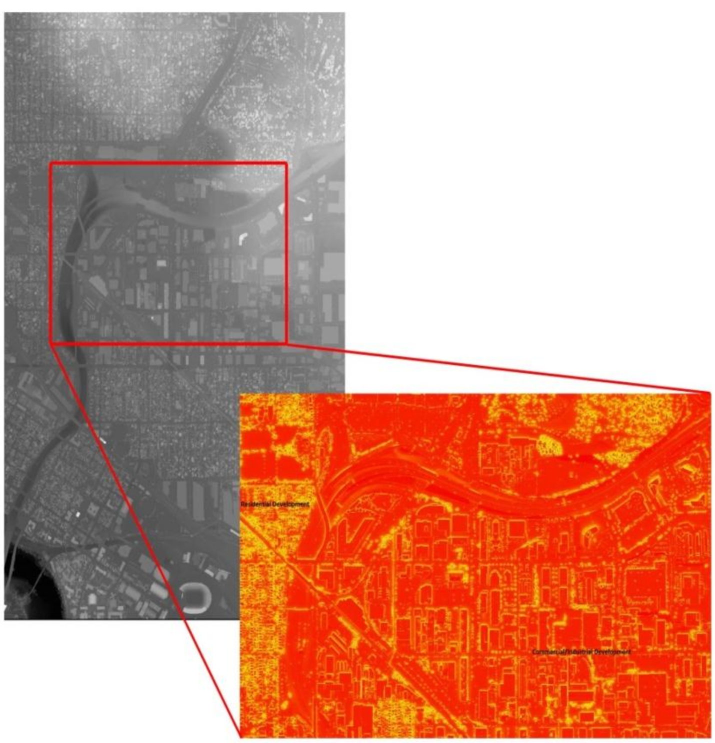


Figure 7. The Digital Surface model was used as the primary input to create the Solar Insolation Model.

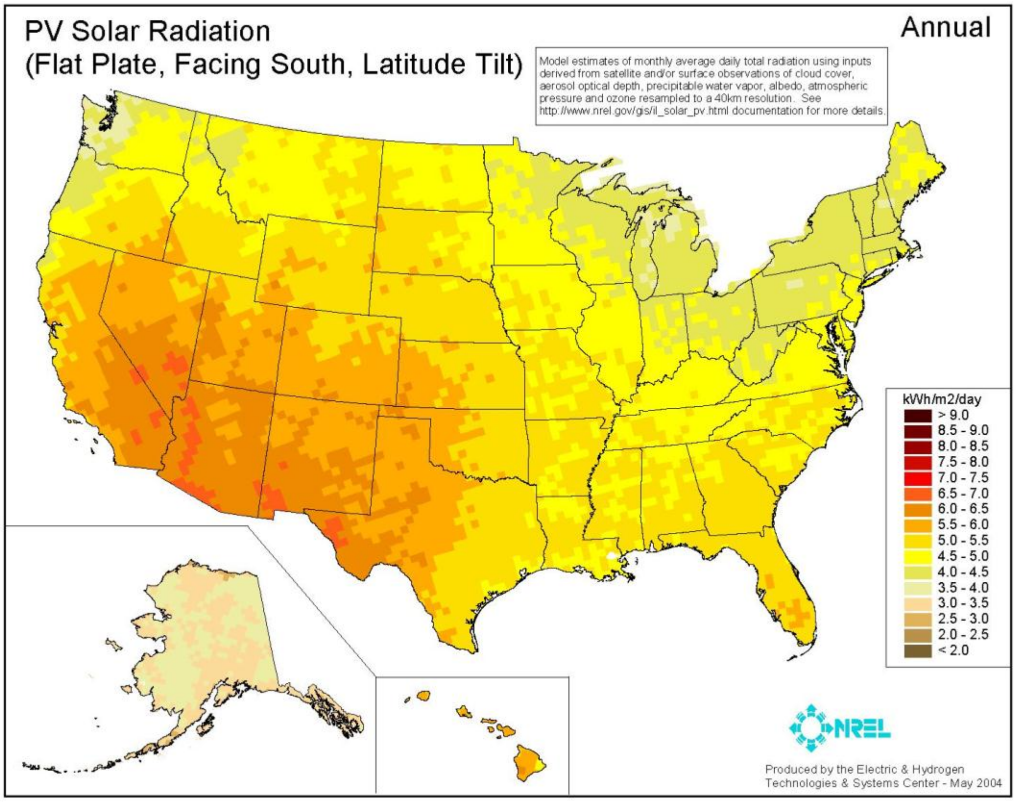


Figure 8. Solar Insolation Values as Calculated by NREL.

Step 2: Compare Solar Insolation Model to Real Data

The solar insolation model represents the electricity that could be produced per unit area if all of the sun's incoming energy could be captured by solar panels. Reflected light is not considered in the calculation. This is unrealistic, however, as solar panels cannot harness all of the sun's energy. In addition, solar installations often have unused space between each panel, further reducing the efficiency of the array.

We utilized actual kWh energy production data from the solar panel installation on the Minneapolis Convention Center roof in order to calibrate the solar insolation model results to a more realistic solar potential output. The convention center was installed in 2010 and consists of 2,613 solar PV modules. In total, each module can produce 230 at the system's maximum production, and the entire installation totals 600kW in size. The panels were produced by Siliken Renewable Energy, and are a fixed roof mount system with 30 degree tilt. 1/3 of the panels have a southwest orientation with the remainder facing south (Westwood 2014). Using monthly data from Convention Center solar panels from 2009 to 2013, we compared the average annual energy production to the solar insolation model results. We traced the solar panels in ArcGIS to identify the space they occupied to calculate how much energy was created per unit area in the hypothetical insolation model versus the real-world example of the Convention Center (see Figure 9).

We created a conversion ratio by dividing the Convention Center data by the solar insolation model results. The amount of energy created by the solar PV system at the Convention Center produced approximately 8% of the total potential energy that is predicted by the solar insolation model (see Table 4). We assumed that this ratio approximates what other fixed large scale commercial or industrial installations could produce under similar conditions throughout Minneapolis. Further limitations of this assumption are discussed later in the report. This 8% conversion ratio could then be used to scale the solar insolation model to real-world energy production expectations for rooftop space across the entire City of Minneapolis.

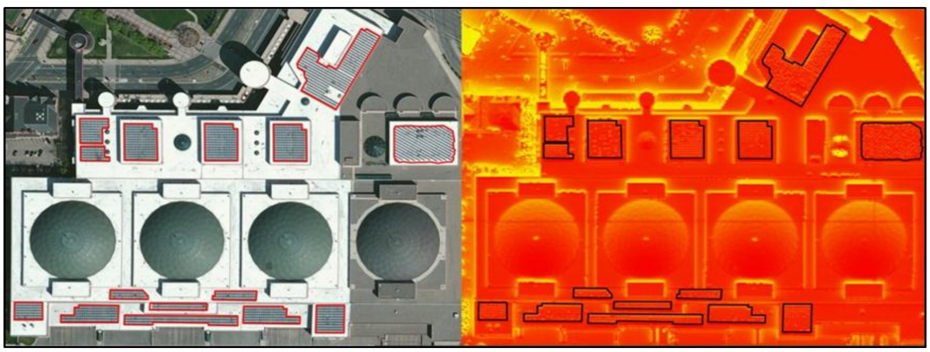


Figure 9. An illustration of the GIS process of aligning real-world Minneapolis Convention Center solar panels with the solar insolation model.

	Energy Production (MWh)
Solar Insolation Modeled Yearly Production	9,156
Actual Convention Center Yearly Production (Average)	735
Conversion Factor (Modeled/Actual)	8.03%

Table 4. Actual vs. Modeled Convention Center Solar Energy Production

Step 3: Identify Solar Potential for Commercial/Industrial/Mixed Use Buildings

The 8% conversion ratio interpolated potential solar energy production of C&I structures across Minneapolis. Using building footprints and the solar insolation model, we calculated the amount of electricity that each building could produce if all of the energy from the sun could be captured by solar panels. This value was then scaled down to estimate production of a solar PV installation through multiplying by the 8% conversion ratio.

The 8% conversion ratio is representative of the efficiency of the entire solar installation. NREL research indicates that cell efficiencies range from 8.6% for emerging PV technologies to 44.4% for the best multijunction cells (NREL 2014). A chart of cell efficiencies from NREL is in the Appendix. There are several reasons for the higher efficiency listed for the cells versus this analysis. First, solar cell efficiency is higher than that of the entire panel. In addition, the rooftop area has some space between cells, meaning that some incoming solar radiation is not captured. With these two factors, it makes sense that the identified conversion ratio is lower than the expected NREL cell efficiency.

Refinements:

The previous steps created rough estimates of useable area on C&I buildings for solar PV installations and potential total solar energy production. However, additional refinements are necessary for a more accurate assessment of roofspace solar capacity.

1) OSHA regulations state that for all C&I solar installations, buildings must have a six foot inward buffer from the edge of the rooftop for worker safety. We added a six foot buffer around the edge of rooftops, and eliminated this area from solar energy production estimates. The initial calculation for the conversion ratio was not affected by this buffer requirement, as only the exact solar panel area was outlined and not the entire rooftop area.

2) Rooftop obstacles further limit the buildable area for solar panels. We identified obstacles through inspection of the digital surface model. We identified areas with a slope of 5% or greater, and reclassified those areas as having 0 production potential. Figure 10 shows the eliminated area on one Minneapolis Rooftop. This step assumed that the majority of commercial and industrial buildings have flat rooftops, thus eliminating sloped areas from the analysis. Strategies for sloped rooftops can be incorporated, and the GIS model outlined in the appendix and available for download has a tool that accounts for south facing slopes.

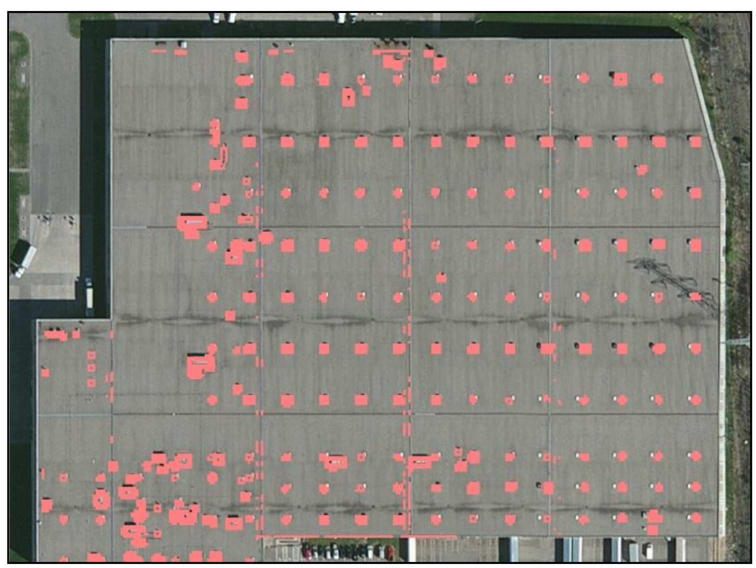


Figure 10. Rooftop area with slope greater than 5 degrees- approximately representative of area unsuitable for solar energy production.

3) Rooftops that did not have the ability to hold installations of at least 5 kW were eliminated from the analysis. These rooftops have very small surface areas, and thus have little value to this report's focus on larger installations. This eliminated a significant amount of rooftop area from the analysis. The entire eliminated area, accounting for each buildings entire footprint equaled 7,766,181 square feet.

Once refinements were in place, potential solar PV capacity of each rooftop was assessed under the assumption that future installations would be similar to the Minneapolis Convention Center's solar PV installation. We calculated the kWh per year and estimated installation size in kW for the Convention Center. The installation size required dividing by 1226, which is the average amount of time that the Minneapolis Convention Center installation was producing energy from 2011-2013. A basic outline of the steps taken to complete this analysis is shown to the left in Figure 11. Further information about the analysis is available in the Appendix, and the data and models from this analysis can be downloaded upon request.

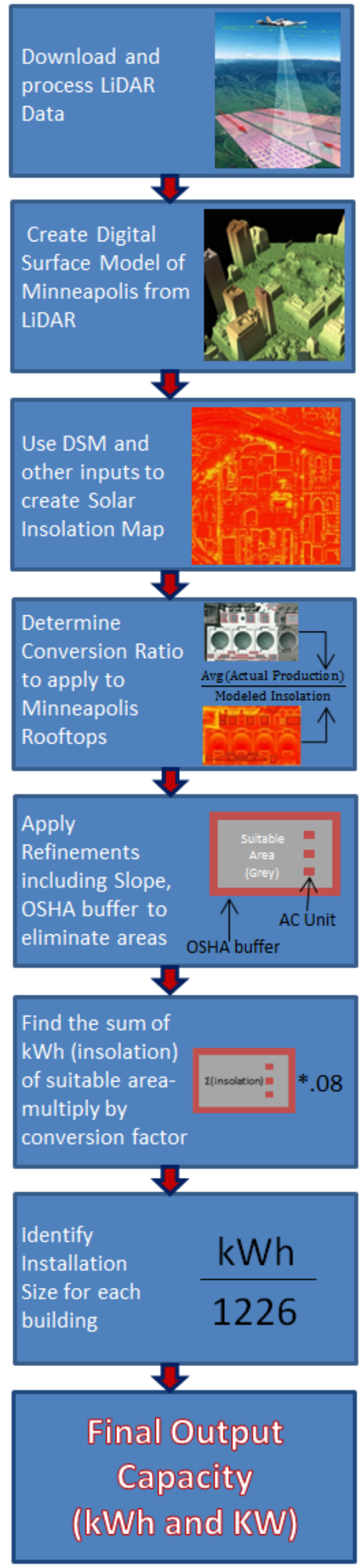


Figure 11. General steps to determine individual and aggregate PV rooftop potential.

Image Sources: http://www.infobarrel.com/Media/What_is_LiDAR_Image
http://blogs.scientificamerican.com/cocktail-party-physics/2012/03/12/l-is-for-lidar/

4.2 Results: C&I Solar PV Capacity in the City of Minneapolis

The GIS analysis showed that the total potential producible energy on Minneapolis commercial, industrial, and mixed use buildings is 364,828 MWh per year, or approximately 8% of Minneapolis energy use in 2012. This equates to a 298 MW installation. This is very much an upper bound of what C&I could produce, as the conversion factor was determined by looking at only the solar panel area of the convention center, and not the entire convention center roofspace. Additionally, the analysis assumes that the entire available area can be used for energy production. In reality, space could likely not be used to its full potential due to installation constraints.

The total building footprint C&I rooftop space is 86,067,165 square feet. Looking at only buildable area (accounting for OSHA buffer and slope), approximately half of the area, 46,180,000 square feet, is suitable for solar panels. This equates to about 154,966 square feet per megawatt if C&I rooftop is utilized to its full capacity.

To address a range of potential solar capacities based upon the uncertainty of the conversion factor, we also investigated the estimated energy production with conversion ratios of 10% and 15%. An increase to 10% or 15% shows what advances in technology and improved PV efficiency could increase energy production. If all solar PV installations had a higher efficiency (conversion factor of 10%), PV units could power approximately 10% of 2012 energy consumption in Minneapolis. If this efficiency increased to 15%, solar PV arrays would provide approximately 15% of Minneapolis energy needs. The solar cell efficiencies in the NREL table in the Appendix indicate that solar panel efficiencies will likely continue to increase. Table 5 shows full results of different conversion factor scenarios.

Table 5. Percent energy needs met by solar solar PV assuming full buildout of C&I rooftop space as a percent of 2012 energy use under various efficiency conditions.

		Conversion Factor			
	2012 PV	8% (Convention Center Ratio)	10% (hypothetical value with improved tech)	15% (hypothetical value with improved tech)	Minneapolis Energy Use (2012)
MWh	2,700	364,828	454,246	681,369	4,538,896
MW	2	298	371	556	3,702
% of Minneapolis Energy Use	0.06%	8%	10%	15%	100%

Figures 12 and 13 on show images of the top 2000 commercial, industrial, and mixed use buildings within the Minneapolis. In all, 3,666 structures can hold installations over 5 kW according to the GIS methodology used, but fewer are represented online due to data limits. The full shapefile can be downloaded upon request by emailing hhhsolar2014@umn.edu The online data highlights the total size of each rooftop, potential yearly kilowatt hours, and estimated installation size. Figure 14 maps the top 100 of these 2000 buildings.

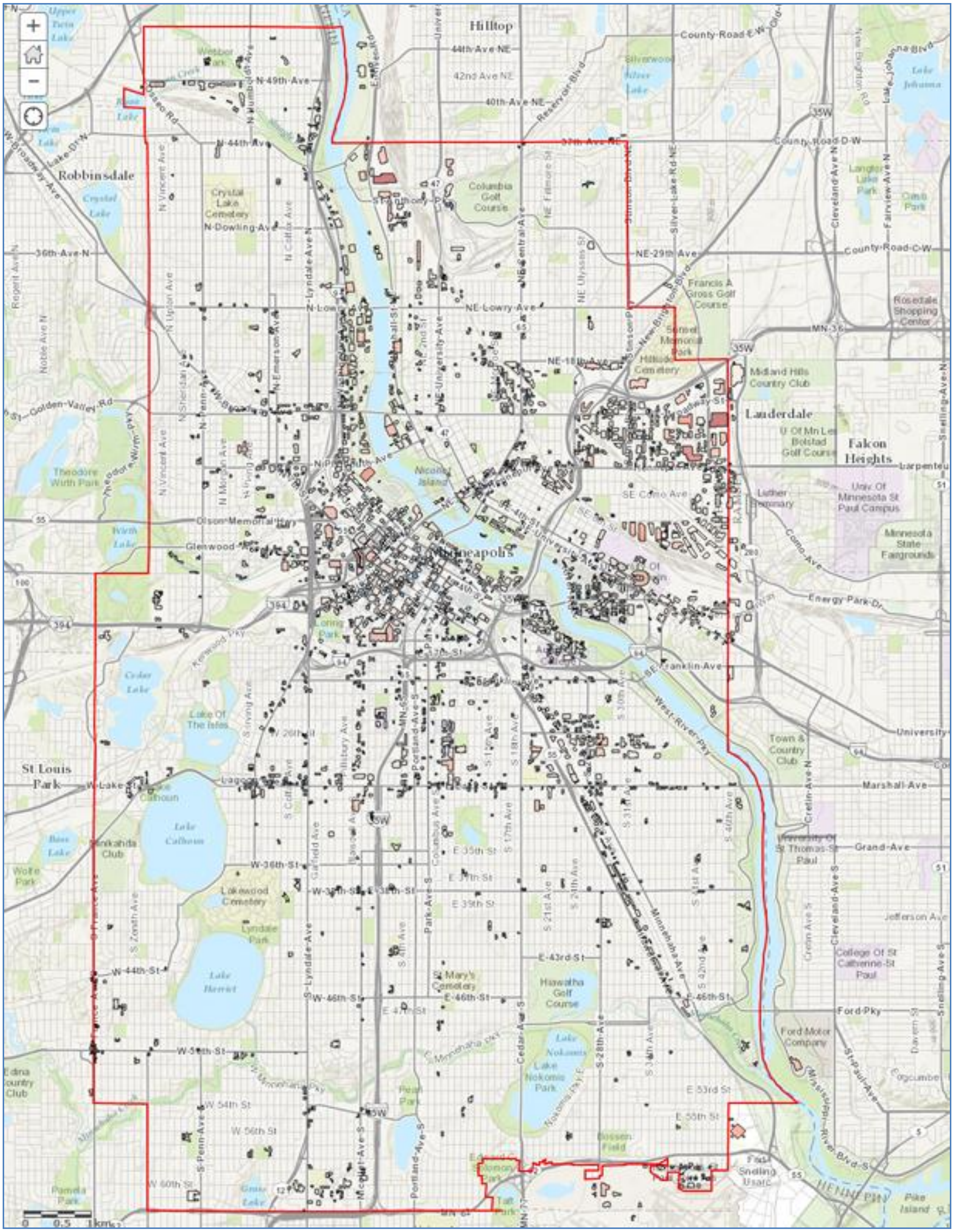


Figure 12. Image of the interactive GIS map showing the top 2000 commercial, industrial, and mixed use buildings for solar capacity in Minneapolis.

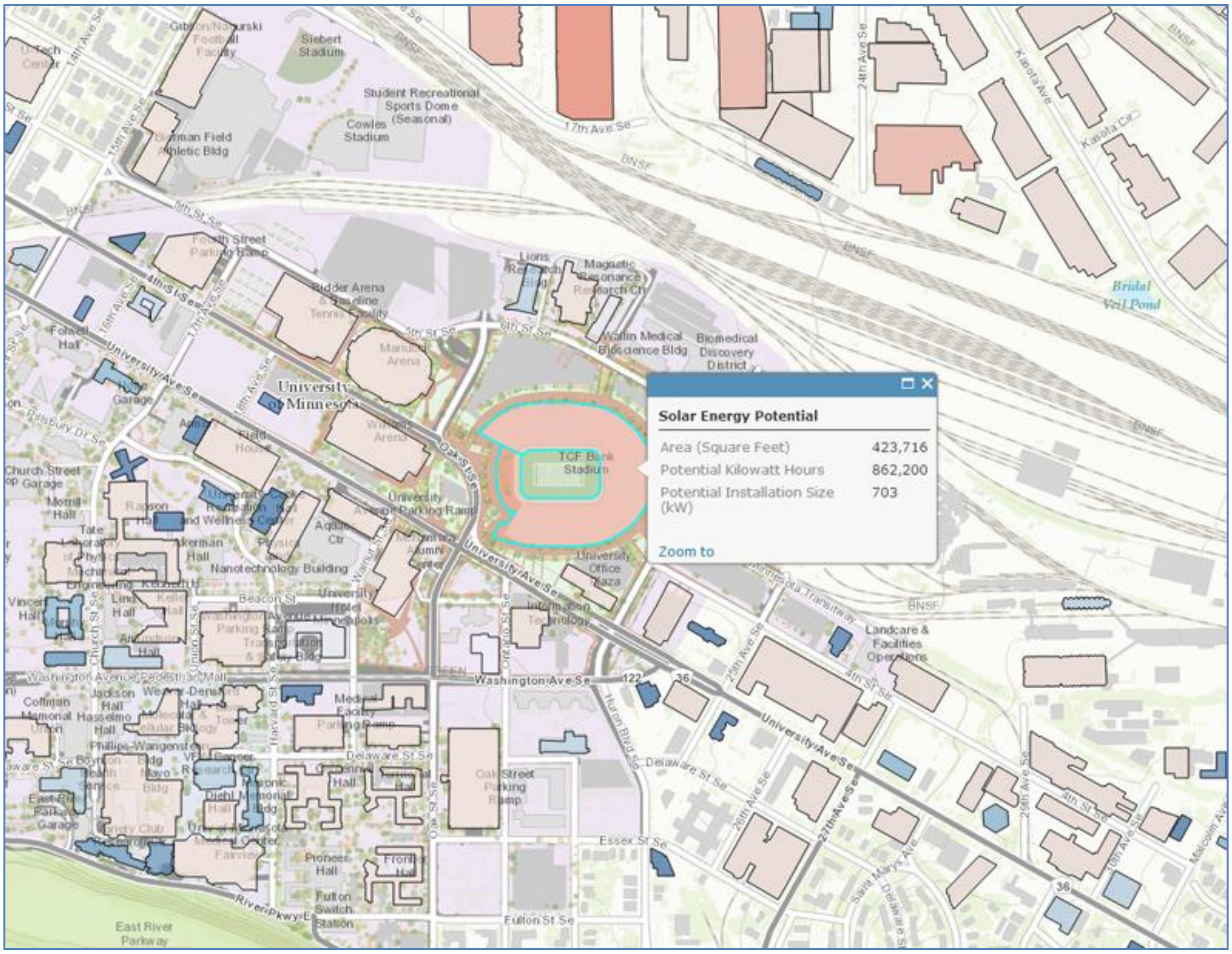


Figure 13. Image highlighting TCF Bank Stadium in the interactive GIS map that shows statistics for solar energy potential in Minneapolis.

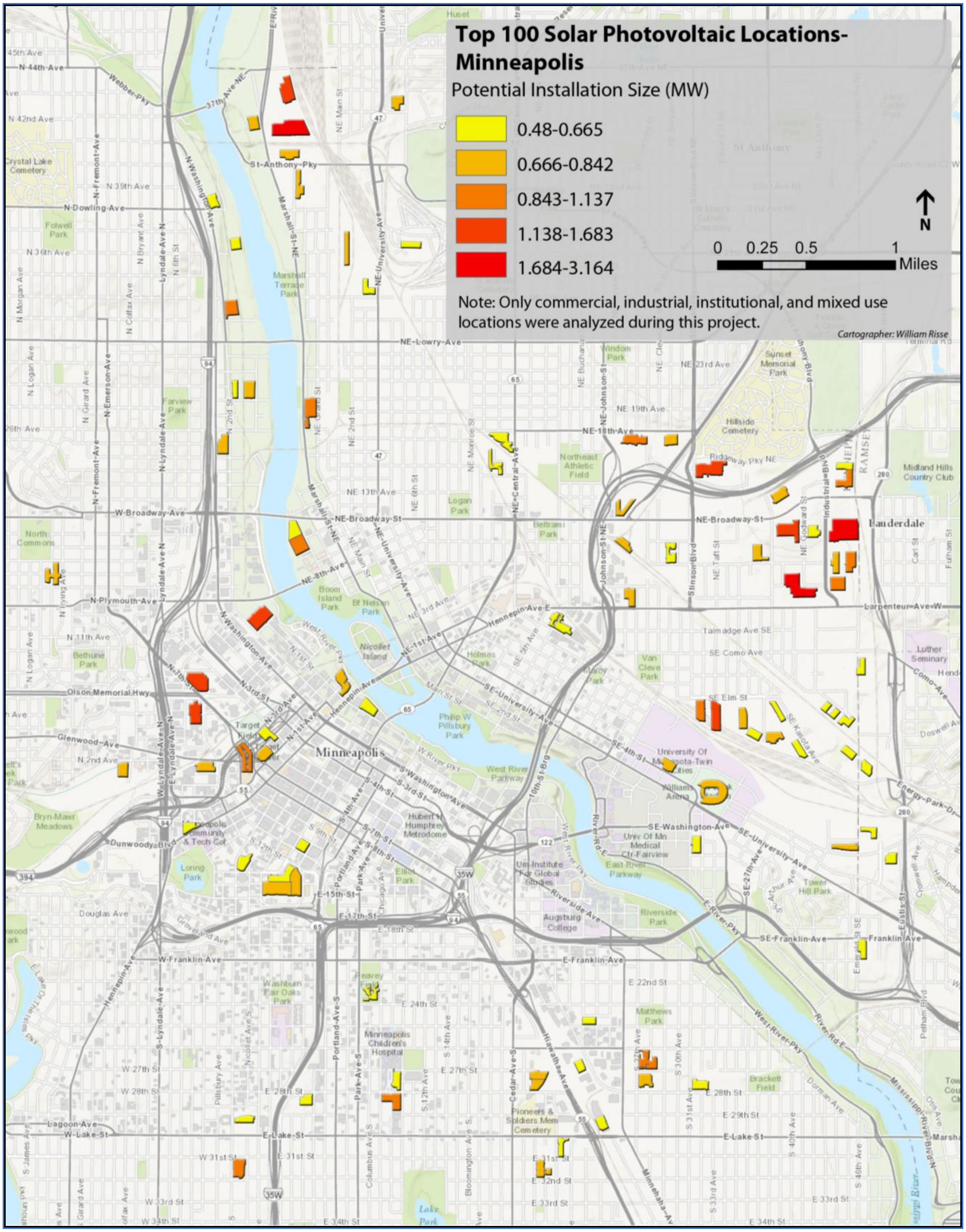


Figure 14. Top Potential 100 Solar PV Buildings in Minneapolis for Commercial, Industrial, and Mixed Use.

Table 6. The top ten potential C&I solar energy producers in Minneapolis identified from spatial analysis.

Business	Area (Square Feet)	0.08% (MWh)	Potential Installation Size (MW)
JJ Taylor Distributing Company of MN	541,104	3,878	3.2
Triangle Warehouse Self Storage	447,373	3,125	2.6
Sears Outlet	403,946	2,646	2.2
UPS Customer Center	295,974	2,062	1.7
Star Tribune- 1st Street	293,172	1,923	1.6
V.A. Medical Center	333,790	1,841	1.5
92.5 KQRS Radio	244,714	1,680	1.4
Northwest Automatic Products	221,165	1,575	1.3
Unknown Building- E River Rd NE and Technology Drive	260,155	1,547	1.3
Honeywell Aerospace	337,407	1,515	1.2
Total:	**3,378,800**	**21,797**	**17.8**

Table 6 shows the potential installation size for the largest (highest potential MW PV system) for the top ten C&I buildings in Minneapolis. Further C and I buildings with significant potential can be identified using the ArcGIS interactive map. Table 7 displays the number of structures that fall within potential installation size classes for all 3,666 structures analyzed. The majority of structures fall within the smaller classes, but there are a significant number of rooftops that have the potential for large scale installations. It takes many small structures to achieve the same solar capacity as fewer large structures. Just 18 large structures account for nearly 9% of the potential solar PV capacity, but it takes 2,190 of the smallest structures to reach 12% of potential solar PV capacity.

Table 7. The number of structure with the ability to hold various sized installations

Installation Size (MW)	*Number of Structures*	*MW (Cumulative)*	*% Total*
>1.00	18	26.6	8.9
.90-.999	5	4.8	1.6
.80-.899	9	7.5	2.5
.70-.799	15	11.1	3.7
.60-.699	18	11.7	3.9
.50-.599	26	14.4	4.8
. 40-.499	47	21.1	7.1
.300-.399	76	26.2	8.8
.200-.299	150	36.8	12.4
.100-.199	384	54.3	18.3
.40-.099	728	46.4	15.6
.005-.039	2190	36.6	12.3

Limitations:

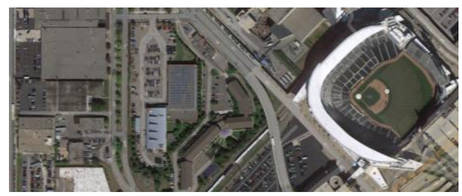
This study provides an estimate of the solar capacity of C&I buildings. As with any geospatial analysis, limitations are inherent to the process. Limitations to this study are listed below, and described in further detail in the Appendix.

1) The Convention Center is a single installation, and electricity production may be different from the average solar array. Additional examples of buildings with installed solar panels would improve analysis results. For example, there will be a difference in energy production between a fixed installation such as the convention center and systems that track the sun.
2) Processing time prevented a more accurate assessment of insolation values. Some accuracy limitations occurred from steps to improve processing time (see Appendix for further detail).
3) Solar systems require specific geometries that could not be easily accounted for in this analysis. Our analysis eliminated some rooftop portions, and at the same time some areas we found "suitable" are not likely to hold solar panels. (See appendix for additional explanation)

Data Inspection:

Analyzing general solar data on several other Minneapolis buildings determined the accuracy of the 8% efficiency ratio. The City of Minneapolis provides installation sizes for 8 of its other solar arrays, but has no actual production data. These include the Currie Equipment Facility, Fire Station No. 6, Fire Station No. 19, Fire Station No. 1, Royalston Maintenance Facility, Jerry Haaf Memorial Ramp, and Fire Station No.4. Three of these were selected to analyze the accuracy of the developed methods. This still allowed for an analysis of the how well the tool classified the solar panel area for these structures. As with the Convention Center, we digitized the area of each solar panel system in aerial imagery. We then determined the sum of kWh and divided by 1226 (average hours the Convention Center produces in a year) to find the installation size. The analysis shows that there is some variation in the tool's ability to calculate the solar potential of the solar area. The model predicts above the actual installation size in one case, and below in two others. This is encouraging, as the model is not consistently overestimating or underestimating, meaning that it is potentially averaging out across a larger dataset. This preliminary data check shows that the model is not seriously skewing results, and validates our analysis. However, without additional data we cannot determine with more certainty how accurate the model calculates potential solar PV installation size. Results of the data inspection are in Table 8 on p.22. Sizes are represented in kW due to the negligible value of MW for the smaller installation sizes.

Table 8. A comparison of the modeled kW installation size versus the actual size as listed on the City of Minneapolis Website

Installation Location	kWh (Modeled)	kW (Modeled)	Actual Installation Size (kW)	Percent Difference	Google Earth/City of Minneapolis Photos
Currie Equipment Facility	52,130 kWh	42.5 kW	40 kW	-6.3%	
Royalston Equipment Facility	147,477 kWh	103.6 kW	101 kW	-2.5%	
Fire Station 19	11,156 kWh	9.1 kW	9.83 kW	7.4%	

5 Financial Analysis of C&I Solar PV

The amount of potential solar capacity in Minneapolis is encouraging, but profit motives for larger installations also require consideration. Commercial and industrial building owners weigh economic benefits heavily in the decision to install solar panels. As policy makers pass new policies, modify statutes, and change rate structures to encourage PV solar energy for C&I customers, investors continually reevaluate the profitability of installing panels on their properties. To understand the financial feasibility of installing solar in the current regulatory environment in Minneapolis, we completed a financial analysis that integrated multiple rate design scenarios and financial incentives for solar PV. The model examined both net metering and value of solar rate structures. Net metering is the current policy, but value of solar tariff (VOST) is an optional rate available to public utilities in lieu of net metering. The Value of Solar methodology was recently approved at the PUC. A Value of Solar Tariff has yet to be filed by a utility, but the rate at which customers will be credited for their solar generation will vary, leaving the exact rate for VOS dynamic and difficult to predict. In order to account for this uncertainty, we assessed VOST under three potential rate scenarios. Net metering and value of solar rate structures are discussed in more detail in the sections that follow. Refer to Section 2 for federal and state incentives relevant to solar PV financial considerations.

5.1 Solar Rate Design in Minnesota

Net Metering:

Net metering has been one of the most successful policies for encouraging the adoption of solar PV systems in Minnesota (Abbey & Ross, 2013a). Unlike traditional metering, which only charges for electricity used by the customer, net metering allows a customer's meter to credit on-site electricity generation back to their bill when they produce more energy than they consume. In Minnesota, customers are compensated for their energy production at roughly the same rate that they pay for electricity (i.e. the average retail rate). For solar energy producers, the use of net metering makes solar PV systems more economically competitive and decreases the amount of time that it takes to make a return on the investment. As the potential profitability of solar PV systems increases, demand for the solar PV systems also increases, which spurs continued investment and research in solar PV technologies. This eventually leads to lower costs for solar panels, as well as reductions in other soft costs, such as installation labor and equipment.

In 1981, Minnesota became the first state in the United States to adopt net metering. Currently, 43 other states and the District of Columbia have also adopted net metering (North Carolina State University, 2013). Throughout the United States, the details of net metering policies differ from state to state in areas such as capacity limits, Renewable Energy Credits (REC) ownership, and applicable technologies. This policy variation can have a substantial effect on solar adoption rates. Minnesota's current net metering rules and regulations apply to installations up to 1MW. Net excess generation for 40kW and under are compensated at the retail rate, and installations between 40kW and 1MW are compensated at the utilities avoided cost (Farrell 2014).

Larger net metering capacity limits would provide financial incentives to larger C&I solar systems. Removing or increasing this 1 MW capacity limit to increase solar adoption is supported by a report from the National Renewable Energy Laboratory:

> *Based on statistical analyses of available data, state policies that currently have a system limit of 1 MW or greater have a mean of 3.44 watts of installed solar capacity per person as of 2008. Alternatively, states that have a system limit of less than 1 MW have a mean of 0.74 watts of solar capacity per person, or 366% less than the states with a higher system limit (Doris, Busche, & Hockett, 2009).*

Net metering, while popular with customers, often faces criticisms from utilities. Net metering customers are credited for the volumetric (kWh) portion of their bill for generation they produce. It is often seen as an inaccurate valuation of the energy produced by solar panels. This is because energy production is only one component of the retail rate. The remainder of the volumetric rate charged by the utility is for additional costs, such as those from the transmission and distribution of electricity, grid maintenance, and administrative costs. Paying customers the full retail rate, utilities argue, is overcompensating solar producers by neglecting the infrastructure costs of supplying energy. Utilities argue this places an undue burden by requiring them to pay for solar-produced electricity that would otherwise not be utilized. Customers, advocates and the solar industry, on the other hand, argue that the retail rate compensation is a rough, easily understandable and easily administered proxy meant to reflect the premium value of distributed solar generation. Distributed solar projects produce energy at times when energy is needed most, particularly on peak summer days when air conditioning demand is high, offsetting expensive peaking generation resources that would otherwise meet this demand. The energy is produced near the demand source, potentially reducing the use of distribution and transmission lines. Additionally, solar power generation produces no emissions and distributed, customer-sited solar projects can provide potential electric grid resiliency benefits.

Minnesota's current net metering rules and regulations apply to installations up to 1MW. Net excess generation for 40 kW and under are compensated at the retail rate, and installations between 40 kW and 1 MW are compensated at the avoided cost (the utility's marginal cost)

Value of Solar Tariff:

More recently in Minnesota, the Value of Solar Tariff (VOST) methodology has been developed as an alternative way to calculate the rate at which solar power producers are compensated by the utility. Modeled after similar policies recently enacted in Austin, Texas, VOS attempts to quantify the true value that solar adds to the utility, customers and society in terms of environmental benefits, decreased generation costs, reduced transmission, and less distribution loss (Tomich, 2014). This more accurate valuation methodology is seen as one way to reconcile the differing opinions of rate structures under the current net metering policy.

The foundation for VOST was developed in statutory obligations laid out by the Minnesota legislature in 2013 which required an alternative to net metering. The Minnesota Department of Commerce points out some of the main stipulations below:

- As an alternative to net metering, investor-owned utilities may apply to the PUC for a value of solar tariff that compensates customers through a credit for the value to the utility, its customers, and society for operating distributed PV systems interconnected to the utility under 1MW and operated by the customer primarily for meeting their own energy needs. The utility must demonstrate that the alternative tariff appropriately applies the methodology established by Department of Commerce and approved by the PUC;
- The methodology must include the value of energy and its delivery, generation capacity, transmission capacity, transmission and distribution line losses, and environmental value.
- The VOST separates the transactions of customer electricity usage and production, allowing utilities to recover of the cost to serve customers who generate on-site solar electricity. Customers are billed for all electricity usage under their existing applicable tariff and are credited for the solar electricity they produce under the approved VOS tariff ("Value of Solar Tariff Methodology," 2014).

Initially the The PUC approved of the Department of Commerce's methodology for VOST in April of 2014. On May 1, 2014, Xcel Energy filed their Value of Solar rate in the community solar garden docket at 14.7 cents, but argued that the interim "applicable retail rate" should be used to credit solar garden subscribers instead (Xcel, 2014a). The issue of which rate Xcel must apply is currently unresolved before the PUC. Though the rate that will eventually be applied to solar gardens is currently unknown, the analysis in the next section applies three hypothetical rates under the VOST. $0.145 was chosen as it approximates the VOST methodology proposed by the Department of Commerce, and subsequently the rate calculated by Xcel upon approval of this methodology by the Public Utilities Commission. The lower bound of $0.075 represents the value that Xcel energy initially proposed using their preferred methodology for VOST. Additionally, a rate of $0.12 is analyzed to account for sensitivity analysis.

The three rate structures used in our analysis of the Value of Solar Tariff are approximations of the proposed rate structures debated at the Public Utility Commission during VOS deliberations. The $0.145/kWh VOS rate scenario is Xcel Energy's estimated application of the VOS methodology. Xcel Energy argued for the lower rate of $0.075/kWh. The $0.12/kWh rate scenario was chosen as a hypothetical middle ground rate for this analysis.

5.2 Financial Analysis Methodology

Rate structures and incentives play a significant role when investors evaluate the possibility of installing solar panels on their rooftops. Both a positive and timely return on investment is generally necessary for C&I installations, and the combination of rates and other incentives are a deciding factor on the feasibility of a solar installation. For C&I investors, the size of the installation is also a consideration since many of these rates and incentives have low capacity limits that are better suited for residential installations.

We completed a financial analysis to evaluate the impact of three rate schemes of VOST and the effect of federal and local government incentives. The purpose of the analysis is to present preliminary analysis on which potential investors can benchmark by including their own physical and financial conditions. The results are sensitive to changes in variables like the cost of the installation per kW, further modifications of caps and termination of incentives like the forthcoming termination of the ITC incentive. Updating is highly recommended.

Financial feasibility indicators such as investment cost, income or reduced costs and net present value (NPV) are basic information tools for potential investors. For the purpose of this exercise, we make the following assumptions for C&I customers:

- Financially feasible projects have NPV higher than zero dollars.
- Lifetime of solar installations is 25 years, based upon most product warranties and literature (Bruckman, 2012; Gross, 2010)
- Given that users of the financial analysis include for profit and non for profit organizations, calculations are presented in earnings before interest and tax (EBIT).

We recognize that companies also obtain additional benefits from such investments, such as social recognition from their stakeholders, which can also have a measured economic effect. However, such impacts are not considered in this analysis. We evaluated the financial feasibility from the investor's perspective in a model created using Microsoft Excel. The model was set to show basic financial information to investors: investment ($), breakeven (years), and net present value ($).

Assumptions

- **"General" commercial industrial rates.**
- **Three VOST:**
  - **$0.145/kWh**
  - **$0.12/kWh**
  - **$0.075/kWh**
- **35,000 ft^2 grocery store with average energy consumption.**
- **10% discount rate, plus sensitivity analysis**
- **Installation costs of $3.5/W for smaller installations and $2.92/W for installations over 1MW**
- **Panel generation capacity loss of 1.5%/year**
- **Solar*Rewards incentive $0.08/W installed**
- **Made in Minnesota incentive $0.18/kWh**
- **30% Investment Tax Credit (ITC)**

There is a wide array of commercial and industrial building types that may have significant roof space available for solar, however, to simplify the financial analysis of the three rate scenarios, we chose one building type as a primary case for comparison. Grocery stores are considered an ideal customer for this analysis given their consistent energy use patterns (E-Source, 2002; Leach, Hale, & Hirsch, 2009). Also, in states that lead in PV energy generation, supermarkets and grocery stores represent more than 85% of the commercial establishments with PV solar installations (Schneider et al., 2014). Additional assumptions were made for grocery store characteristics and behavior, and are presented in the box aside.

This section was built in three stages:

Stage 1) A financial feasibility analysis for VOST at three levels.

Stage 2) A sensitivity analysis for small (10-90 kW) and large (100-1000 kW) installation sizes.

Stage 3) A sensitivity analysis with 8 discount rates ranging from 3 to 20% was used to represent variations in customer preferences.

The applied range of discount rates offers an array of options so that potential investor can better estimate the financial analysis of their potential investment. It starts with a conservative rate where the Federal Reserve Rate was used (commonly used as a conservative reference point), 10% as the mid point; which is a commonly used discount rate for private companies, and 20% for the more demanding investors. Discount rate is one tool than can be used for equalizing risk, where a low discount rate is used for low risk investments. As reference for investors, 10% was informally found to be commonly applied discount rate for comparable long-term investments in the energy industry.

"Made in Minnesota" and "Solar*Rewards" incentives were considered when applicable, and the federal Investment Tax Credit was assumed for all cases. For stages 2 and 3, net present value at 25 years was the chosen indicator.

5.3 Results: Financial Analysis of Solar PV

5.3.1 Initial financial feasibility findings

For Stage 1 we present one table per rate, where a 10kW installation is evaluated at 10% discount rate. Table 9 presents the $0.145/kWh Value of Solar Tariff rate as an illustration of the outputs. With an installation cost of $35,000 (10kW at $3.5/W; SEIA, 2013) we came to the following conclusions:

1) A grocery store can effectively reduce their energy bill by 5%.

2) The payback period is of 15 years, assuming minor maintenance costs of approximately 4% of total costs[1].

3) The 25-year net present value of the investment is $172,000.

Overall, calculations show that this solar PV project is financially feasible and might be attractive for grocery stores, although there is a heavy upfront investment.

1 To date, the literature review and informal consultation did not offer a clear indication of actual maintenance cost, and 4% was found to be reasonable for the analysis

Table 9. Financial Analysis Results

Project Characteristics		
VOST	0.145	
Grocery Store Characterisitcs		
Area	35,000	ft2
Energy consupmtion	1,750,000	kWh/year
Load	31	kW
Proyect Size		
Solar Energy Goal	15,330	kWh/year
Installation size	10	kW
Array size	1,473	ft2

Investment		
Installation costs	3.5	$/W
Total investment	35,000	$
Financial results		
Discount rate	3	%
Payback period	9	years
NPV (25 years)	48,380	$

5.3.2 Installation size sensitivity analysis findings

In the second stage, we address the installation size and the influence of incentives for solar energy. The installation size determines the size of the investment and the energy that it generates, and therefore has a high impact on the financial feasibility of PV installations. Government financial incentives for solar PV are also capped by installation size.

The incentives we included in our analysis were the Investment Tax Credit, Made in Minnesota, and Solar*Rewards. Made in Minnesota has a 40 kW DC cap and Solar*Rewards a 20 kW DC cap. Those caps encourage smaller solar arrays, and lead investors towards the range of10 kW to 40kW solar PV installations.

To test the installation size sensitivity, we based our analysis on the results obtained and presented in the first stage (section 5.3.1). We ran the model for four different rate structures, and used net present value as our financial indicator under each model. In all cases, the federal Investment Tax Credit is identical. It is important to note that the Solar*Rewards and Made in Minnesota incentives do not apply to all users modeled, and that the exercise has the intention to show the impact that they could have on financial feasibility. For the smaller installations, we ran the model for nine installations sizes ranging 10-90 kW with 10kW increments. For larger installations we ran the model for ten installations with sizes ranging from 100-1000kW.

1. small clients 10-90kW, **without** Solar*Rewards and Made in Minnesota incentives (Figure 14)

2. small clients 10-90kW, **with** Solar*Rewards and Made in Minnesota incentives (Figure 15)

3. large clients 100-1000kW, **without** Solar*Rewards and Made in Minnesota incentives (Figure 16)

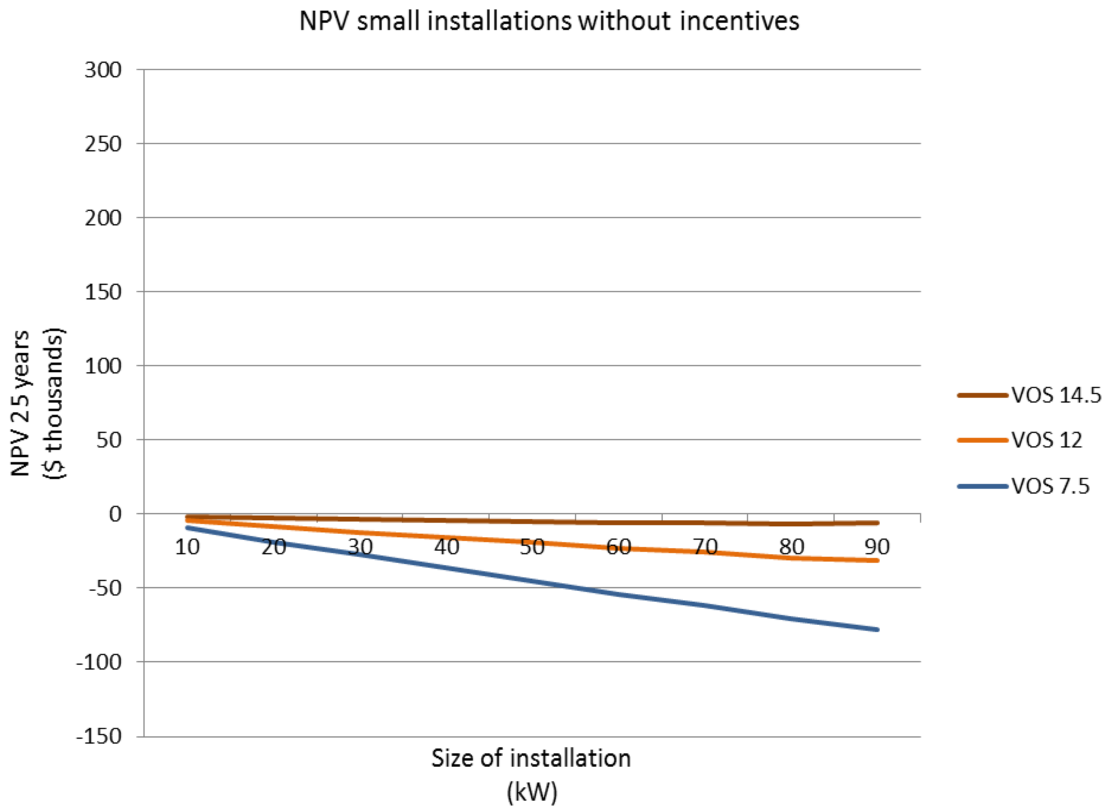


Figure 15. Net present value of small installations (10-90 kW) without state incentives

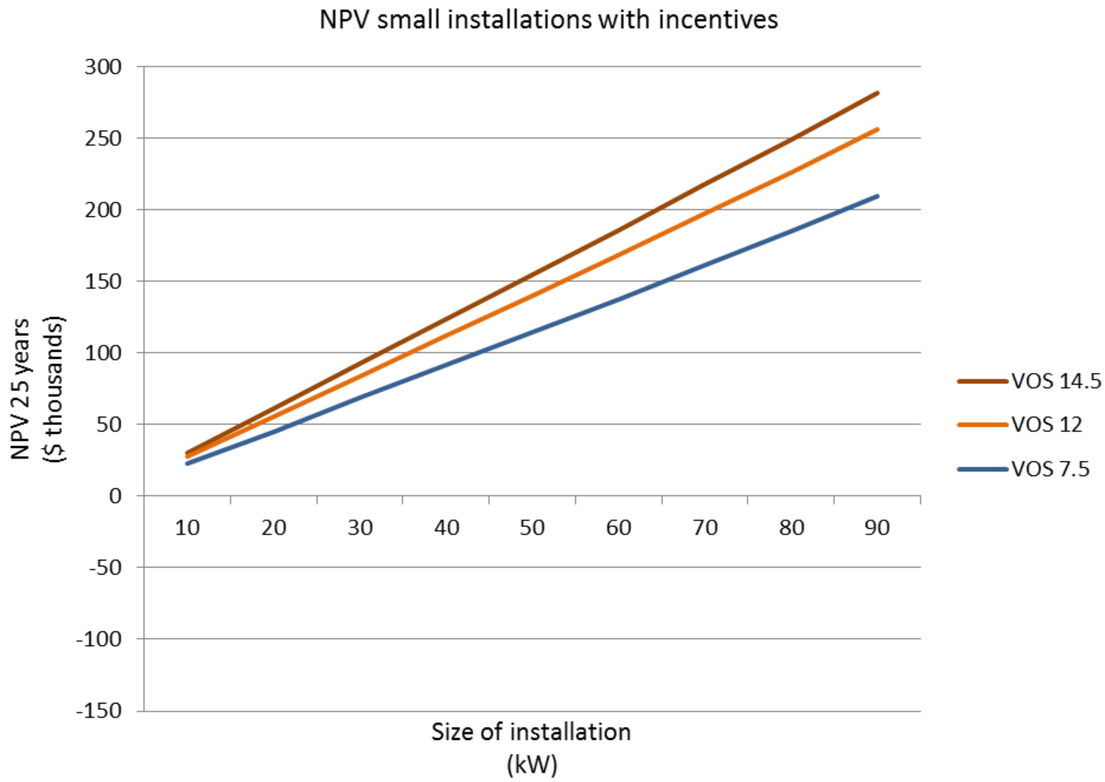


Figure 16. Net present value of small installations (10-90 kW) with state incentives

In all cases, the cause for negative net present values are attributed to non-recovered capital in combination with an assumed 10% discount rate (further analysis on discount rates is in the following section). Figures 15, 16, and 17 show how Solar*Rewards and Made in Minnesota incentives are very effective at making solar PV installations financially feasible.

For smaller installations (Figure 15), we found the installations are financially feasible without the incentives if value of solar was set at $0.145 and $0.12/kWh. Installations are not financially attractive with net metering or a value of solar rate of $0.075/kWh or lower. In this scenario, only smaller installations (10-40 kW) supported by Solar*Rewards and Made in Minnesota incentives are financially attractive.

The analysis shows that larger installations can be made financially feasible with VOST above $0.12/kWh. with VOST above $0.12/kWh, installations between 800 and 1000 kW are financially feasible.

5.3.3 Discount rate sensitivity analysis findings

Investors frequently use discount rate as a way of making adjustments associated with risk. Therefor, in the private sector, the discount rate is a choice that is made by the investor. where the a low discount rate is used for low risk investments. Investors have their own opportunity costs for the resources they manage. Building on top of the previous assumptions, we modeled a small solar PV installation of 20kW to evaluate a range of discount rates for each VOST. We included the incentives of Made in Minnesota, Solar*Rewards, and ITC. As shown in Figure 18, VOS at higher discount percentages and a rate of $0.12/kWh may still make solar PV a good investment. The Appendix graphs various size installations with and without incentives at a 10% discount rate.

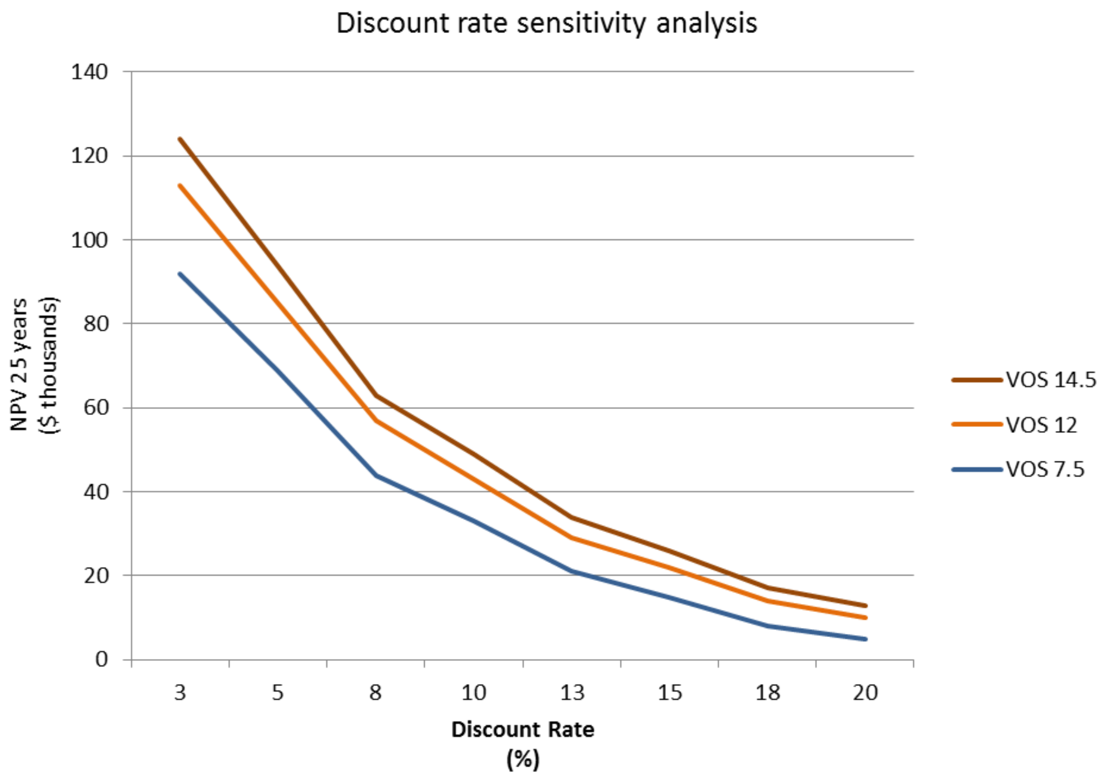


Figure 18. Discount rate sensitivity analysis for smaller installations (10-90 kW)

6 Discussion: Application of Results

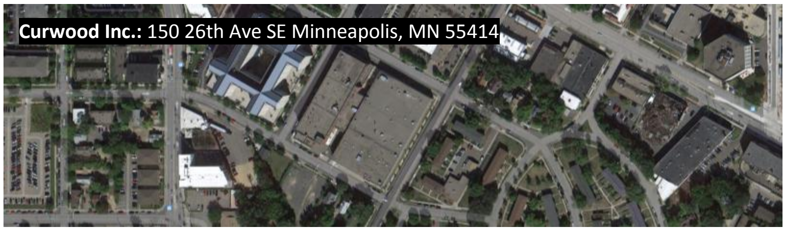
6.1 Case Study: Linking Spatial and Financial Analysis to Site Identification

We combined findings from our spatial and financial analyses to examine three case study buildings. For each building, we analyzed how different incentives would influence large scale installations, using a stringent discount rate of 10% to evaluate financial outcomes for more cautious solar investors (see Table 10). The case study buildings are briefly outlined below:

The first case study, **J.J Taylor,** is located within a long-term industrial site. The structures in this area are not planned to undergo changes, and adjacent development is unlikely to shade the property.

The second case study examines the **Home Depot and Rainbow Foods at the Quarry Shopping Center**. These buildings were constructed in 1997, and Quarry Center is an important commercial area in the Northeast Neighborhood. Long term land uses are unlikely to change.

Curwood Inc. is located near the University of Minnesota Campus. This area is very similar to the Lake Street Corridor, in that increased density and development is likely in the future. Curwood Inc. is near to the light rail, and land use changes should be considered in planning solar installations.



We found that under a VOST rate of $0.12/kWh, the two larger case studies have the potential to have a positive NPV and the smaller installation is not financially feasible. In addition, the larger installations have a shorter payback period, and higher ROI (see Figures 19 and 20). Under the 3% discount rate, and for VOST of $0.075 ROI values are investigated further for other rates below. The results show that under all VOST rates, the larger installations will see the largest ROI.

Table 10. Information on large scale commercial and industrial case studies-payback, NPV, and ROI were calculated under a VOS rate of $0.12/kWh

Case Study	Area (Square Feet)	kW	Total Investment	Discount Rate	Payback Period	NPV (25 years)	ROI
J.J. Taylor Distributing Company of MN, Inc.	541,104	3,200	$7,040,000	10%	12 years	$1,217,000	0.17
Home Depot and Rainbow Foods (A portion of the Quarry)	194,666	991	$2,328,000	10%	9 years	$285,000	0.12
Curwood Inc	103,069	396	$1,206,000	10%	16 years	$-56,000	-0.05

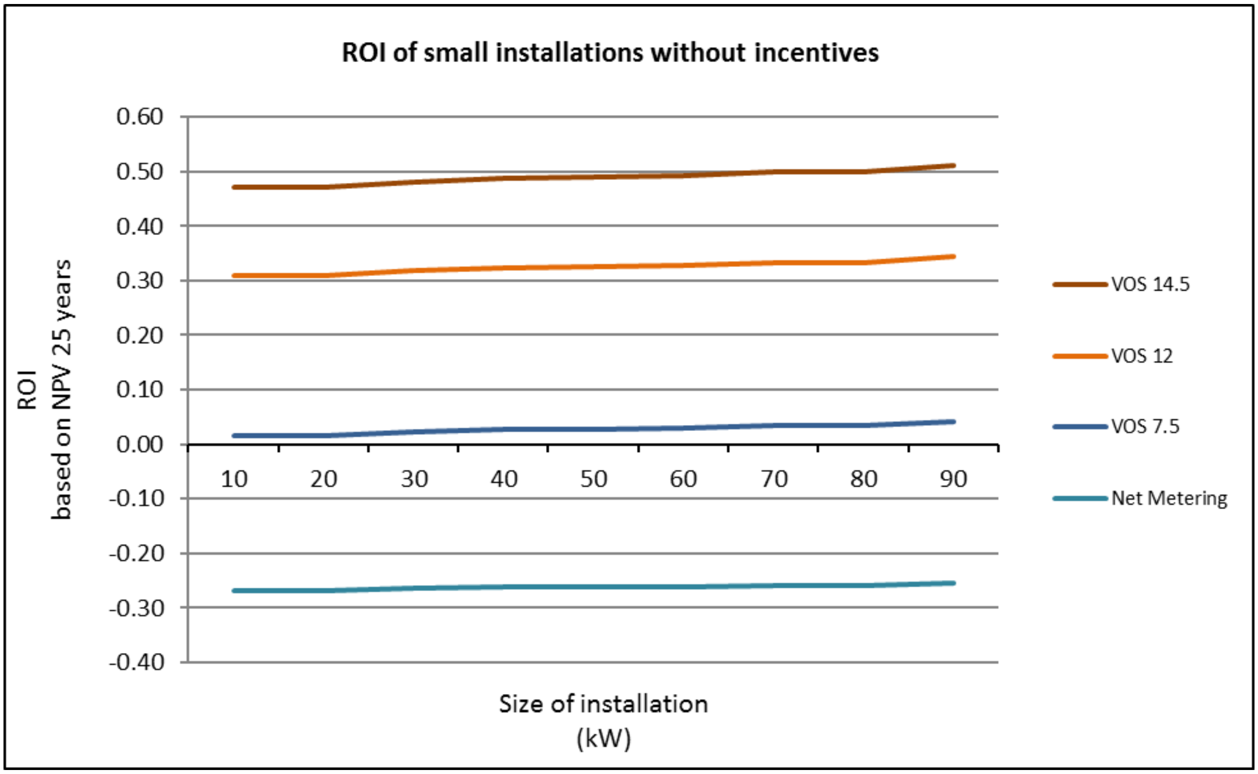


Figure 19. ROI of small installations(10-90 kW)--with no incentives applied

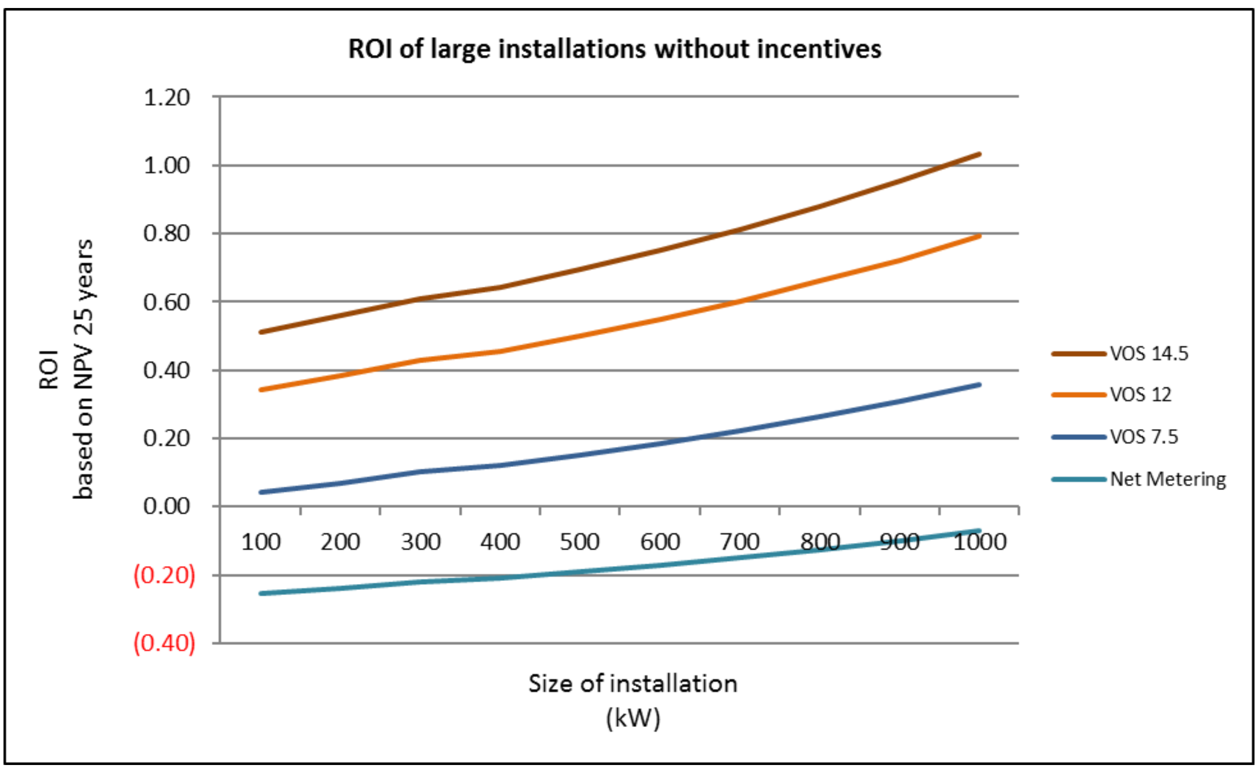


Figure 20. ROI of large installations (100-1000 kW)--with no incentives applied

6.2 Land Use Planning Implications: Priority C&I Solar Implementation Zones

From the initial GIS results of the solar PV capacity, we identified priority locations for groupings of several building. Identifying areas or zones with excellent potential for solar PV implementation can guide short and long-term plans and land use policies, specific to land use trends. It may also help identify areas where third-party ownership or community solar systems could be the most profitable by maximizing solar resources. The following discussion introduces industrial employment districts and commercial corridors throughout the City that exhibit significant potential for solar PV installations.

6.2.1 Industrial Land Uses: Long Term Stability

In our analysis of the Minneapolis Plan (2009) and Industrial Land Use and Employment Policy Plan (2006), we identified and noted anticipated growth in existing and future commercial, industrial, and mixed-use parcels. From a land use planning perspective, Industrial Employment Districts are priority areas for implementing solar systems because they are likely to retain industrial and commercial buildings over a 25 year period (i.e. lifespan of a solar system). While the Industrial Employment Districts were established in 2006, prior to the recession, they still continue to be recognized by the City. Stable land uses provide an opportunity for new policies to protect solar resources and incentivize large scale implementation and investment over a long period of time.

The Industrial Land Use and Employment Policy Plan (2006) identified seven industrial employment districts:

1. Humboldt (North)
2. Shoreham Yards (East)
3. North-Washington Jobs Park (NW Downtown)
4. Upper River (North)
5. SEMI (East)
6. Seward/Hiawatha (South)
7. Mid-City (East)

High Solar Potential Industrial Employment Districts

While all seven areas should be considered for solar implementation, two had significantly higher solar capacity than the rest: (1) Mid-City, and (2) SEMI, both located in Northeast Minneapolis. Table 11 and Figure 21 gives information about solar potential in these districts.

Table 11. Solar Capacity of two Industrial Employment Districts; Mid-city and SEMI

	Mid-City	**SEMI**
District Size:	830 acres	413 acres
No. of Buildings Suited for Solar:	196 buildings	63 buildings
Total Sum of all Rooftop Space:	8,682,314 sq. ft.	2,710,898 sq. ft.
Potential PV Capacity:	40,536 kW	12,785 kW
Average Building Capacity:	207 kW	203 kW
Potential Annual Production:	49,697,458 kW/h	15,673,958 kW/h

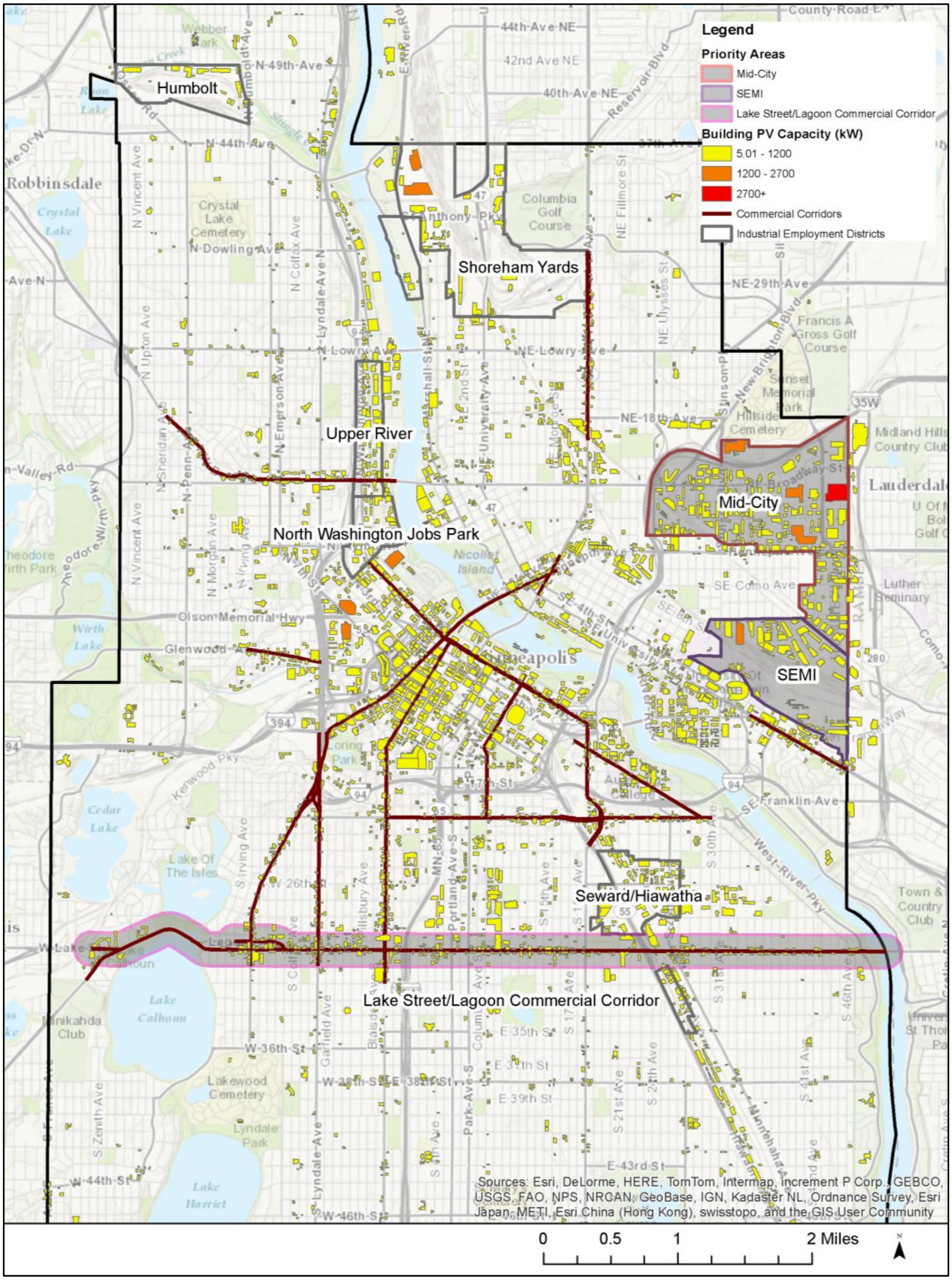


Figure 21. Mid-City and SEMI industrial employment districts and the Lake Street commercial corridor have good roofspace for solar PV arrays.

6.2.2 Commercial Corridors: Long-Term Growth

In contrast to SEMI and Mid-City, commercial corridors in Minneapolis are expected to change and experience growth over a 25-year period. The Minneapolis Plan (2009) identified several commercial corridors throughout the City that anticipate increased density to 50-120 dwelling units per acre. These areas are have high potential for solar implementation because they are targeted areas of growth, but require different approaches for guiding new installations and protecting existing underutilized solar resources. While there are trade-offs to consider, such as opportunities to add new development or increase the property tax base, solar development in these corridors would benefit from additional restrictions for new construction, including height and setback restrictions, solar ready requirements, and more complex coordination and management of solar systems by multiple parties.

High Solar Potential Commercial Corridor: Lake Street

The commercial corridor with the greatest potential for solar implementation is the Lake Street/Lagoon Corridor, extending from west of Lake Calhoun to the Mississippi River. This 5.7 mile long corridor has the potential for 13.4 MW of solar capacity (see Table 12). This area will likely see rapid growth and redevelopment, so it is imperative for the City to make sure solar resources can be readily utilized (be solar ready).

Table 12. Solar capacity of the Lake Street/Lagoon Commercial Corridor

Lake/Lagoon Street Commercial Corridor	
Corridor Length:	5.76 miles
# of Buildings Suitable for Solar PV:	305 buildings
Total Sum of Rooftop Space:	139,694 sq. ft.
Potential PV Capacity:	13,415 kW
Average Building PV Capacity:	44 kW
Potential Annual Production of PV Installations:	16,446,790 kW/h

7 Recommendations

Our recommendations strive to break down the barriers of high up-front solar installation costs and policy challenges to installing larger solar PV arrays. Our financial analysis demonstrated that larger PV arrays have the shortest payback period and highest ROI under the Value of Solar rate structures. The recommendations focus on both state-level policy changes for Minnesota and City-level policy changes for Minneapolis. Table 13 summarizes our recommendations.

Table 13. Summary of Recommendations

Statewide Recommendations	City-Wide Recommendations	City: Industrial Employment District Recommendations	City: Commercial Corridor Recommendations
• Expand Capacity for Solar Rewards and Made in Minnesota Incentives • Clarify Legislation for Third Party Solar Models • Continue Current Tax exemptions, and add Tax Exemptions for Third Party Financing (PPA)	• Encourage third party ownership (Climate Action Plan goal) • Encourage "Net zero" energy buildings (Climate Action Plan goal) • Facilitate PACE program • Encourage public-private partnerships. • Create a solar overlay district.	• Performance based incentives for maintaining and operating efficient solar system • Net Zero energy buildings (Climate Action Plan goal)	• "Solar Ready" buildings and Green building codes (Climate Action Plan goal) • Development incentives • Explore solar access protections

7.1 Statewide Recommendations

Expand Capacity for Solar Rewards and Made in Minnesota Incentives

Up front financial incentives that decrease initial investment costs are one of the best strategies to increase solar implementation with the C&I class. Currently, incentives are capped at capacities of 40kW for solar systems. Increasing the incentive limit to 1MW would allow solar systems on large rooftops of C&I buildings to be profitable with a shorter ROI. For example, if the PUC expanded incentives to 1MW, the ROI would be 1.5, even under a $0.075/kWh VOST rate structure (see Figure 22 and 23).

An incentive program for PV arrays over 40 kW could be advantageous because it would allow for greater total solar capacity from fewer installations, and have economic efficiencies over small installation incentives. However, any new incentive program for larger installations would need to be carefully scaled to best allocate scarce incentive funds. The largest projects should receive the most incentive funding, but a capacity cap would still be necessary for the program. For example, if a 5MW limit was placed on the new incentive program, it would take four years for the top ten largest capacity C&I buildings to install solar on their rooftops (see Table 6). Yet, over this four-year period, the City of Minneapolis could add 20 MW of capacity from solar PV through only ten solar PV installations.

Figure 22. NPV of large installations (100-1000kW) with incentives

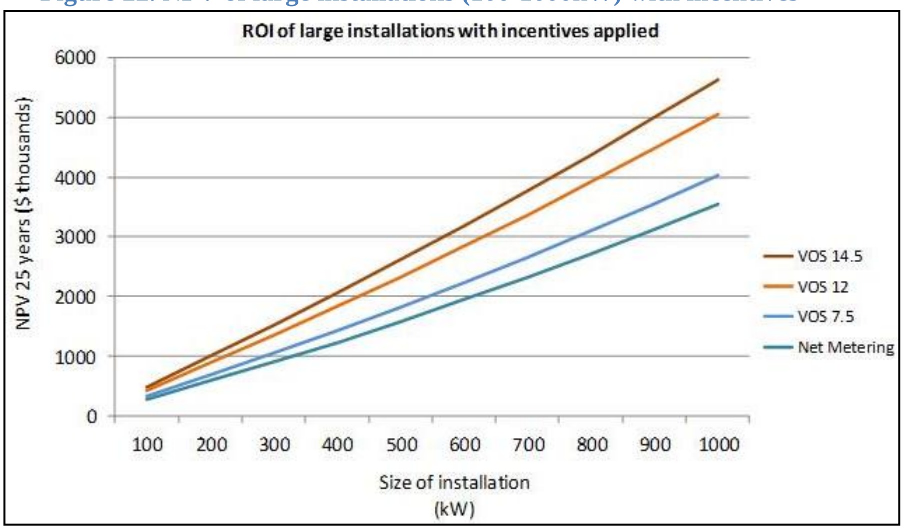


Figure 23. ROI of large installations (100-1000 kW) with incentives

Clarify Legislation for Third Party Solar Models (PPA and Leasing)

Solar PV arrays typically require the owner to finance the large up-front costs of their installation. Since C&I buildings have extensive capacity, third party power-purchase agreements (PPAs) or financing and leasing could be a profitable way to reduce initial cost barriers (Abbey & Ross, 2013). Third party ownership could work for C&I building owners who may not want to deal with the maintenance and operation of the system, but want to maximize the solar capacity (Abbey & Ross, 2013). In solar PPA, a third party owns a solar PV array on a customer's property, and then sells the electricity generated back to the customer. Solar energy systems are provided as a service for solar PPA models. In solar PV leasing, a customer leases a solar PV system and has access to all of the energy produced by the leased solar PV array. Third party ownership and financing is an important way to help the C&I sector overcome the large capital investment barrier to installing large solar PV arrays that have the fastest payback period and highest ROI.

Pursuant to Minn. Stat. 216B.02, third party PPAs and leasing have limited authorization. According to a report developed by Fresh Energy, a third party ownership company may contract with up to 25 persons before being considered a "public utility" under law, subject to

Commission regulation (Abbey and Ross, 2013). The report also notes that the statute language was developed prior to modern solar technology.

While state statute allows third party ownership to exist, the limited authorization of up to 25 subscribers has been a market barrier to expanding solar leasing and ownership at a large scale. Yet, there are both advantages and disadvantages to large-scale third party ownership models. This topic should be explored further in the context of Minneapolis' needs. The Community Solar Gardens program also provide a third party leasing model that may be the best way to maximize large capacity rooftops in the near-term.

Continue Current Tax Incentives, and Add Tax Exemptions for Third Party PPA

The State of Minnesota has multiple existing tax exemptions for solar energy. Since 2005, solar PV system purchasers are exempt from sales tax on systems (*MN 297A.67, §29*). The sales tax exemption has no expiration date. Solar installations on commercial, industrial, and residential properties are also exempt from property tax valuations (*MN 272.02*). The exclusion of solar PV from property tax calculations has been in effect since 1992. The legislature should continue these solar tax incentives.

If the Minnesota legislature provides clarification on third party solar models in state statutes, tax code improvements are a natural next step to promote solar PPAs. It is currently unclear in Minnesota state legislation whether onsite PPA solar PV systems sales are subject to taxes.

The case study of J.J. Taylor Distributing, Inc. has a potential solar capacity of 3.2 MW. This large rooftop has a tremendous amount of capacity, but it requires a significant up front , initial investment to install the maximum capacity. J.J. Taylor Distributing could benefit from using a third party financing and ownership or leasing model that would allow many parties to help with the installation, operation, and maintenance of the system.

"Minnesota has a sales tax exemption for the direct purchase of a solar energy system, but no clear exemption for taxes on power purchased from an onsite solar PV system" (Abbey & Ross, 2013, p.41). Minnesota could follow neighboring Wisconsin's 2011 legislation that clearly exempts onsite solar PPA sales from state taxes. This legislative change could encourage the C&I sector to use PPA financing structures and reduce the amount of up-front capital necessary to install a large solar array.

7.2 City of Minneapolis Recommendations

The City of Minneapolis' Climate Action Plan (2013) guided many of our Minneapolis recommendations. The Climate Action plan states policy goals that are priorities to advancing solar energy. The first subsection describes recommendations for the city as a whole. The remaining two subsections discuss implementation strategies specific to industrial employment districts and commercial corridors. The following City level policy recommendations are specific to increasing investment in solar PV arrays by the C&I sector in Minneapolis.

7.2.1 City-Wide Recommendations

Encourage third party ownership (Climate Action Plan goal)

As aforementioned, third party ownership is a strategy to reduce initial costs of installing solar PV arrays. While a great option for C&I buildings, third party ownership and financing is an especially palatable option for non-taxable organizations to benefit from solar incentives, including non-profit businesses (Abbey & Ross, 2013). In the near term, the City of Minneapolis should encourage the implementation of the Community Solar Gardens Program as a way to increase third party leasing through this subscription based program.

Facilitate PACE program

In 2010, the state Minnesota passed legislation to enable Property Assessed Clean Energy (PACE) financing. In December of 2013, the City of Minneapolis passed a resolution to designate the Saint Paul Port Authority to implement and administer the PACE of Minnesota financing program (City of Minneapolis, 2013a). The City of Minneapolis should help facilitate the administering of PACE by dedicating additional staff members to the program.

PACE financing is a program available to businesses installing renewable energy infrastructure, including solar PV arrays. PACE allows a city to finance renewable energy projects without requiring a down payment from a business, and is repaid over a period of 10-20 years through special property tax assessments on the business. It is a way to break down the barrier of high initial costs of solar PV installations. The three case studies introduced in the previous section could benefit from the use of PACE financing to reduce up front costs. This in turn can benefit the City of Minneapolis through the increased use of renewables with these large installations.

Encourage Public-Private Partnerships

Public Private Partnerships could be a key strategy to enable private sector investment in solar installations (Morley 2014). The Mid-City and SEMI industrial employment districts and Lake Street/Lagoon commercial corridor, identified in the previous section, are priority areas for this type of investment. Minneapolis could invest in the conditions assessments for solar suitability on rooftops and assist with some of the capital costs in installing large solar systems on privately owned land. The public benefits would be transitioning to more local energy resources (Morley 2014).

Create a solar overlay district

In Minneapolis, a solar overlay district could have certain policies in addition to those of the base zoning. The city-level policy would create City zones with additional solar incentives or restrictions. Some of our recommendations, such as green building codes and development incentives, could be enacted as part of solar overlay district policymaking. This would protect solar resources by guiding new construction and ensure that areas most suitable for solar energy installations would be the focus. Mid-City and SEMI, the two industrial employment districts we identified as well-suited for solar installations and the Lake Street/Lagoon commercial corridor are good candidates for inclusion in a solar overlay district.

7.2.2 Industrial Employment District Specific Recommendations

The stability of the industrial employment districts allows Minneapolis policies to have a more long-term focus. Therefore, recommendations do not focus on new construction, but instead concentrate on retrofitting existing buildings and modifying solar incentives. Since SEMI and

Mid-City were the industrial employment districts with the greatest potential for solar PV installations in terms of capacity, we envision our recommendations being particularly relevant to these areas.

Performance Based Incentives

Since industrial employment districts represent long term stability in terms of land use, ownership, and general building type, performance based incentives could assist with maintaining long-term solar systems. Performance based incentives could be tax based or cash incentives (Morley 2014, p.70). By focusing on industrial employment districts over the long term, the City can make sound investments through offering these incentives.

Net Zero Energy Buildings (Climate Action Plan Goal)

Net zero energy buildings could be more easily achieved through green building codes that require solar readiness. Net zero energy buildings promote energy conservation, efficiency, and local energy generation. Industrial employment districts are ideal for net zero energy buildings due to their large capacity for local energy generation and benefits to reducing overall energy consumption within the industrial sector. The City should promote net zero energy buildings through sponsoring assistance with retrofits for solar PV and improved energy efficiency.

7.2.3 Commercial Corridor Specific Recommendations

Unlike the industrial employment districts, the following implementation strategies specific to commercial corridors focus on new construction and anticipated density increases as being most relevant to solar implementation. We envision the Lake Street/Lagoon commercial corridor as the most likely area to employ these strategies because our spatial analysis highlighted this street as prime for solar PV installations.

Solar ready building certification for new construction (Climate Action Plan goal)

Solar ready standards could be employed by the City of Minneapolis in commercial developments and re-developments to ensure ease of solar PV installation in the future. Solar-ready requirements deal with electricity and plumbing systems. For instance, Chula Vista, California has legislation for solar water heater pre-plumbing and PV pre-wiring (Morley 2013). Since the Lake Street commercial corridor will likely see new construction and redevelopment, incorporating solar energy into these projects will make it easy to install more solar PV arrays in Minneapolis.

Green building codes for solar readiness (Climate Action Plan goal)

Green building codes help ensure that new buildings are optimally prepared for future solar installations. This is important since commercial corridors will have new construction and redevelopment. Site design requirements, such as those in Laramie, Wyoming, mandate setback and building orientations to facilitate solar insolation collection (Morley 2013). Green building codes could be part of stipulations for a solar overlay district and the design review process.

Development incentives

Development incentives provide special treatment to projects that include a solar PV installation. Minneapolis already has an expedited permitting system in place for solar PV arrays. Minneapolis could add density and height bonuses for developers that install solar systems. For example, Portsmouth, Virginia lets developers add 1-2 stories to buildings that install solar systems (Morley 2013). This is particularly relevant for commercial corridors, such as Lake Street, that have increased density as a goal in their small area plans.

Figure 24. Solar panels may be integrated with green building plans, such as green roofs and rooftop gardens.
Source: lid.ok.state.edu

Solar Access Plans

Easements, permits, and fences are ways to protect access to sunlight on properties. All of these are important tools for commercial corridors such as Lake Street because new construction and redevelopment may increase shading, and remove opportunities for solar PV arrays. An easement is a right of use or entry to a property without owning it. Solar easements ensure access to sunlight by restricting development on parcels that would cause shading. Easements are voluntary agreements, and thus not as difficult to implement as other solar access protection measures. Per Minnesota state statute, solar easements may not decrease property values, and easements that would increase property values are exempt from being included in land valuations for tax purposes (*MN 500.30, 2013; MN 462.357, 2013*).

Minneapolis law legalizes solar easements, but property owners are currently not utilizing solar easements. Education or having city property owners lead the way in securing solar easements may be ways to expand their use. Solar access permits prevent future construction from shading a property through permitting policies. The Village of Prairie du Sac in Wisconsin has solar access integrated into their permitting system, and could be a model for Minneapolis (Morley 2014). The City of Boulder in Colorado is a good example of solar fence legislation. Solar fences limit shading in initial development of all properties in an area (Morley 2014). This is good to keep in mind for large redevelopment projects in Minneapolis, but is not relevant for the City, being that much of Minneapolis is already built out.

8 Conclusion

Minneapolis can meet their climate action goals through a myriad of approaches, but C&I customers are essential partners in meeting these goals because they consume the majority of electricity produced on an annual basis. The existing system of incentives regulated by the PUC and sponsored by Minneapolis's incumbent electricity provider, Xcel Energy, centers on improving the energy efficiency of buildings and increasing small-scale renewable energy installations. Current incentives do not help C&I customers install large-scale solar PV arrays that have a shorter payback period and higher return on investment. Policy changes outlined in this report will help change this limitation, and help Minneapolis achieve its renewable energy goals.

Areas of further research include C&I studies in other cities. U-Spatial's work on creating a state solar map will enable an easier replication of this study in other Minnesota cities. While some of our recommendations are specific to Minneapolis, many may be applicable to other locations in Minnesota and across the United States.

In addition, institutions, such as churches and schools, are another important sector of potential solar PV producers in Minneapolis that deserves more research. The techniques described in this report could identify ideal school and church locations for solar installations. In particular, third party ownership could work well for institutional buildings.

It is an exciting time in the renewable energy field. Much progress has been made in recent years, but much remains to be done. As the Minneapolis Energy Pathways study asserts, "the City and utility must move beyond traditional energy audit programs to transformative and innovative strategies that will increase market penetration and savings by orders of magnitude," (2014, p.19). The techniques in this analysis will assist the C&I sector in solar implementation as part of this renewable energy transformation.

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10 Appendix

10.1 Spatial Analysis- Data Overview

Email hhhsolar2014@umn.edu to download data used and created by this project. An online interactive version of the final map output can be found at http://bit.ly/1kBZCBT. The online version only highlights the top 2000 potential producers, while the data download includes additional buildings of smaller potential installation size. You will receive an automatic response with a link to data including:

Raster Data

- Solar Insolation Raster of Minneapolis (Yearly watts hours per square meter).
- Solar Insolation Raster of Minneapolis (Monthly watts hours per square meter).
- Digital Surface Model (DSM) of Minneapolis

Vector Data

- C&I building footprint with potential kilowatt hours and installation size (kW) in the attribute table (See important field under Step 3 below)
- Minneapolis Municipal Boundary

Solar Tools.tbx (For ArcGIS version 9.3-10.2)

- Area Solar Radiation Iterator: Tool showing "Solar Area Radiation" inputs with iterator attached. This allows for iteration of split DSM's.
- Commercial and Industrial Optimized Calculator: Tool that runs through all processes performed in step 3 of this analysis. In short it uses various inputs to identify the potential solar capacity of rooftops. Requires DSM input, Solar Insolation Model input, and Building Footprint Input.
- Residential Optimized Calculator: Similar to the commercial calculator, but optimized to account for south facing rooftops. Requires DSM input, Solar Insolation Model input, and Building Footprint Input. This tool is the better choice if evaluating all land uses at the same time, without splitting of the building footprint.

As previously mentioned, U-Spatial is in the process of creating a solar insolation map for the entire state of Minnesota. This eliminates the time and effort that must be committed to the creation of the solar insolation model. Step 1 is the most time consuming and difficult portion of the GIS analysis, and we recommend that those with minimal GIS experience wait for U-Spatial to release the data before duplicating this work.

10.2 Spatial Analysis- Analysis and Process Steps

Step 1: Create Insolation Model

1) Download LiDAR data from MNGeo. LiDAR data for MN is publicly available (http://www.mngeo.state.mn.us/chouse/elevation/lidar.html)
2) Download Rapidlasso LiDAR processing tools (http://rapidlasso.com/lastools/)
3) Add LasTools.tbx into ArcMap and Use "Las2Las(project)" in order to convert the data from LAZ format into LAS format. LAS format is useable within ArcMap. (Batch processing recommended if converting multiple tiles)
4) Go to workspace folder in ArcCatalog, right click and create a new "LAS Dataset." Add LAS files into LAS Dataset and import into ArcMap.
5) Use Tool LAS Dataset to Raster (See Figure A.1)
6) Due to the large size of the raster, and the processing constraints of the "Area Solar Radiation" tool, it is necessary to split the raster into pieces. Use the "Split Raster" tool to split the raster into approximately .5 by .5 km pieces.
7) Apply the "Area Solar Radiation" tool to each raster. An iterator can run through all pieces of the split raster (See data download from hhhsolar2014 for tool). Many inputs into the tool are modeled after Brandt's work in Stillwater (Brandt, 2013).
8) Merge all raster pieces into one using the "Mosaic to New Raster" tool. This creates the final Solar Insolation Model of Minneapolis.

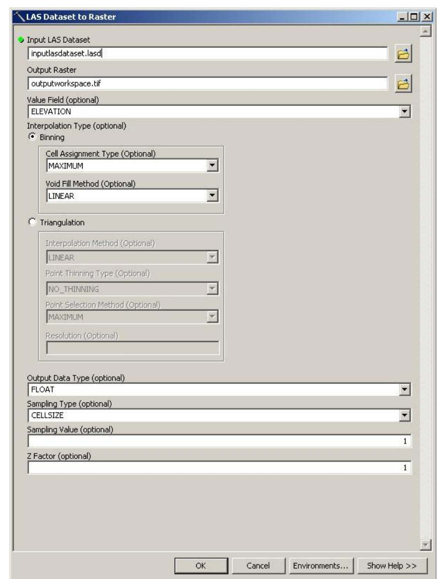

Figure A.1. Inputs for the creation of the Digital Surface Model.

Table A.1. Average Monthly Insolation Values for Minneapolis as identified using the insolation model. Shadowing leads to values far lower than values calculated by NREL.

Month	$Wh/m^2/month$	Days in Month	$Wh/m^2/day$	$kWh/m^2/Day$
January	11965	31	385.97	0.39
February	22588	28	806.71	0.81
March	50519	31	1629.65	1.63
April	79322	30	2644.07	2.64
May	107592	31	3470.71	3.47

June	115254	30	3841.80	3.84
July	113282	31	3654.26	3.65
August	91232	31	2942.97	2.94
September	59500	30	1983.33	1.98
October	30114	31	971.42	0.97
November	13770	30	459.00	0.46
December	8815	31	284.35	0.28

Step 2: Compare Solar Insolation Model to Real Data

1) Obtain actual solar production data on installation (Ideally multiple).
2) Obtain aerial imagery and digitize solar area on imagery. Assess to be sure that LiDAR data and aerial imagery align.
3) Use the "Zonal Statistics as Table" to identify the sum of solar energy within the digitized area. (See Figure A.2)
4) Divide the actual solar energy production by the modeled production value to obtain a "conversion factor" between the model and actual array. Be sure all values are in kWh. (Note: Solar insolation output is in watt hour, and must be divided by 1000 to obtain kWh).
5) Apply conversion factor to step 3.

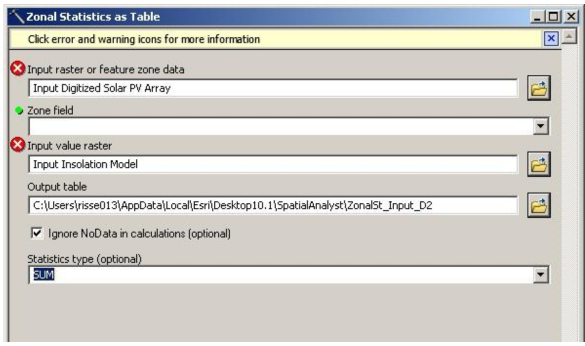

Figure A.2. Screenshot of the ArcGIS tool used to identify the modeled insolation of the Convention Center.

Step 3: Identify Solar Potential for other Commercial/Industrial/Mixed Use Buildings

The analysis steps for this section can be found in the hhhsolar2014 data download. To look at the GIS processes, open the toolbox in ArcGIS. Then, edit the toolbox to view the tools and outputs used for this analysis. This allows for evaluation of each tool and changes to the process if necessary. The tool is ready to use, but refer to the tool help before running the tool for specific instructions. The "Commercial and Industrial Optimized Calculator" (Figure 11) were the approximate steps used in this analysis, but have been refined further in the toolbox to simplify processes. The final output from the tool is the addition of three key fields in the attribute table (Figure A.3):

"tot_kWh"- This represents the approximate kilowatt hours that each building can produce assuming that 100% of the sun's energy can be converted to electricity by solar panels.

"Pot_kWh"- This represents the approximate kilowatt hours that each building can produce when accounting for constraints of solar technology.

"Install_Size"- This represents the approximate size of solar PV that could be installed on each rooftop.

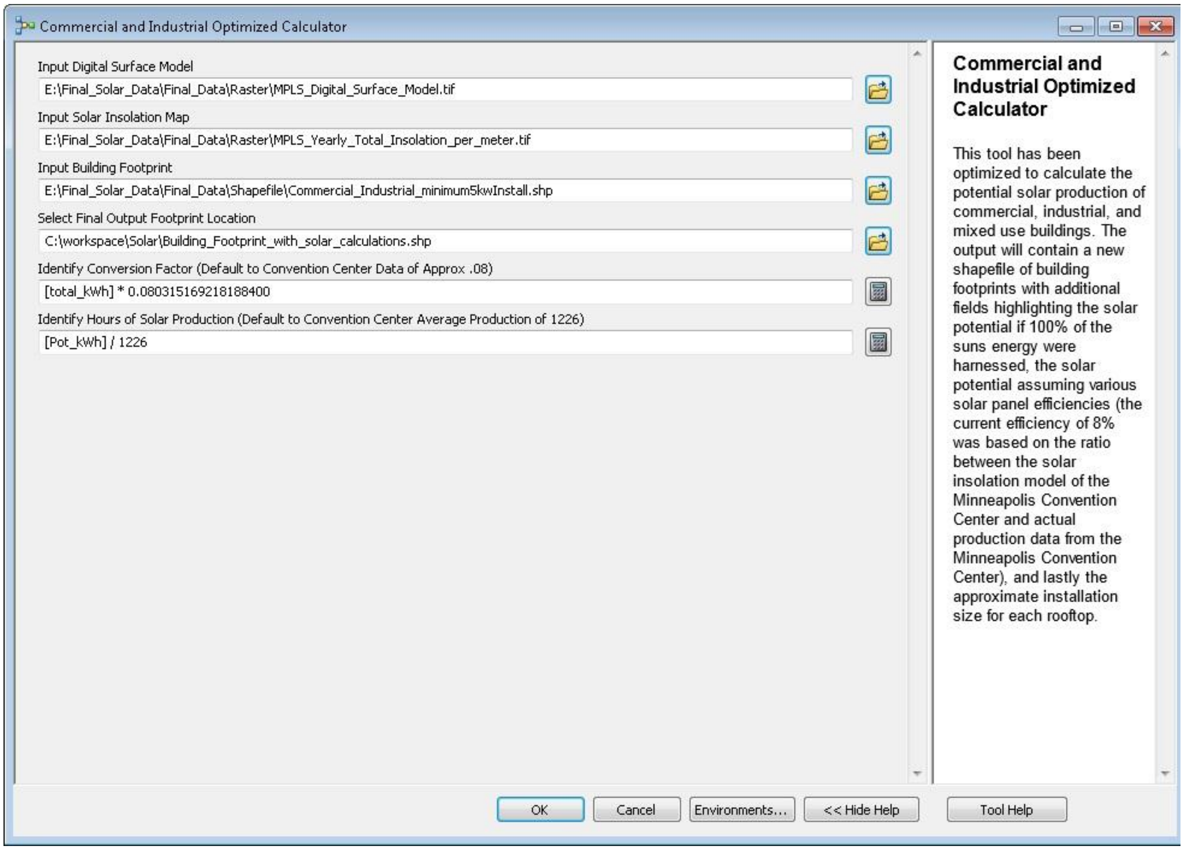

Figure A.3. The tool created using ArcGIS ModelBuilder for use in future analyses

Limitations

Minneapolis Convention Center Data

The solar PV installation on the Minneapolis Convention Center first came online in 2011, and technological improvements continue to be made to solar panels. New panels are likely more efficient. In addition, a large portion of the Minneapolis Convention Center solar PV installation faces southwest. This means that it is not producing energy during morning hours.

The results from this analysis would be more robust if additional installations were incorporated into the study to better understand the differences between the solar insolation model and raw energy data of real solar panels. An average production of multiple installations would provide a more accurate assessment of what a solar array can produce, and we could refine the scaling factor of .08 efficiency. Data from additional solar PV installations in Minneapolis, however, may be difficult to obtain.

GIS Processing Time

An additional limitation to the model was the processing time for the “area solar radiation” tool in GIS due to the large size of Minneapolis. In order to speed up processing, the Minneapolis model had to be split into approximately .5 by .5 kilometer tiles. Also, as recommended by Brandt, the sky size was limited to 512. Sky size was an important component of our calculations. A larger sky size would further refine the solar insolation model. Even with this adjustment, processing took over a week on a desktop computer. Splitting the data into tiles also affected the edge of each tile. For example, the southern portion of each tile likely recorded higher incoming radiation values, as the edge of the tile did not pick up any obstacles from the adjacent tiles. The effect can be seen in Figure A.4. It is most apparent in the downtown area, where buildings are many different heights. In areas where buildings have similar heights, the affect was less apparent.

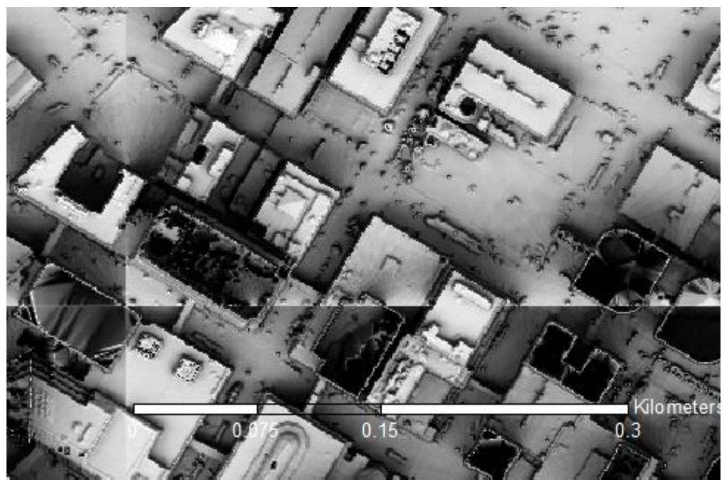

Figure A.4. An illustration of one shortcoming of the solar insolation map- due to processing restraints tiles had to be merged together, leading to some differences between the edges of adjacent tiles

Spatial Constraints

The study accounts for all “flat” roofspace, but does not account for spatial constraints. For example, a rooftop may have a large amount of flat space, but in a shape that does not accommodate solar panels. Further investigation is necessary to identify appropriate geometries for solar panels on rooftops. In addition, the total available space on rooftops is rarely used in solar PV installations. This means that the study likely overestimates what would be installed in real world scenarios. However, it also highlights the fact that more energy can be produced by being efficient, and using all available space for energy production. Another spatial is that the structural stability of rooftops was not analyzed in this study, since we assumed all flat rooftops could structurally bear solar panels.

Despite these limitations, our results show that C&I rooftops have significant potential to help Minneapolis reach its increased renewable energy goals through solar PV implementation. The analysis also highlights the point that the largest rooftops provide a more economical solution to renewable energy needs in Minneapolis as the largest 18 potential installations compose almost 9% of the total solar potential. The 2,190 smallest structures, which would individually need to be connected to the grid, account for just 12.3% of the solar potential. While this spatial analysis serves as a useful tool for bounding physical capacity, financial and legislative parameters are other essential pieces to determining how Minneapolis will reach its renewable energy goals.

10.3 NREL Best Research-Cell Efficiencies

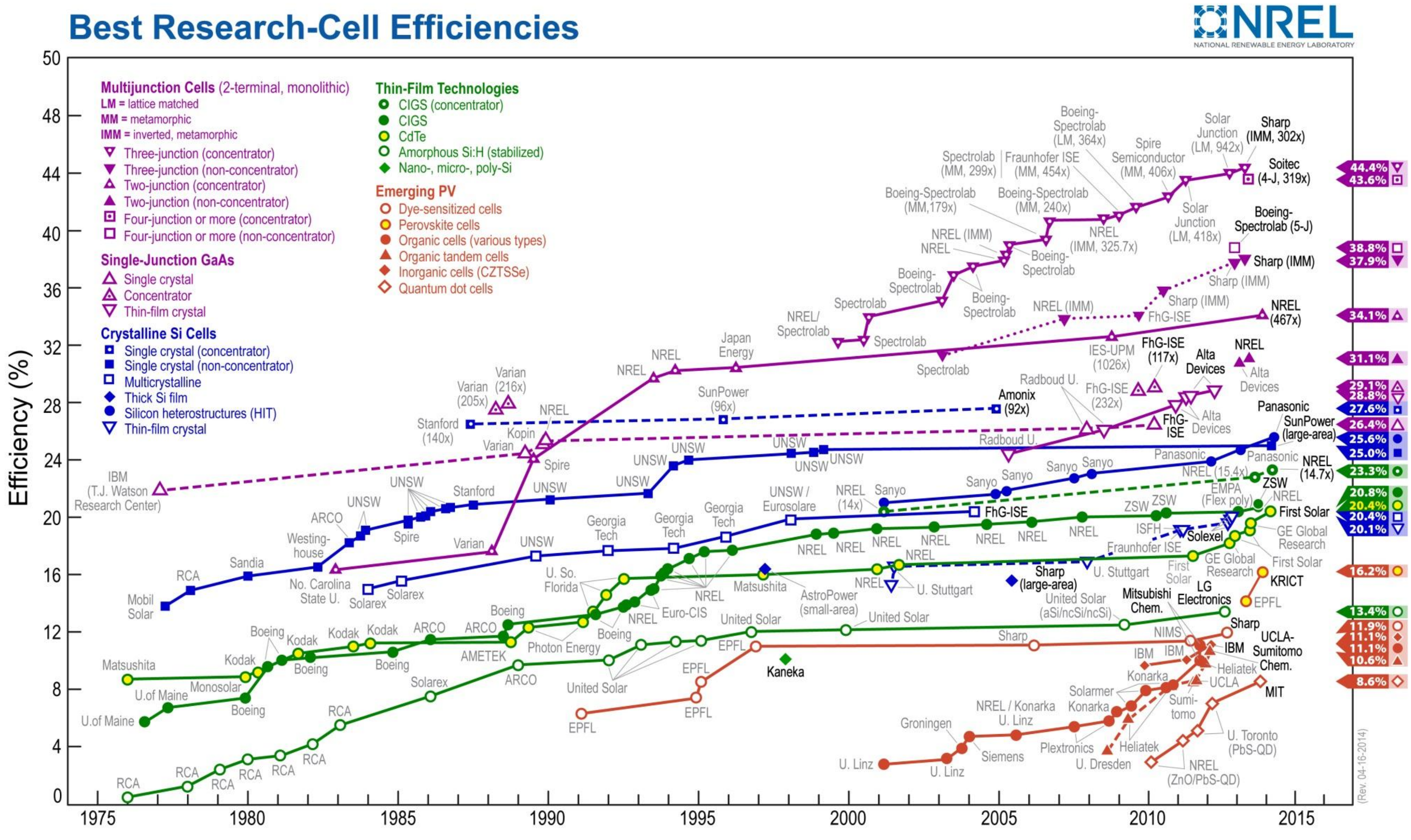

Figure A.5. Best Research Cell Efficiencies
Source: NREL 2014