Reduce Salt Usage by Preventing Snow Drifting on Roads – A Solar Snow Fence Technology

Mijia Yang, Ph.D., P.E.
Professor
Department of Civil, Construction and Environmental Engineering
North Dakota State University, Fargo, ND

Dan Gullickson
Blowing Snow Control Shared Services Supervisor,
Minnesota Department of Transportation

Presentation Outline

(1) Salt usage on Minnesota roads

(2) Snow removal reduced by controlled snow drifting

(3) Manufacturing of solar snow fence

(4) Field implementation, monitoring, and data collection of the solar snow fence

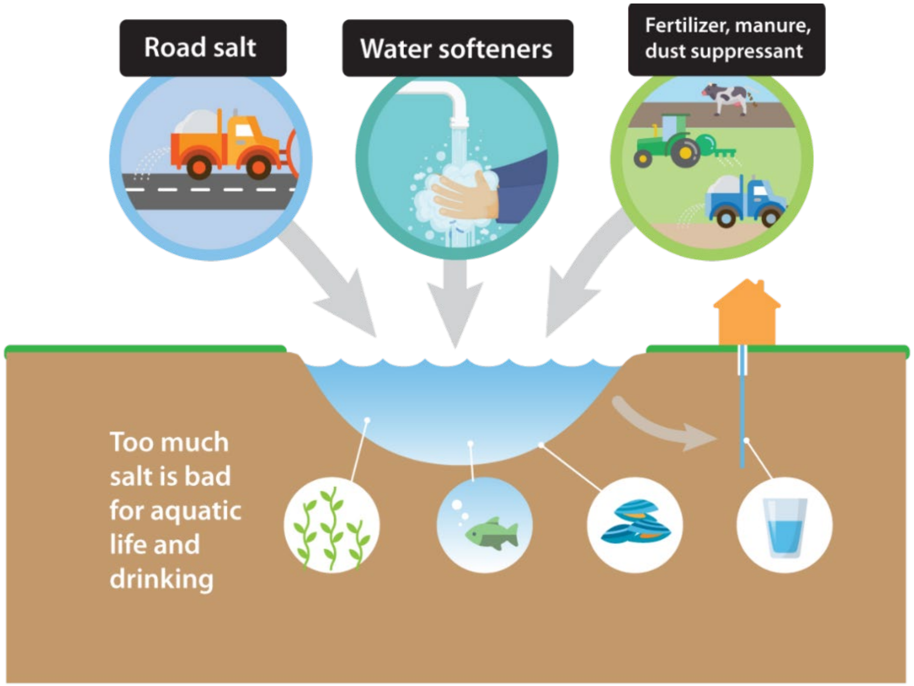
(5) Cost-benefit analysis of the solar snow fence in different lengths and different usage approaches

(6) Conclusions

Salt Usage on Minnesota Roads

(1) Minnesota Pollution Control Agency (MPCA) estimates Minnesotans apply about 445,000 tons of salt to paved surfaces every single year.

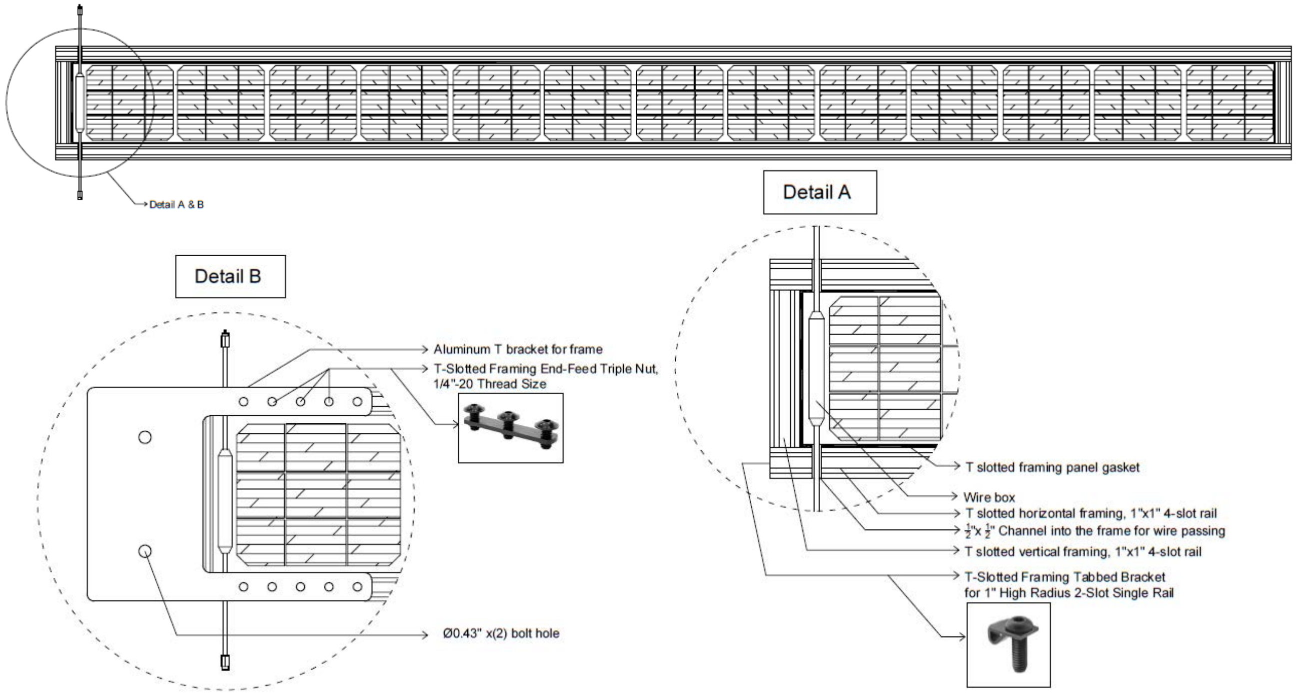
(2) In the winter of 2012-13, a typical severe winter, MnDOT used 304.6 thousand tons of salt and 44.3 thousand tons of sand.

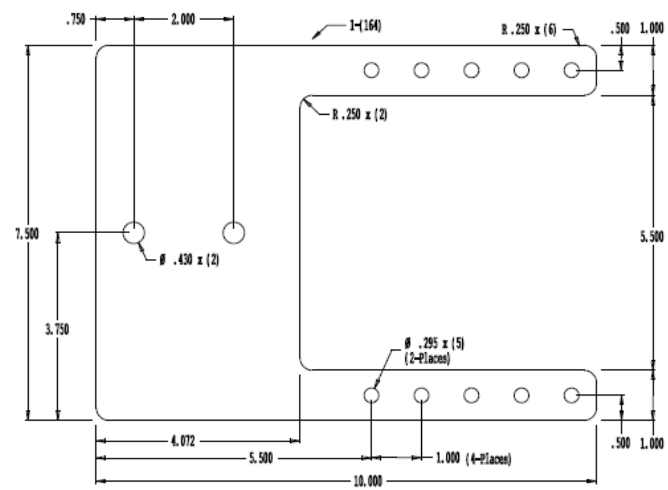


Snow Removal Reduced by Snow Fence

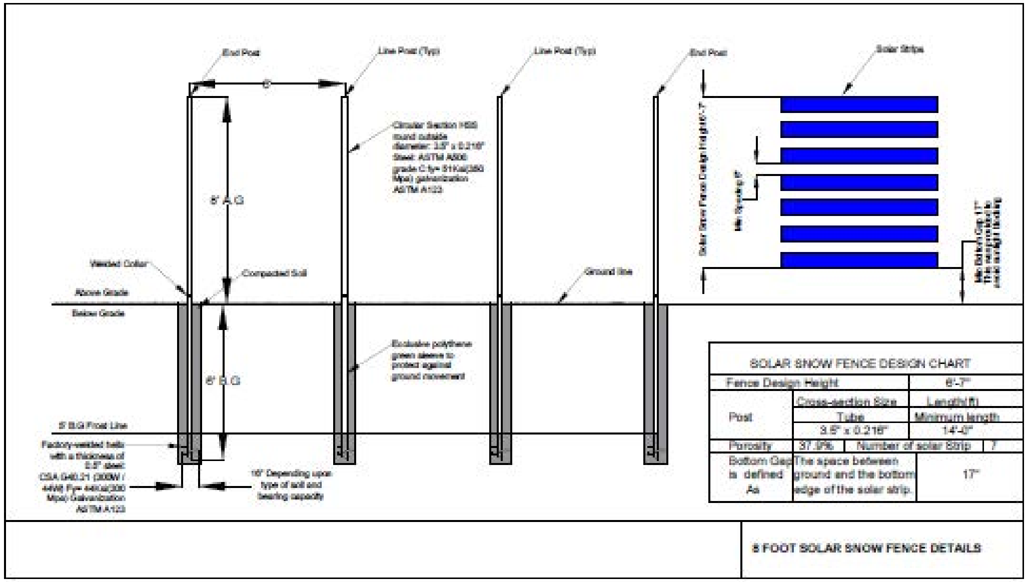
1) The decision whether to plow or salt is made with great consideration and based on the latest weather information available.
2) Less snow drifting leads to less snow removal and less salt usage.
3) Snow fences reduce the amount of plowing needed to keep roads clear of snow, and they greatly improve visibility during blizzards (Tabler, 2003). A 15-year study on I-80 in Wyoming showed snow fence reduced snow removal by 1/3 to ½.
4) Snow fence also reduces crashes in blowing snow conditions by 60%.
5) A mechanical snow removal costs $3/ton in 2003, while a snow fence of 4 ft can retain 4.2 tons of snow per ft.

Manufacturing Solar Fence Strip (1)



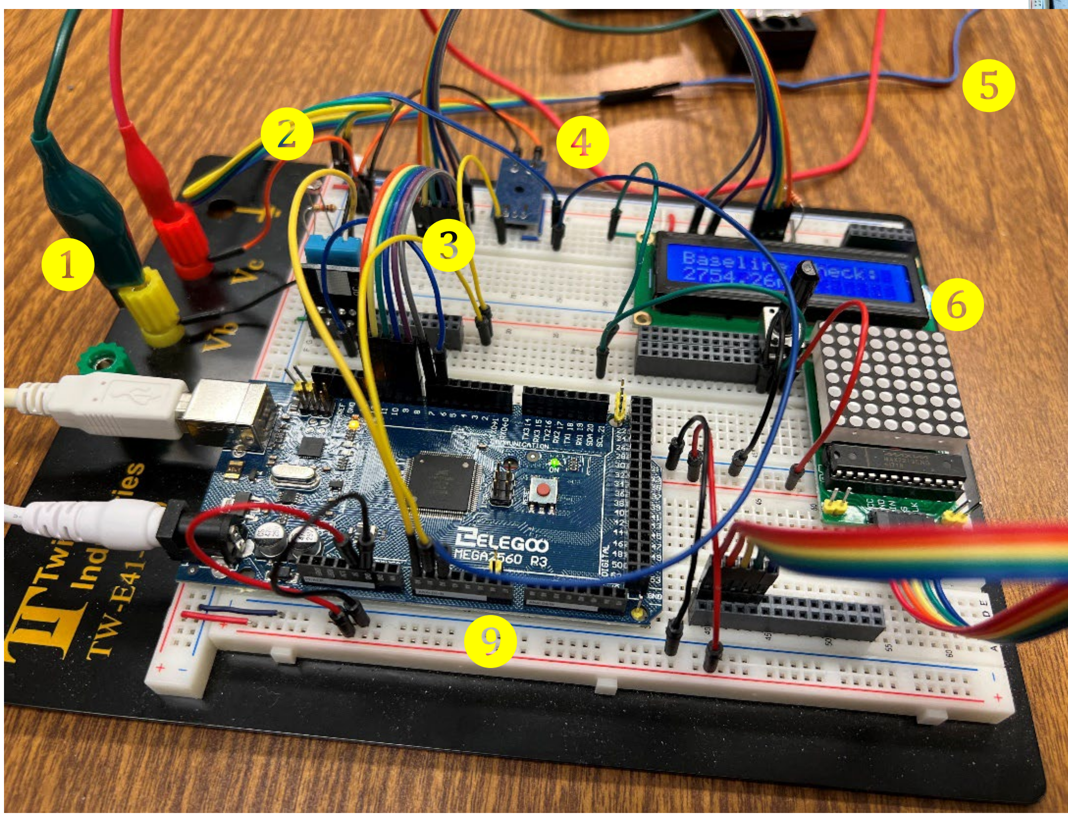


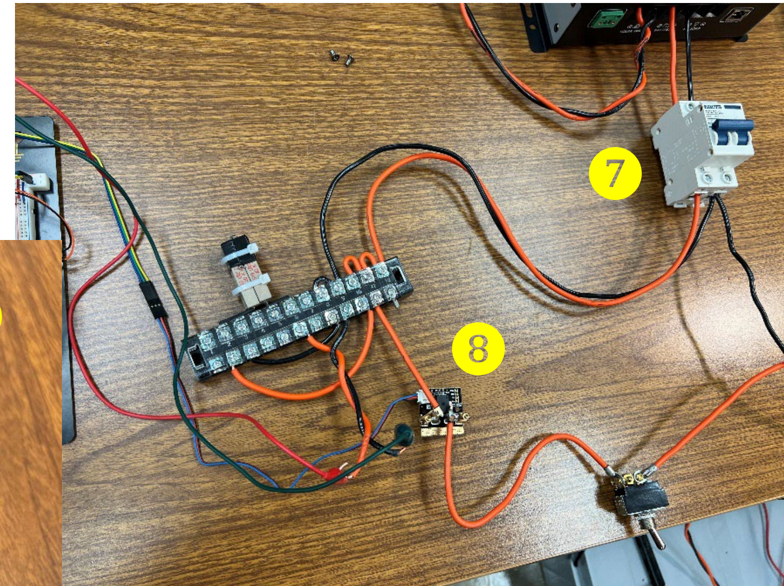
Manufacturing Solar Fence Strip (2)



Lab Inverter/Controller Testing (1)

Monitoring system (Circuit):





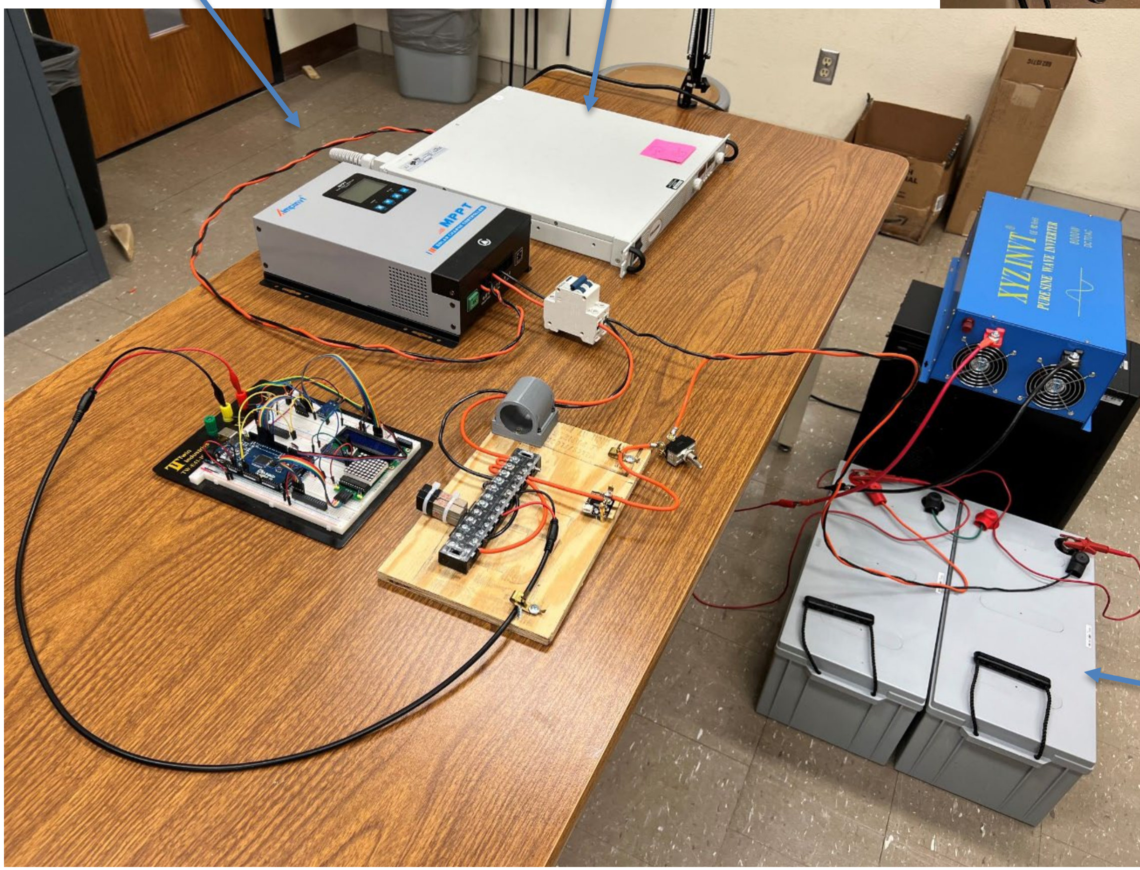
1. Voltage input
2. Light sensor
3. Temperature/humidity sensor
4. Voltage sensor
5. Current input
6. Display
7. Switch/fuse
8. Current sensor
9. Arduino processor

Lab Inverter/Controller Testing (2)

Power system:

Charger

DC voltage source



Inverter

AC 110-V load

Batteries

Implementation Site

Field Construction (1) – Pile Drilling

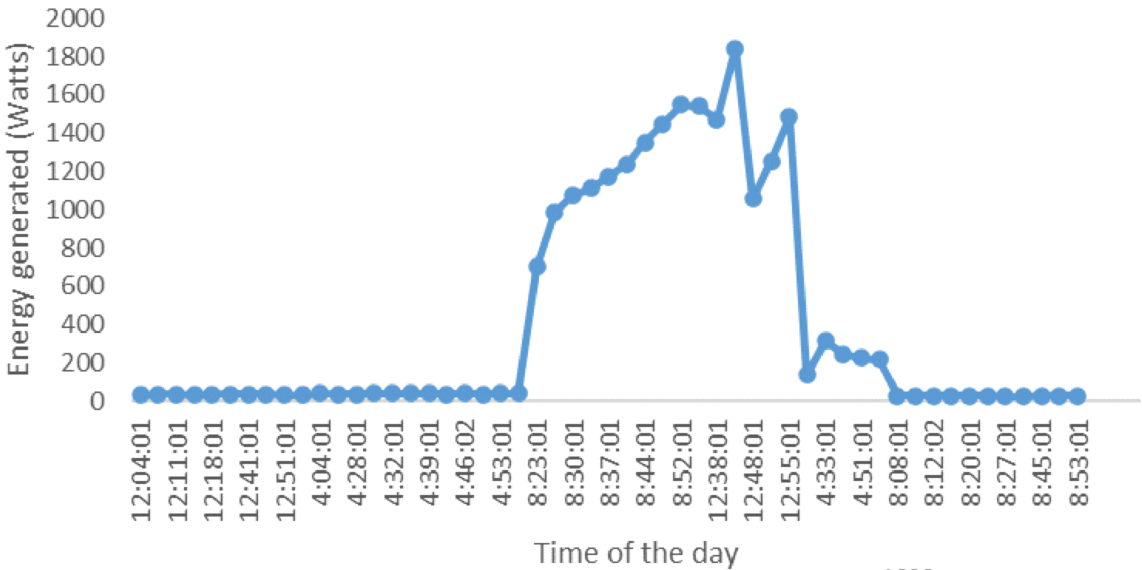
Field Construction (2) – Solar Strip

Field Construction (3) – Control Station

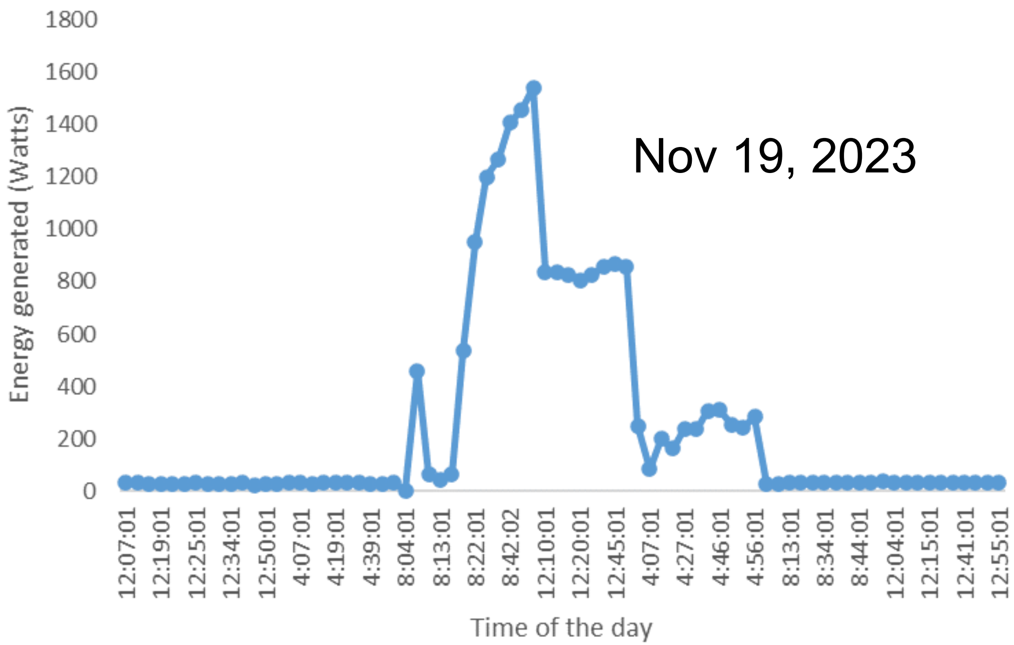
The solar snow fence in Remote View

Remote Control of Snow Melting Pads

Energies Produced in Two Days of Nov.

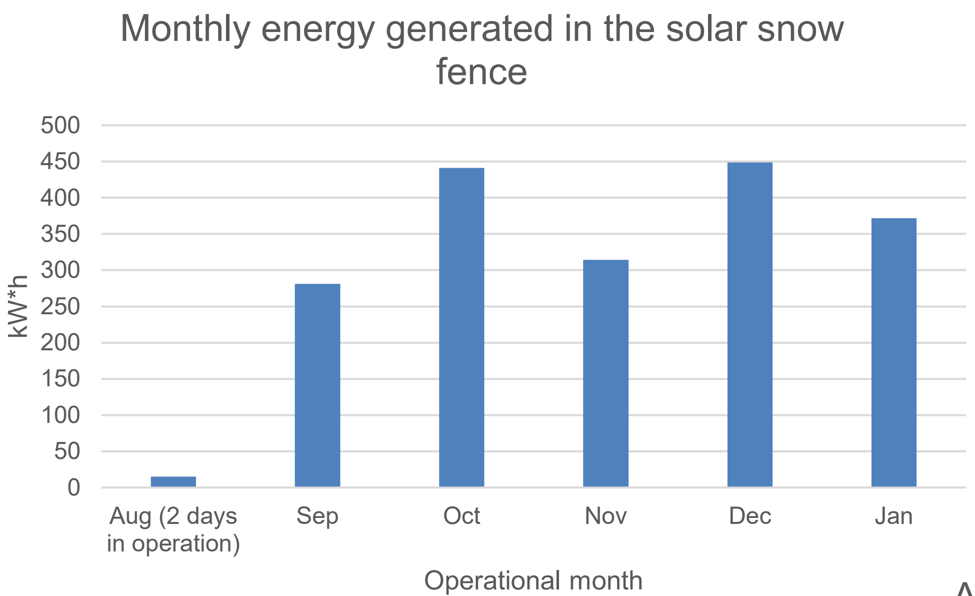


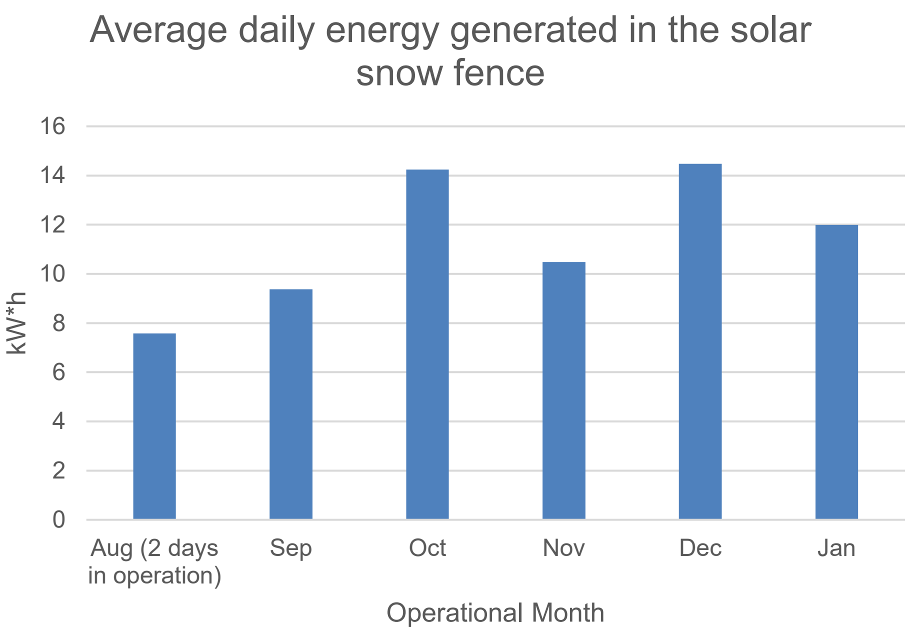
Nov 18, 2023



Nov 19, 2023

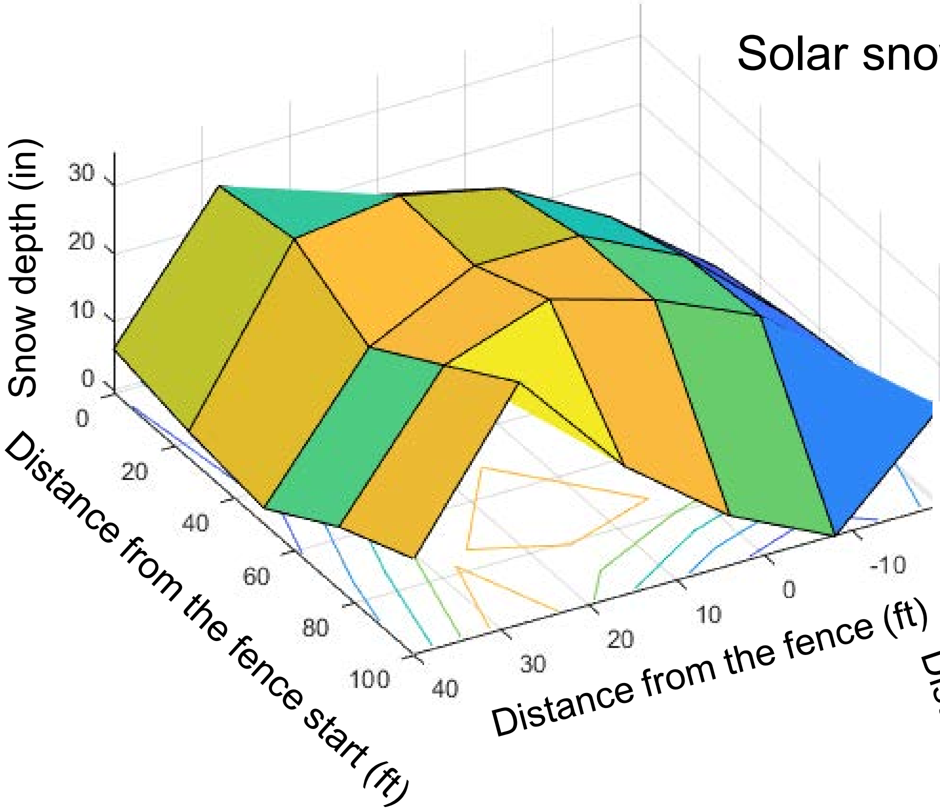
Energies Produced in the Past Half Year

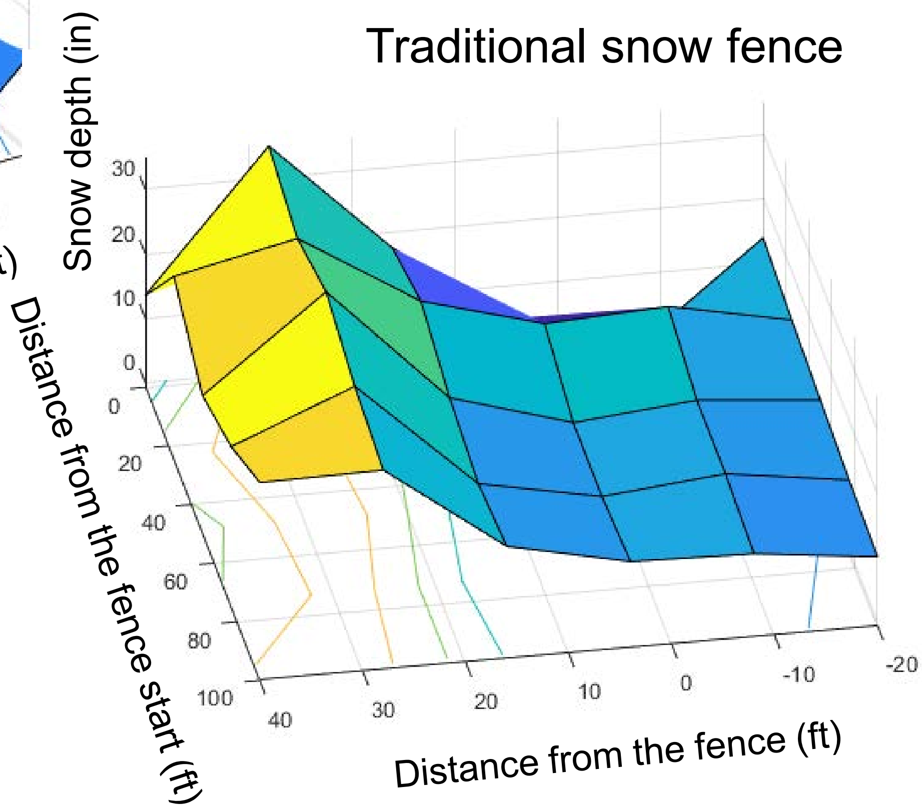




Comparison of Drifting Snow

Comparison of the Fence Effectiveness





Snow depth measurement at 1/28/2024

Cost-Benefit Analysis of the Solar Snow Fence

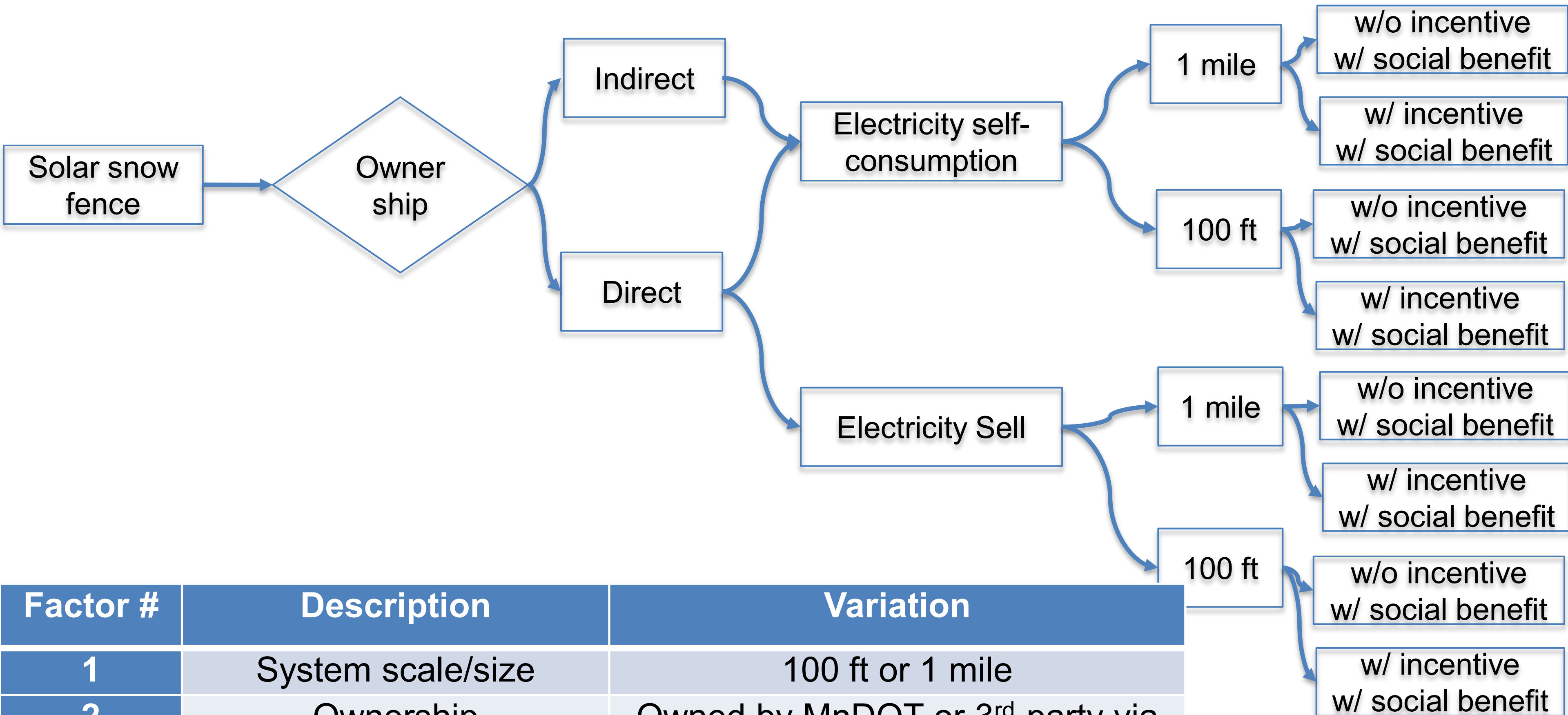
Total Cost = Direct Capital Costs + Indirect Capital Costs + O&M Costs +Future Costs

Direct Capital Costs	Indirect Capital Costs	O&M Costs	Future Costs
1. Module Price 2. Inverter Price 3. BOS Equipment 4. Direct Installation Labor 5. Grid Interconnection and Transmission 6. Supply Chain Costs	1. Permitting and Environmental Studies 2. Customer Acquisition and System Design 3. Other Overheads 4. Sales Taxes	1. Inverter Replacement 2. Insurance Cost 3. O&M Annual Cost	1. Recycling Cost 2. System Salvage Value

Total Benefit = Incentives + RECs + Revenues Generated + Electricity Cost Savings + Environmental Benefits

Incentives	RECs	Revenues Generated	Electricity Cost Savings	Environmental Benefits
• Federal ITC • Other Incentives	• Renewable Energy Certificates (RECs)	• Revenues generated by selling solar power to utility companies	• Lower electricity price through PPA • Avoided electricity costs due to self-use	• GHG Emission Cost Savings

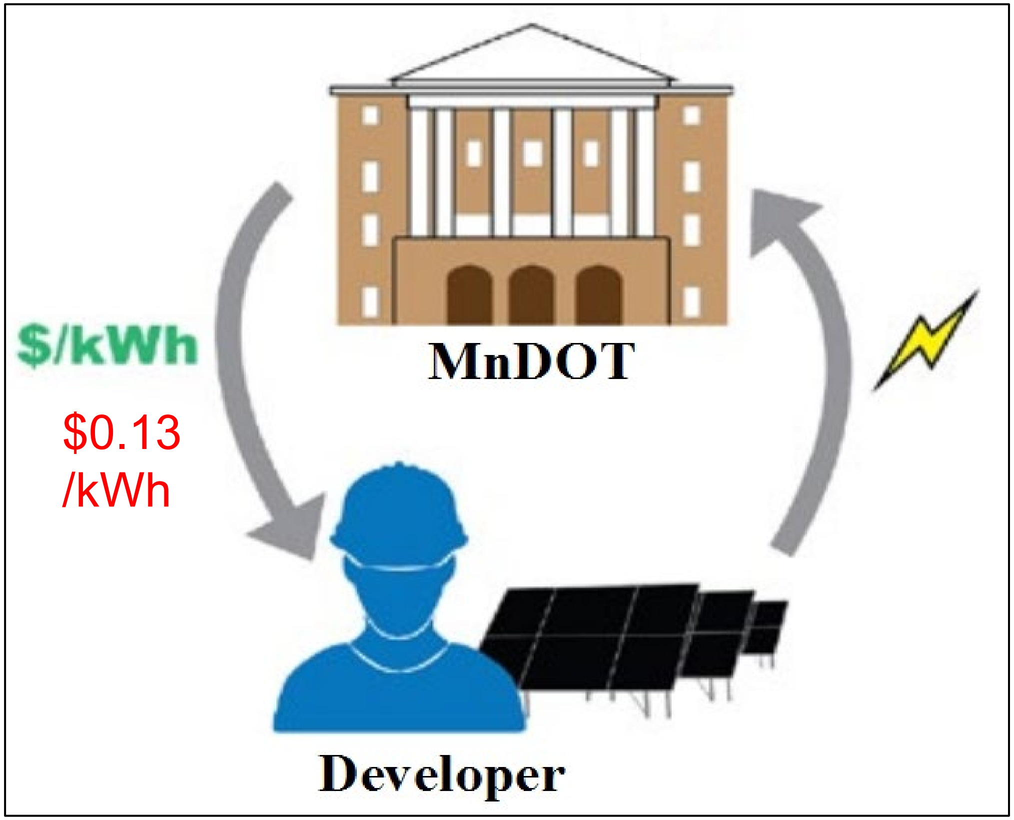
Cost-Benefit Model in One Chart



Factor #	Description	Variation
1	System scale/size	100 ft or 1 mile
2	Ownership	Owned by MnDOT or 3rd-party via PPA
3	How to use the generated electricity	Selling to utility or self-used
4	If including environmental and/or social benefits?	Included or Not included
5	If including incentive(s)?	Included or Not included

Power Purchase Agreement (PPA) Model

- A PPA is a financial mechanism that allows MnDOT to accrue the benefits of solar power but without owning the system.
- In a PPA, a solar project developer procures, builds, operates, and maintains the solar system, while the MnDOT buys power from the developer at a negotiated rate [1].



Potential solar developers for PPA in Minnesota

- Great River Energy
- Cedar Creek Energy
- AMERESCO
- Northern States Power Company (Xcel)
- US-Solar (MN)
- Minnesota Power (ALLETE)
- Otter Tail Power Company
- Marshall Solar, LLC
- Allco & Ecos Energy

[1] NREL. (2016a). Using Power Purchase Agreements for Solar Deployment at Universities. Retrieved from https://www.nrel.gov/docs/gen/fy16/65567.pdf

Case Scenarios

Case scenario	Ownership	Electricity usage	Social benefits	Incentives
1	Direct	Sell	No	No
2	Direct	Sell	Yes	No
3	Direct	Sell	No	Yes
4	Direct	Sell	Yes	Yes
5	Direct	Self-consumption	No	No
6	Direct	Self-consumption	Yes	No
7	Direct	Self-consumption	No	Yes
8	Direct	Self-consumption	Yes	Yes
9	Indirect	Solar PPA	No	NA
10	Indirect	Solar PPA	Yes	NA

Social Benefits of Solar Snow Fences (1)

When integrating these two cash flows, the results are primarily influenced by the cash flow for the snow fences due to the significant benefit of using snow fences, even though snow fences only account for a small portion of the total capital cost (including the PV system).

Structural Snow Fence Benefit Information		Comments/Notes
Drifting Savings* [$/mile-Year]	$34,486.03	Agency cost savings of drifting snow events
Blow Ice Savings* [$/mile-Year]	10,207.09	Agency cost savings of blowing snow and ice events
Avoided Crashes* [$/mile-Year]	29,638.00	Cost savings from fatal, injury, and property damage crashes
Avoided Travel Time* [$/mile-Year]	12,826.93	Savings caused by travel time reductions due to improved road conditions
Avoided Carbon Emissions* [$/mile-Year]	$241.40	Cost savings from reduced carbon emissions by agency equipment
Salvage Value [$/foot]	$0.09	For steel poles

Social Benefits of Solar Snow Fences (2)

PV System's Benefit Information		Comments/Notes
Federal ITC or other incentives	10.00%	(U.S. DOE, 2021)
RECs* [$/REC or $/MWh]	$0.65	(MnDOC, 2019)
Price to sell back to a utility company [$/kWh]	$0.11	(Yang et al., 2021)
PPA for 3rd-party ownership [$/kWh]	$0.10	(NREL, 2016a)
Bituminous Coal [Per Short Ton]		
Heating Value [MMBtu]	24.93	(U.S. EPA, 2014)
1 kWh to Btu	3,412	(U.S. EIA)
Electricity Output [kWh]	7306.57	(U.S. EPA, 2014)
kg CO_2	2,325	(U.S. EPA, 2014)
g CH4	274	(U.S. EPA, 2014)
g N2O	40	(U.S. EPA, 2014)
Greenhouse gas (GHG) Emission Cost Savings		
Per metric ton CO_2	$42.00	(U.S. EPA, 2017)
Per metric ton CH4	$1,200.00	(U.S. EPA, 2017)
Per metric ton N2O	$15,000.00	(U.S. EPA, 2017)
GHG Emission Ratio (Coal/Solar)	8.37	(Fan, 2014)

Other Specs for PVSF (1)

PV Panel Information for Snow Fences		Comments/Notes
Panel Capacity [Watt]	40	Rated power of the PV panel purchased (Figure 4.19)
Panel Length [feet]	6	Actual dimension of the PV panels purchased
Panel Width [feet]	0.5	Actual dimension of the PV panels purchased
Number of Panels per 100 ft	112	Seven customized panels (0.5×6 ft) per section, installed vertically on snow fences (Figure 3.6)
Degradation Rate [%]	0.8	(NREL, 2012)
Array Type	Fixed	Not adjustable to not influence the original function and effectiveness of the snow fences
Tilt [deg]	90	Vertical installation as shown in Figure 3.6
Azimuth [deg]	180	Facing South
Latitude	46.88° N	Actual installation location (Figure 3.1)
Longitude	96.66° W	
Annual AC Energy Output: 100 ft [kWh]	2,869	Calculated based on the actual measurements (for 6 months) and by using the online PV Watts Calculator developed by NREL (Pvwatts) for the other 6 months (as shown in Figure 4.2)
Metric Tons of CO2 Equivalent/year: 100 ft	2	Calculated by using the EPA Greenhouse Gas Equivalencies Calculator (National Average) (U.S. EPA)

Other Specs for PVSF (2)

	Study No.			
	1	2	3	4
Interest Rate (%)	0.35%	5.5%	5.5%	5.5%
Project Length	1 Mile	1 Mile	100 ft	1 Mile
Panel Capacity [Watt]	100	100	40	80
Panel Length × Width [feet]	12×0.5	12×0.5	6×0.5	12×0.5
Number of Panels	3,520	3,520	112	3,520
Module Cost ($/Watt)	0.85	0.85	1.25	1.02
Inverter Cost ($/Watt)	0.15	0.15	0.20	0.20
BOS Equipment Cost ($/Watt)	0.35	0.35	2.09	1.71
Direct Installation Labor ($/Watt)	0.20	0.20	0.30	0.20
Grid Interconnection and Transmission ($/Watt)	0.05	0.05	0.07	0.05
Permitting and Environmental Studies ($/Watt)	0.05	0.05	0.06	0.05
Customer Acquisition and System Design ($/Watt)	0.05	0.05	0.08	0.05
Other Overheads ($/Watt)	0.20	0.20	0.30	0.20
Inverter Replacement ($/Watt)	0.09	0.09	0.11	0.09
Insurance Cost by Capacity ($/kW-yr)	5.00	5.00	6.70	5.00
O&M Annual Cost by Capacity ($/kW-yr)	10.00	10.00	12.27	10.00
DC System Size (kW)	352	352	4.48	281.6
Annual AC Energy Output (kWh)	352,348*	352,348*	2,869**	281,894*
Snow Fence Installation Cost ($/ft)***	72.10	72.10	153.20	72.10
Snow Fence Recycling Cost ($/ft)	0.25	0.25	0.50	0.25

*Estimated using (Pvwatts); **Calculated based on the actual measurements (for 6 months) and by using (Pvwatts) for the other 6 months; ***Material and installation costs for steel posts (the number of the posts depends on the size of the PV panel, i.e., the number of posts in Study 3 is nearly doubled compared to that in Study 1, 2, and 4.

Simulation Study I and II

Simulation Study I and II: Calculation using real field costs and recorded production for a scale of 100 ft and 1 mile, with the new interest rate of 5.5%.

With field installation of the PV panels and data collection stated in the report, we are simulating the cost-benefit analysis based on real data collected from our panels.

There are several factors that have been modified from the previous version of the calculator.

Economies of scale: 100 ft vs 1 Mile

- Cost Efficiency: With a larger project, there may be opportunities for cost efficiencies. Bulk purchasing of materials, equipment will trigger discounts
- Installation Costs: The cost of installation may not increase linearly with project length
- Total Capital Costs: While certain costs, such as solar panels and inverters, may scale with project length.
- Logistical Challenges: Longer projects may introduce logistical challenges in terms of material transportation and management.
- Operational and Maintenance Costs: Operational and maintenance costs may scale differently

Payback Period (PP), Net Present Value (NPV), Internal Rate of Return (IRR).

Cost Information for Structural Snow Fences

Structural Snow-Fence Cost Information		Comments/Notes
Unit Hight [feet]	8	Based on actual installation (Figure 3.6)
Unit Length [feet]	100	-
Install & Material Costs [$/foot]	$153.20	Based on actual installation of the steel posts (about 6 feet apart)
Land Cost [$/linear foot/year]*	$1.00	Rental cost (Provided by MnDOT)
O&M Cost [$/Year]	$3,000.00	Including the cost of lawn mowing for safety purposes around the PVSF
Property Tax	$0	Lease: Paid by landowners
Recycling Cost [$/foot]	$0.50	(Ernie's Wagon)
Real Discount Rate* [%]	5.5%	(Federal Reserve, 2024)

Simulation Study I and II Results

Study 3 (100 ft – Real Power Generation)					Study 4 (1 Mile – Ideal Case Based on Actual Data)				
Case Scenario	NPV	PP (Yr)	IRR	Rank*	Case Scenario	NPV	PP (Yr)	IRR	Rank*
Case 10	$8,678.39	11	11.85%	1	Case 10	$861,183.99	5	28.09%	1
Case 9	$8,253.44	11	11.56%	2	Case 9	$819,430.89	5	27.03%	2
Case 4	-$9,401.21	>25	2.27%	3	Case 4	$102,456.98	22	6.29%	3
Case 3	-$9,849.41	>25	2.10%	4	Case 3	$58,419.38	23	5.96%	4
Case 2	-$11,617.72	>25	1.71%	5	Case 2	-$9,406.86	>25	5.43%	5
Case 1	-$12,065.92	>25	1.54%	6	Case 1	-$53,444.46	>25	5.11%	6
Case 8	-$12,661.68	>25	1.50%	7	Case 8	-$89,824.53	>25	4.89%	7
Case 7	-$13,109.87	>25	1.34%	8	Case 7	-$133,862.13	>25	4.58%	8
Case 6	-$15,280.21	>25	0.93%	9	Case 6	-$226,958.10	>25	4.05%	9
Case 5	-$15,728.40	>25	0.77%	10	Case 5	-$270,995.69	>25	3.76%	10

Summary and Conclusions

- A solar snow fencing system has been designed, built, and installed in the field. The performance of the system has been monitored over the past 6 months.
- The average energy generated is around 10-30 kW*h, depending on the solar intensity of the day.
- The electricity generated has been used by three melting pads, which rendered the snow fence system to be an active system and has an infinite reservoir capacity.
- All the electrical, the monitoring system, the data collection system, and the snow melting schedule can be controlled remotely. All these systems are powered by the solar energy generated.
- PPA will be a better approach to implementing the system. Long solar strips with fewer posts can reduce the payback years tremendously.

Next Steps

- Looking into ways to utilize solar energy generated through solar snow fences, such as for lighting of rural intersections, farm irrigation systems, and recharge stations in highway rest areas, etc.
- Explore solutions for similar projects under different terrain and location conditions
- Cost Optimization: Improvement of the system connection between PV panel and the steel post design will be recommended for cost effective purposes.
- Efficient logistics management is highlighted as a potential factor for cost reduction.

Questions?

Mijia.yang@ndsu.edu; yao.yu@ndsu.edu;

Tel: 701-231-5647; 701-231-8822