NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

Performance, reliability, and durability of solar PV systems in the Northern regions of Canada

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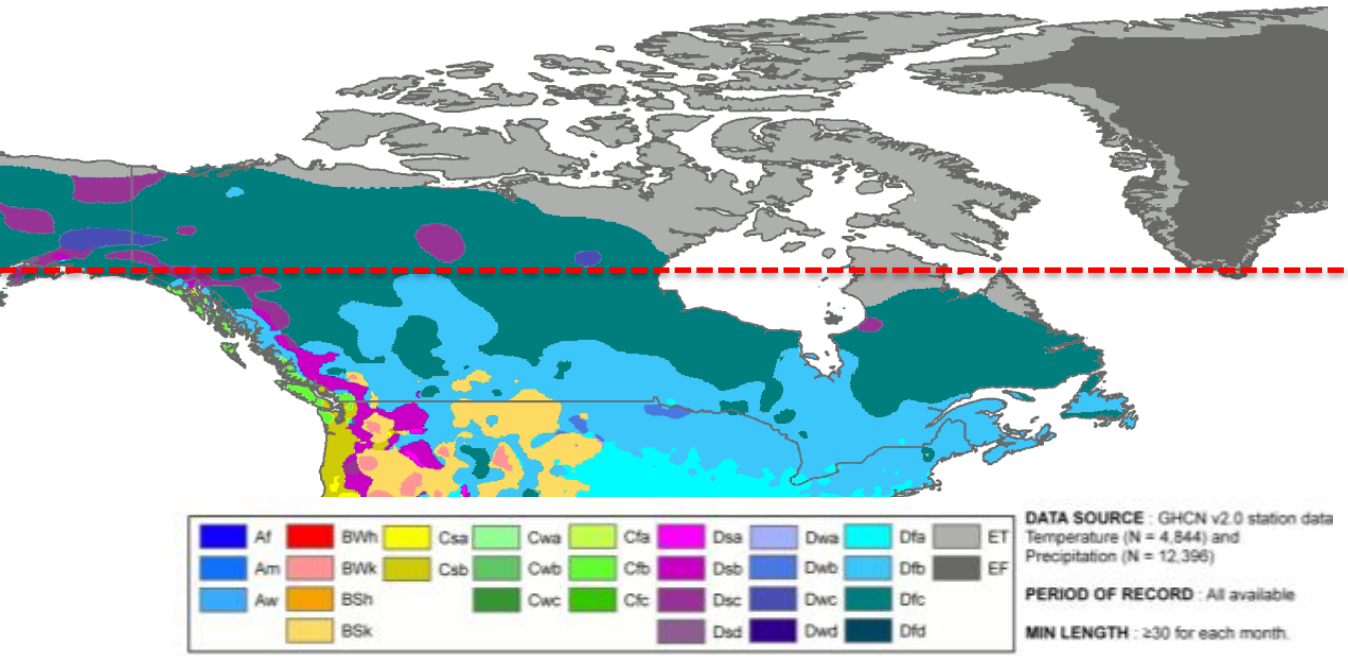
October 1, 2015

Outline

- Northern Canadian regions of interest
  - Climate profiles
  - Solar resource maps
- Performance
  - PV in cold climates
  - Monitoring of systems
  - Case Study: Fort Simpson
- Durability
  - Degradation modes
  - Report from Sweden
- Reliability
  - Case Study: Nunavut Arctic College
- Call-out for participation

Northern Canadian regions of interest

Climates typical for Northern Canada



By World_Koppen_Map.png: Peel, M. C., Finlayson, B. L., and McMahon, T. A. (University of Melbourne)
derivative work: Br-Sc-94
(World_Koppen_Map.png) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

60th parallel

Dfc (Subarctic):

- Long cold winters, short cool to mild summers.
- Permafrost common
- No wet/dry season, precipitation equally distributed.

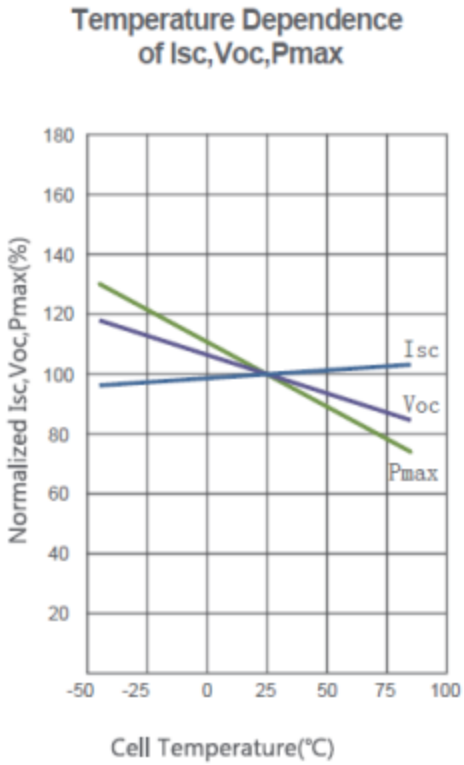
ET (Polar Tundra):

- Colder, drier, warmest month has an average temperature below 10ºC.
- Strong, cold wind, north of the tree line.

Performance

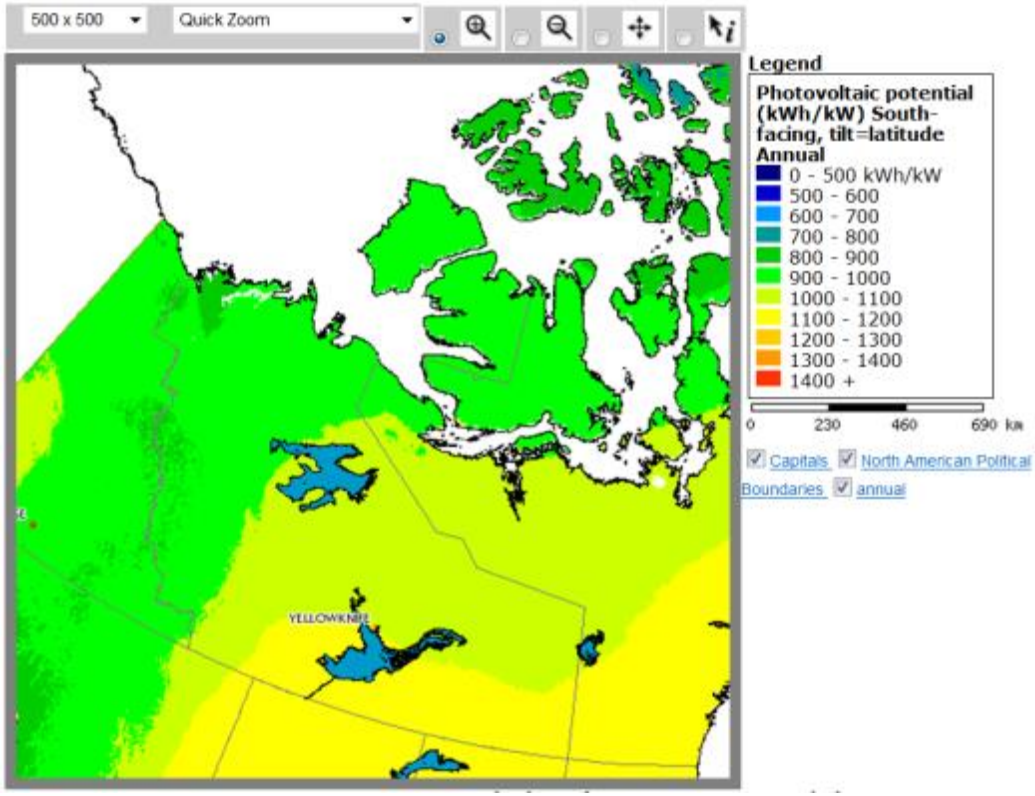
PV performance in cold climates

- c-Si PV cells perform significantly better at lower temperatures
- Rated maximum power is increased on the order of 0.5%/ºC drop in temperature from 25 ºC (the reference temperature for ratings).
  - For example, at 0 ºC, the maximum power will be increased to 112.5% of the rated value.
- Resistance is lowered in the conductors (PTC), decreased wiring losses



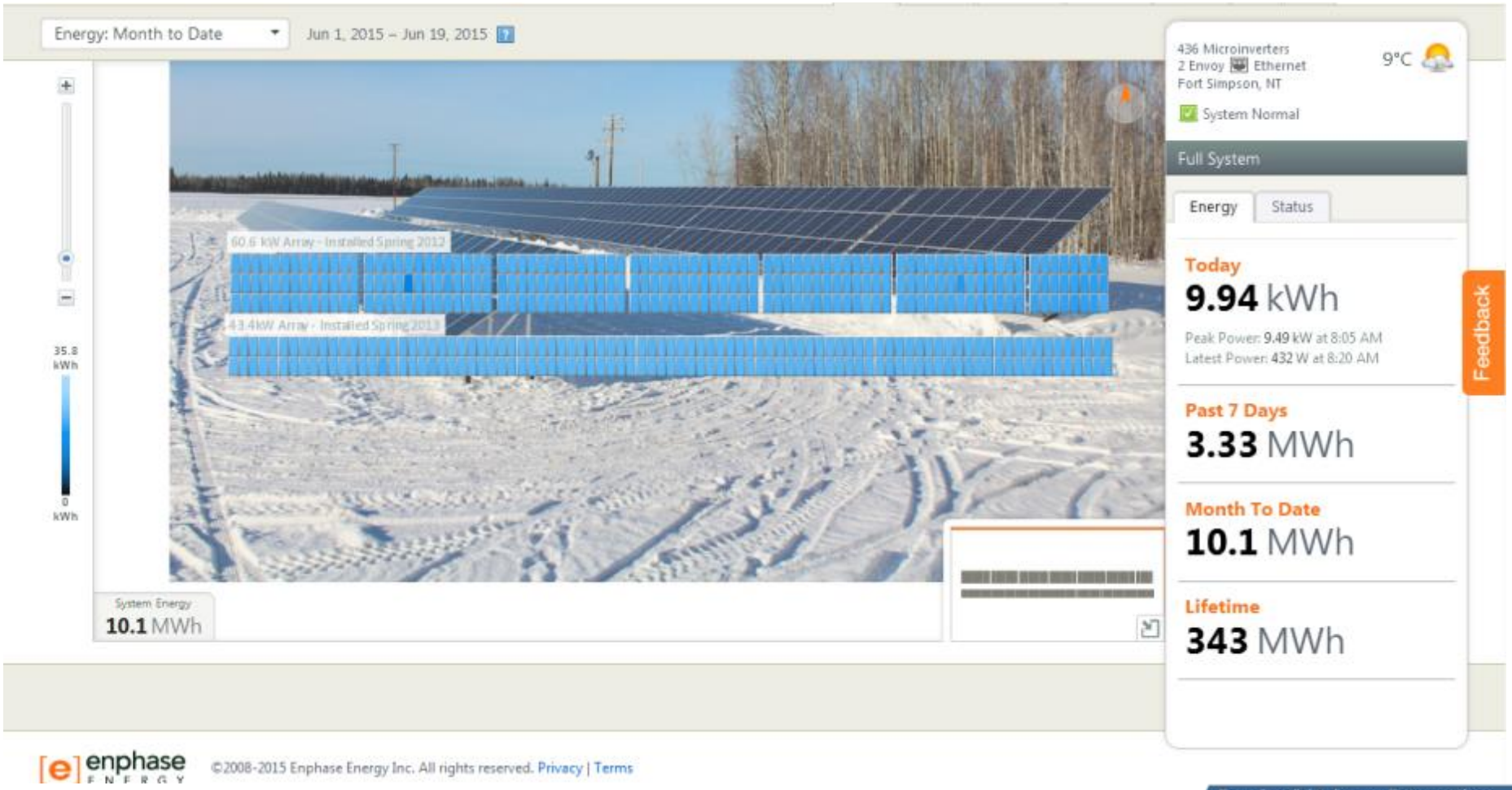
NWT Solar and PV Resource Map

http://pv.nrcan.gc.ca/

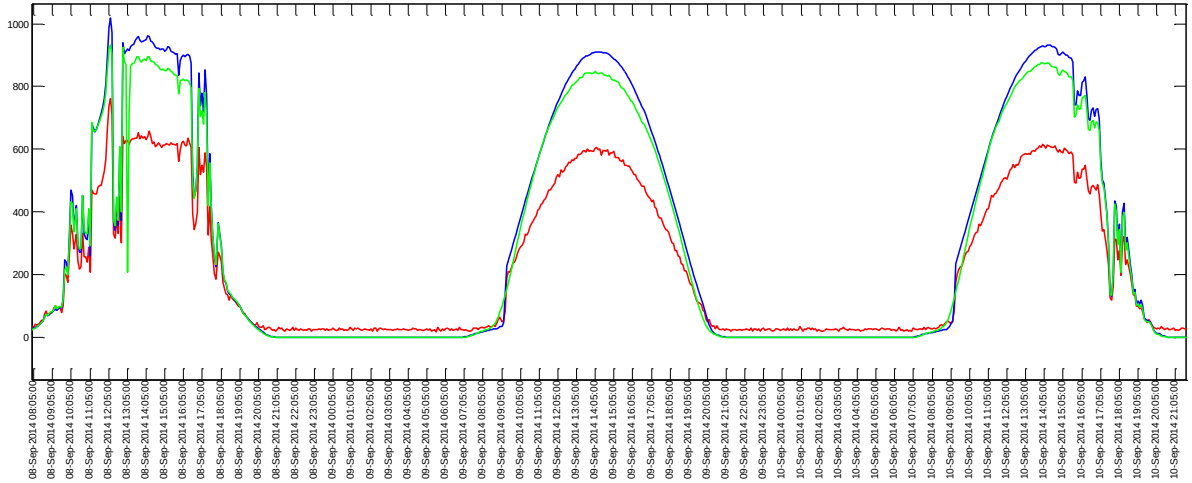


Solar PV map provides estimates in many of the targeted communities. Adding irradiance sensors to 15 solar PV systems to improve the accuracy of our solar PV potential database North of the 60th parallel.

Case Study: Fort Simpson, NWT
104.24 kW system (436 microinverters)



Irradiance and temperature measurement system commissioned (2014)



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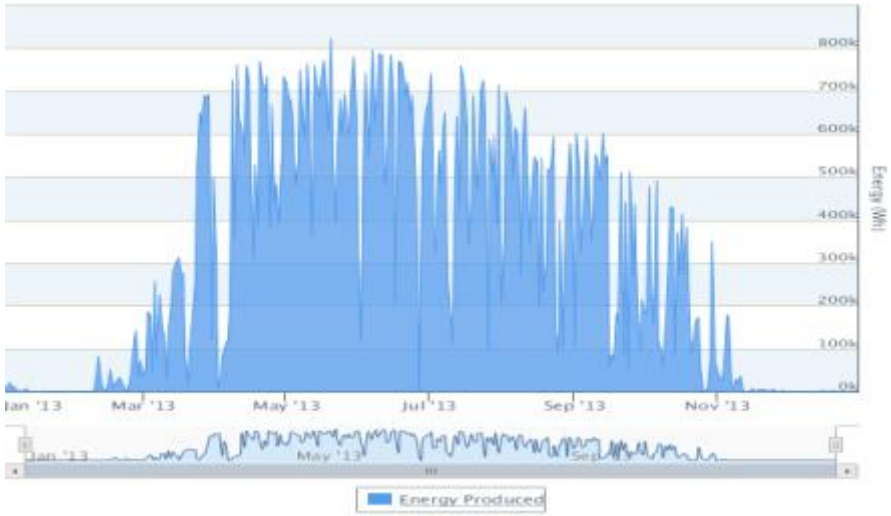
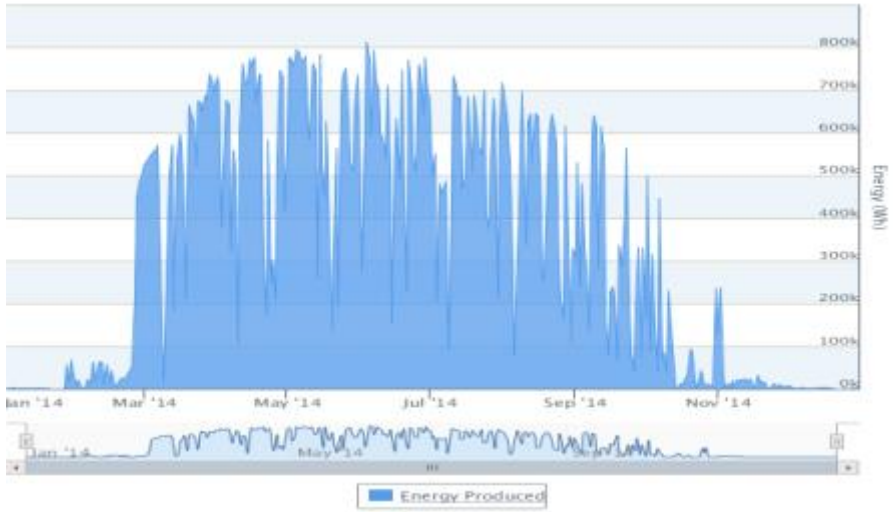
Comparing two years yield from Fort Simpson





2013

109 MWh (**1046 kWh/kWp**)

2014

116 MWh (**1113 kWh/kWp**)

*(Recall that expected yield is in the range of **1088 kWh/kWp**)*

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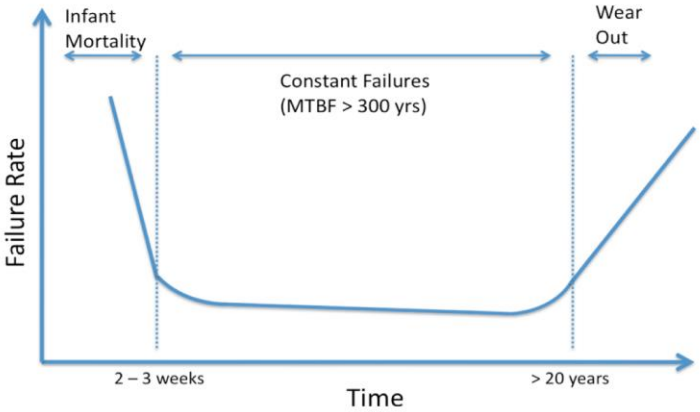
Durability

Microinverters are suitable for the North?



Microinverters have many advantages over traditional string-inverter architectures

- Eliminate the problem of single-points of failure
- Modular
- Performance easily monitored with increased granularity
- Problems with one module do not affect the entire string/array

However, since they are usually mounted outdoors, we would like to verify that they would be suitable for Northern Canadian climates

20 year old modules from the roof of our lab near Montreal

What are some of the major causes of degradation?

- Humidity
- Precipitation (rain, snow, hail)
- Thermal cycling
- UV exposure
- Wind

Reliability

Nunavut Arctic College, Iqaluit

- 3.2 kWp system installed in 1995
- 5 strings of 12 modules, façade mounted and connected to a single Satcon Prosine 5000 GT 3-kW inverter
  - (3 strings Siemens M55, 2 strings Solec S-53)
- Average specific yield was approximately 630 kWh/kWp for the period 1996-2003

Monitoring system re-commissioned, 2014

- Monitoring campaign since November 2014 with newly calibrated equipment

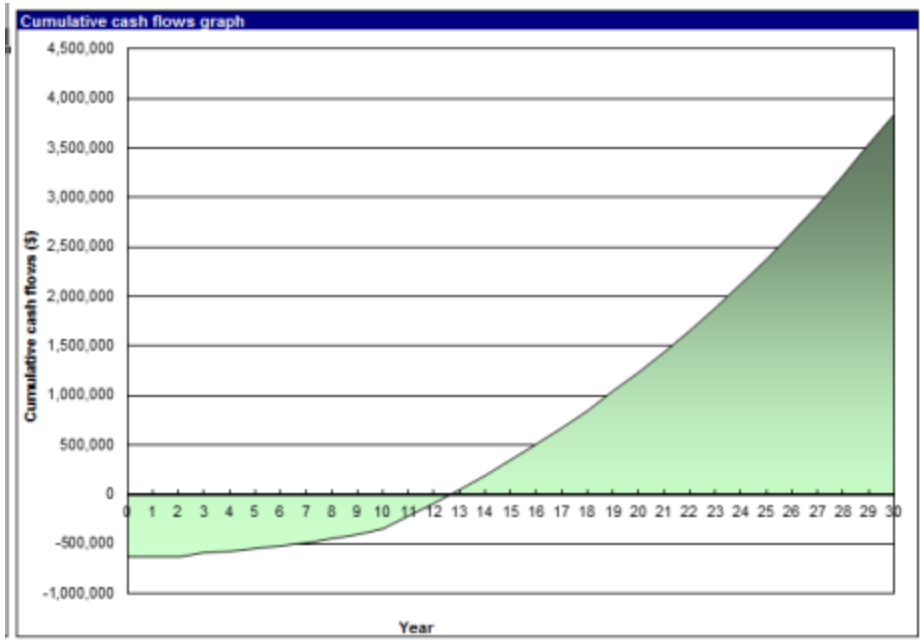
- **Preliminary data shows that system continues to produce, even after 20 years, with no interventions since installation**

Result of visual inspection, 2014

- 69 façade mounted modules were inspected
- Only minor cases of delamination (less than 0.14% of 4 modules, representing 0.5% of the entire array)
- Negligible speckling (spot delamination), cell discolouration.
- Surprisingly, no other issues discovered!

Solar PV system cash-flows

- High upfront costs (work to be done here to reduce soft-costs, eg. Simplify installation and permitting)
- Low O&M expenses (2014 estimate $25/kWp)
- If properly maintained and monitored, PV systems can produce for a very long time (**just how long though?**)



We are interested in data from other examples of

- PV North of the 60th
- Older vintage modules
- Older vintage inverters
- Monitored PV systems
- Microinverter systems

Please get in touch with us with any information that might help.

Questions?

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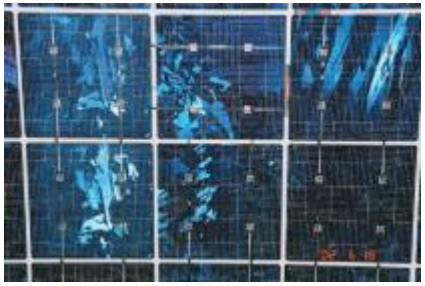
Appendix

Overview of PV Systems

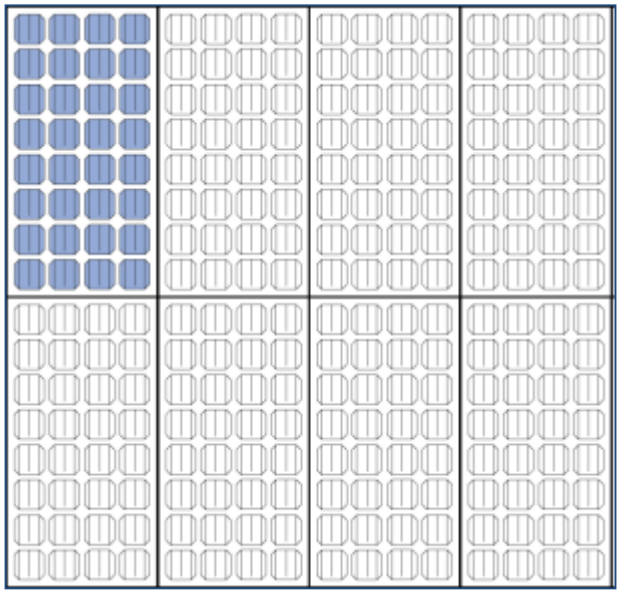
Solar PV Cells, Modules, and Arrays



PV Cell

PV Module

PV Array



Solar photovoltaic (PV) modules come in a variety of sizes. Large power systems combine modules in parallel and series to increase the power output.

Inverters

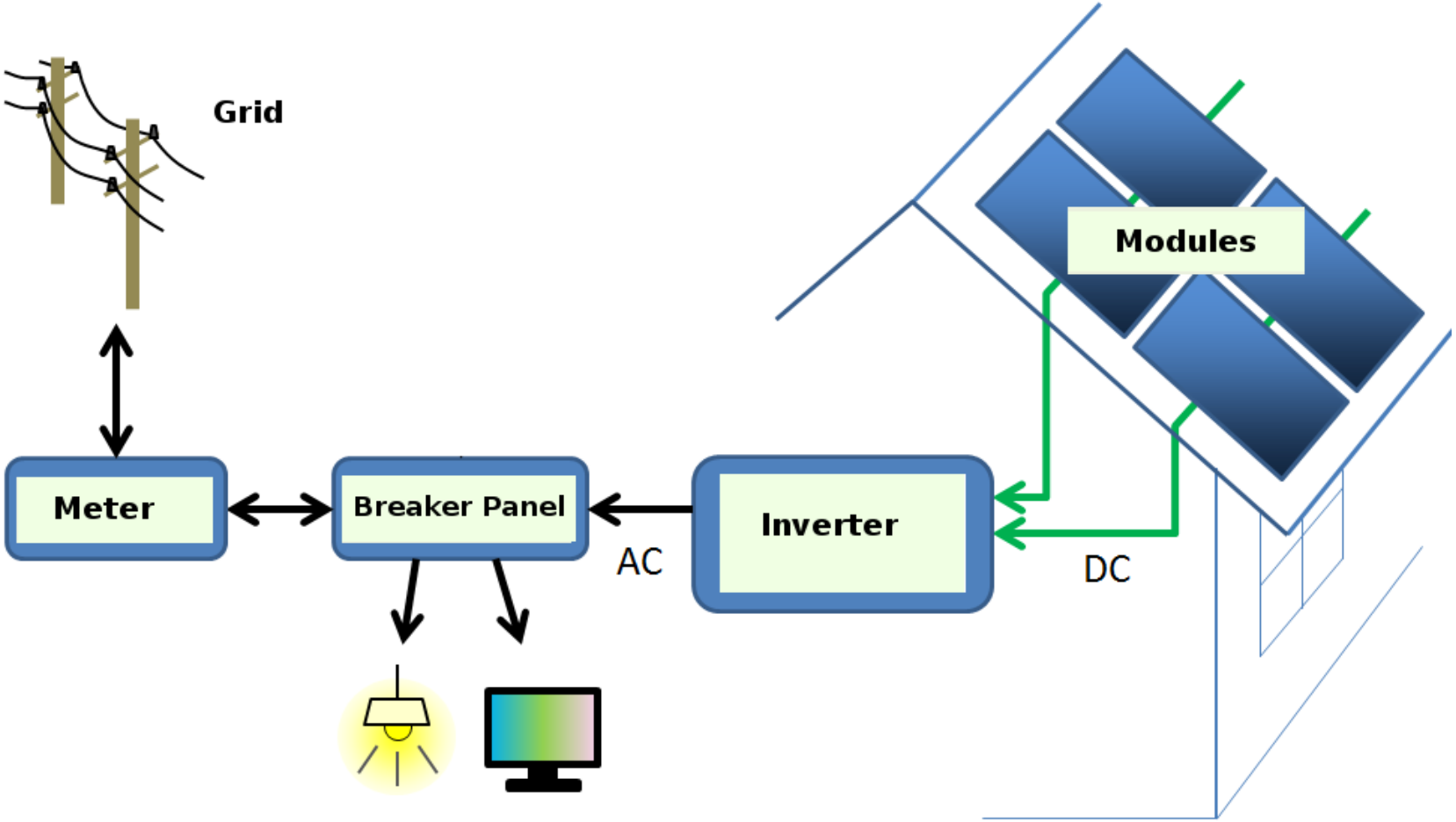
Inverters convert the direct current (DC) produced by the solar modules into alternating current (AC) which is traditionally used by the grid

3 kW-12 kW grid-connected solar inverter (string-level)

8 kW grid interactive or autonomous inverter (string-level)

215 W grid-connected microinverter (one per module)

How it all connects together…



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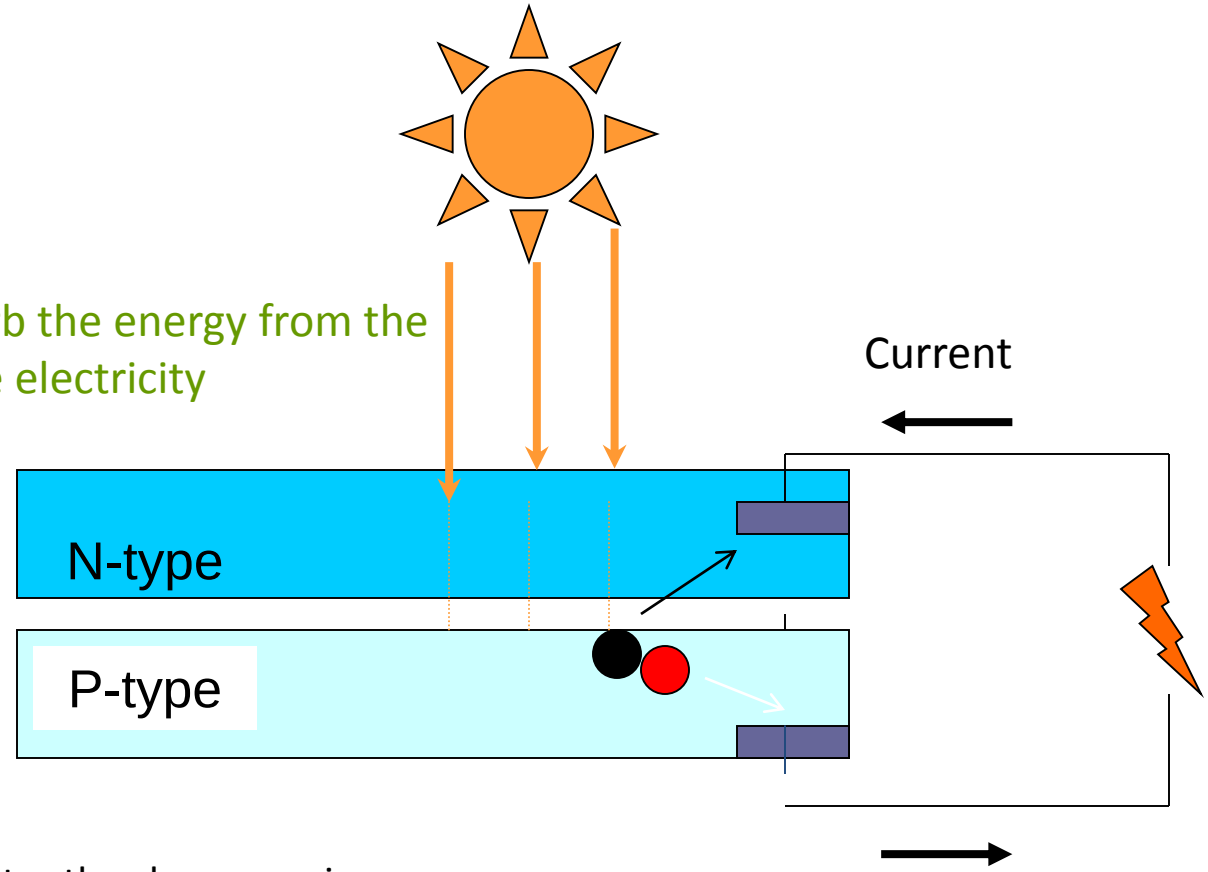
Solar Photovoltaic (PV) Energy

The solar cells absorb the energy from the photons to generate electricity



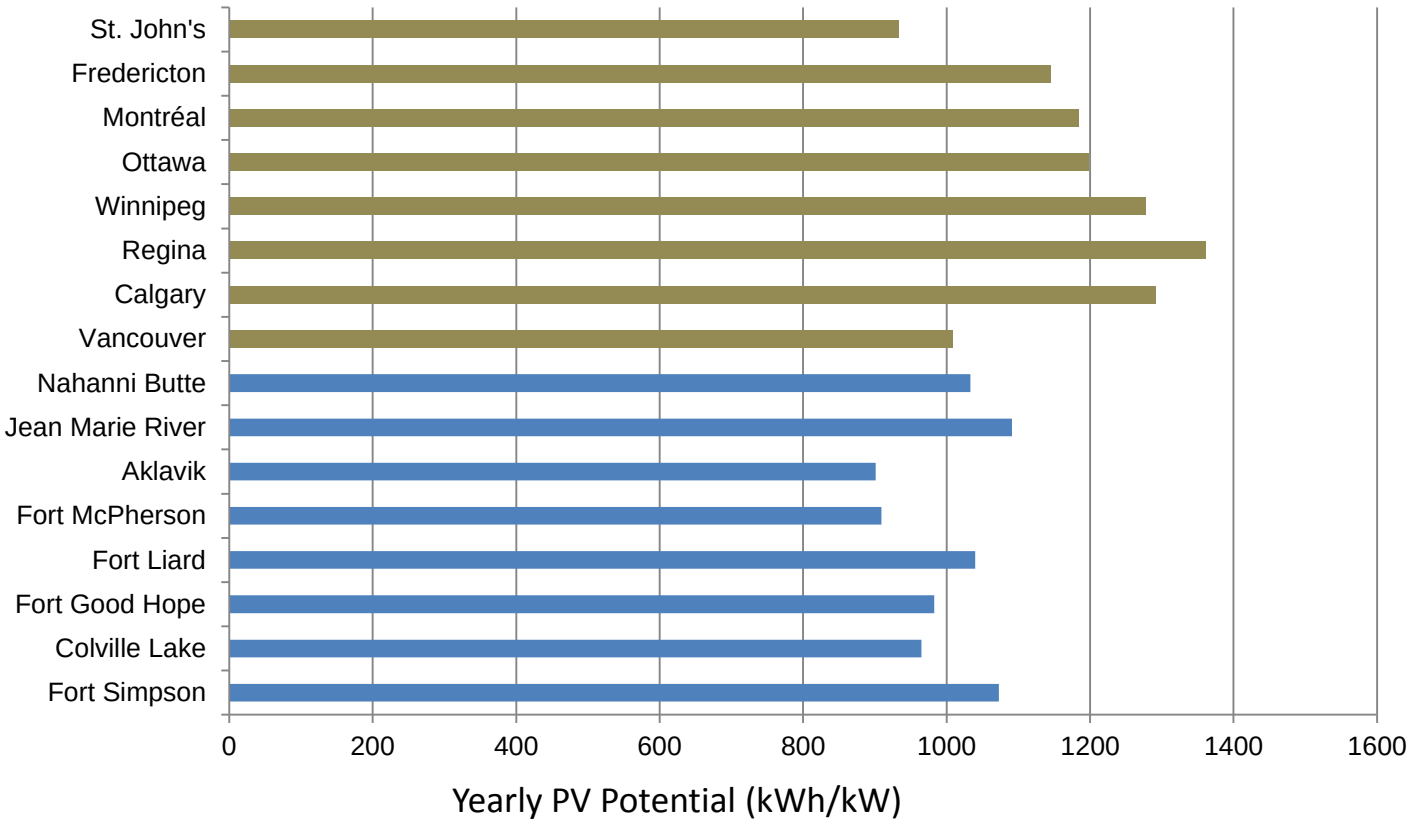
- The energy of the photons excites the charge carriers.
- A voltage (EMF) is generated by the PN junction, separating the negative and positive charges. The wires connecting the two layers conducts a current.

Dispelling the myth – Northern PV potential

The PV potential is not nearly as different as might be expected…

Major Canadian Cities
933 – 1361 kWh/kW

Remote NWT communities
901 – 1091 kWh/kW



…and the cost of diesel electricity production in the NWT makes PV very competitive

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PV Maps/Database – Fort Simpson

http://pv.nrcan.gc.ca/

Fort Simpson, Northwest Territories/Territoires du Nord-Ouest
Geographic location -> -121.36E,61.85N

PV potential (kWh/kW)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°
January	41	38	41	33
February	77	75	78	68
March	126	133	132	127
April	116	140	131	143
May	94	127	112	137
June	84	122	104	135
July	84	118	101	129
August	83	107	96	114
September	75	87	82	87
October	56	58	58	55
November	43	41	43	36
December	29	27	29	23
Annual	906	1073	1005	1088

Based on constant performance ratio of 0.75

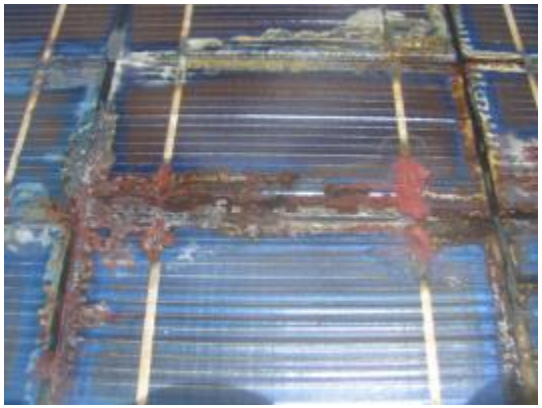
For Sarnia it is 1202; Montreal 1185 kWh/kW

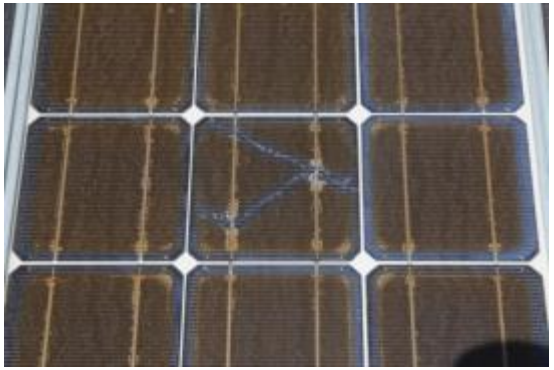
Mean daily global insolation (kWh/m^2)

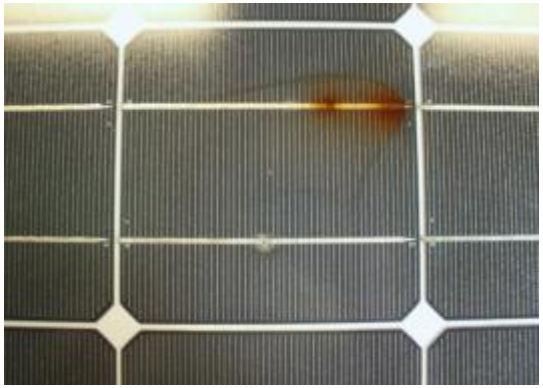
	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	1.8	1.6	1.8	1.4	1.9	0.4
February	3.7	3.6	3.7	3.3	4.2	1.1
March	5.4	5.7	5.7	5.5	7.4	2.6
April	5.2	6.3	5.8	6.4	9.4	4.4
May	4.0	5.5	4.8	5.9	9.4	5.6
June	3.8	5.4	4.6	6.0	10.3	6.1
July	3.6	5.1	4.4	5.6	9.1	5.7
August	3.6	4.6	4.1	4.9	7.3	4.3
September	3.4	3.9	3.7	3.9	5.2	2.6
October	2.4	2.5	2.5	2.4	3.0	1.2
November	1.9	1.8	1.9	1.6	2.1	0.5
December	1.2	1.2	1.2	1.0	1.3	0.3
Annual	3.3	3.9	3.7	4.0	5.9	2.9

Need to improve models that translate irradiance on the horizontal plane to tilted planes for locations north of 60°

Solar PV module degradation examples (continental USA)

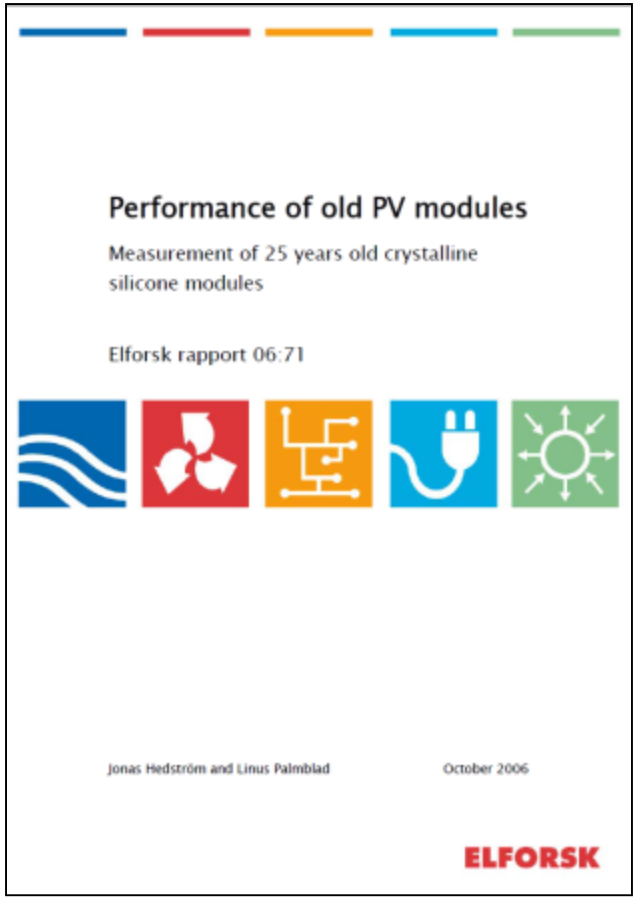






From NREL Silverman presentation

Example of a cold-climate module study from Stockholm, Sweden (Dfb)


Performance of old PV modules

Measurement of 25 years old crystalline silicone modules

Elforsk rapport 06:71

Jonas Hedström and Linus Palmblad

October 2006

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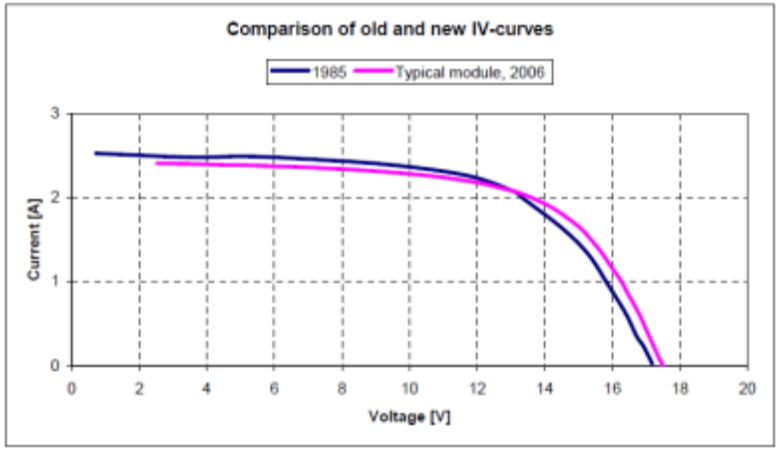


Figure 11. Comparison of IV-curves from the 1985 measurement and from a typical module from the 2006 measurement. Both IV-curves are compensated to G_{STC}=1000 W/m^2 and T_A=28 °C.

- Measured 20 c-Si modules in 1985 and then again in 2006 (25 years).
- Average peak power in 2006 was only 3.8% lower than average measured in 1985
- This was within the measurement uncertainties of 5% and well below the expected 12-13% degradation expected for that length of time
- Only 1 of 20 modules showed visible signs of significant degradation

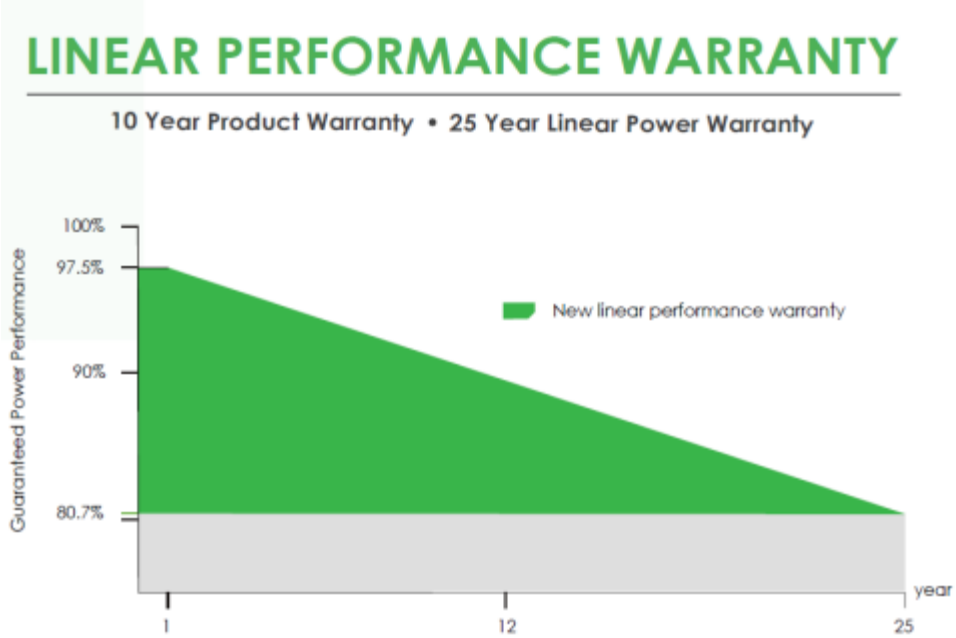
Early off-grid example from here in Yellowknife (1982)

- Four 50W modules (1979 vintage) in service on an off-grid houseboat since 1982, and are apparently producing at 70% of rated (to be verified). From photos they appear to be in very good condition.

- We will have the opportunity to test these modules in the near future to see how they perform and will include the results in our study on durability of PV in the North

PV module manufacturer's performance warranties

Typically, c-Si solar PV panels sold today are guaranteed to perform within 80% of their rated output after 25 years, with a linear performance degradation over that period (approximately 0.8% reduction per year).



Can we expect even better performance in the North?

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