DTU Foton

Module Design and Production

34553 Applied Photovoltaics

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Abstract: In this exercise you will design and build a c-Si PV panel for powering a small refrigerator.

References and links

- Slides from class (Block 1)
- Lecture slides from 34552 week 4.

Safety

- Use face masks and sanitize
- Work under exhaust hoods when soldering
- Wear heat resistant gloves when soldering and/or working with hotplates.
- Use common sense when handling glass.
- Use welding gloves if working with the laminator while it's on.
- If in doubt, ask an instructor.

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1. Introduction

In this exercise, you will in your group first design a solar panel for an off-grid refrigeration application. You will fabricate once the design is completed.

Competition:
Your group will enter a competition with the panel where the winner will be announced at the end of the course.
The winner will be chosen based on the following criteria:

- Power output
- Aesthetics
- Quality (EL images)
- Workmanship

2. Objectives and Methods

A manufacture of Peltier cooled camp refrigerators wants to make a solar powered version for leisure activities. The fridge is shown in Figure 1. The top will be redesigned so it supports a seamlessly integrated solar panel with maximum dimensions of 528 mm x 372 mm.

Figure 1: Peltier cooled camp fridges.

The panel will be connected to a charge controller and a 12 V battery. The specifications of the charge controller are shown in the datasheet below.

Specifications:

	GV-5-Pb-12V
Maximum Recommended Panel Power:	65W
Rated Battery (Output) Current:	5A
Nominal Battery Voltage:	12V
Max Input Voltage:	27V
Recommended Max Voc at STC:	22V
Minimum Battery Voltage for Normal Operation:	7.2V
Trickle Charge to Recover Dead (0V) Battery:	Yes
Input Voltage Range:	0-27V
Maximum Input Short Circuit Current*:	5A
Continuous Rated Load Current:	5A
Maximum Input Current**:	9A
Charge Profile:	Multi-Stage with Temperature Compensation
Absorption Voltage:	14.2V
Absorption Time:	2 hours
Float Voltage (Pb models) or CV Voltage (Li models):	13.8V
Load (LVD) Disconnect/Reconnect Voltage:	11.4/12.5 V
Battery Temperature Compensation:	-28mV/°C
Operating Temperature:	-40°C - 8
Maximum Full Power Ambient:	50°C
Electrical Efficiency:	96% - 99.85% typical

Figure 1: Specifications of the charge controller used in the fridge application

The Peltier element draws 3 amps so this part of the system consumes about 36W. Add another 5W for the fan and the total load for the fridge is approximately 40 W.

During operation the PV panel is expected to have operating temperatures between 10 ºC and 55 ºC. The charge controller is a buck type converter, which means it needs a PV voltage that is at least 1 V above the battery voltage. The battery voltage will be at maximum 14 V.

Table 1: Requirements for PV Panel

Parameter	Values
Size of glass	528 mm x 372 mm
Distance from glass edge to PV cell edge	15 mm and 25 where the cell strings are connected
Cell to cell bit spacing	2 mm
Electrical outlets (+ - output connectors)	Spaced 20mm apart and 50mm from the short edge
Operating temperatures	10 ºC to 55 ºC

The solar cells are 156mm x 156mm with four busbars (Figure 2). Also available for your module are cells cut into thirds (52 mm x 156 mm) and cells cut into sixths (52mm x 78mm).

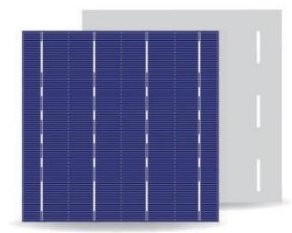


Figure 2: Photo of a 156mm x 156mm four busbar cell (front and back)

Task 1 Panel design

Voltage requirement

Use the spreadsheet template uploaded to DTU learn. Fill in the short circuit (Isc) and maximum power point (Imp) currents for the 3rd cut and 6th cut cells. Finish the design of the module by filling out the yellow cells. Complete the following items:

- Calculate how many cells are needed in series to reach a voltage compatible with the battery and charge controller?
- Choose the cell size that you want to use (cell C24).
- Choose the number of series cells and parallel strings (C25 and C26).
- Make a sketch of the module design that includes the cell bit spacing, cell edge clearances, and the interconnection ribbons from the cell strings to the electrical outlets. Make sure this design meets the requirements specified in Table 1.
- Calculate what is the voltage at the highest and the lowest temperatures? (Red cells G20 and G21). Will these voltages still be compatible with the charge controller?

Once you have completed the above items you are ready to proceed to Task 2 (panel fabrication).

Table 2: Module design spreadsheet uploaded to Inside. The red cells are to be filled in and the blue cells are calculated

Parameter @ 25 °C	Full Cell	3rd Cell	6th Cell	String	Module
Short circuit current (A)	9.07			0.00	0.00
Open circuit voltage (mV)	634			11.41	11.41
Power (W)	4.5			0.00	0.00
Voltage @ MPP (mV)	512			9.22	9.22
Current @ MPP (A)	8.55			0.00	0.00
Tc on voltage (%)/K	-0.33				
Tc on Current (%)/K	0.058				
Tc on power (%)/K	-0.41				
Length (mm)	156	52	52	484	528
Width (mm)	156	156	78	318	372
Cell spacing	2				
Area (cm^2)	243.36	81.12	40.56	1460.2	1964.2
Efficiency	20%			20%	0%
Voc at 10 deg C					
Voc at 55 deg C					

Task 2 Panel Fabrication

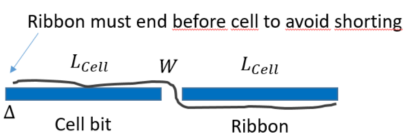
Now you and your group are going to make the panel you designed. This part of the exercise is hands on and you will use your crafting skills.

The sequence you will follow is:

1. Cutting soldering ribbons
2. Tabbing and stringing
3. Layup and string interconnection
4. Lamination
5. Trimming, junction-box mounting, and framing

Soldering Ribbons

In this exercise, stringing is done manually with the help of a soldering iron and a hot plate. First you will cut the strings to the correct length. The length is the (2 x cell length + cell spacing) – a few mm. For the third cut cells it is about 2 x 52mm + 2mm – 6mm = 100mm. You need one ribbon pr. cell for each bus bar on each cell.



$$L_{Ribbon} = 2 * L_{Cell} + W - \Delta$$

We have cut ribbons of approximately 100 mm and fluxed them so they are ready to solder. Prior to soldering the ribbons needs to be fluxed, i.e. submerged in flux.

Figure 3: Fluxing the ribbons

Tabbing

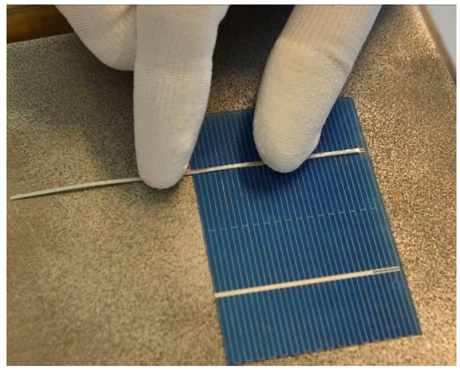
Use soldering gloves, which provide a bit of thermal insulation so the heat transfer from the hotplate is delayed. Make sure you are working under an exhaust hood. Always feel free to ask an instructor if you are in doubt.

Figure 4: The tabbing workstation

Follow these steps with reference to the pictures in Figure 5:

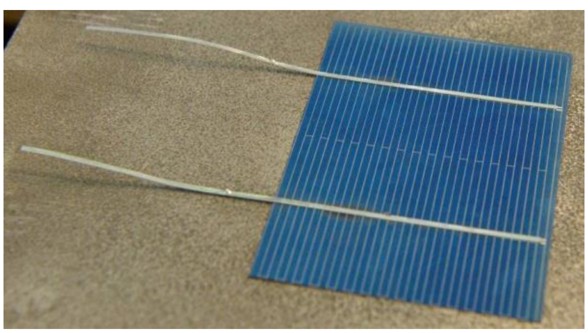
1. Place a single cell bit on a hotplate sunny side up and adjust the hotplate temperature to ~70-100 ºC.
2. Take a ribbon and place it on top of the busbar so that the end of the cell is aligned with the end of the ribbon.
3. Put the hot soldering iron down on one end of the cell and slide it slowly over the ribbon. *(Since a lot of heat needs to be transferred, make sure to hold the soldering iron at an angle maximizing the contact area to the ribbon).*
4. Make sure it is soldered to the cell. Note that the straighter the ribbons are, the easier it will be to string all the cells together.
5. Stack the tabbed cells in a neat and orderly fashion. Treat the cells more gently than how you will treat the finest porcelain in your home to avoid microcracks in the cells.
6. Repeat this process for all the busbars and all the cells. After a day of soldering you will become an expert ☺


Step 1: place cell on hotplate


Step 2: align ribbon to busbar


Step 3: solder the ribbon (start)


Step 3: solder the ribbon (finish)


Step 4: Assess the solder job

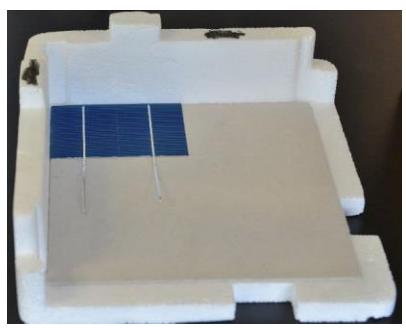
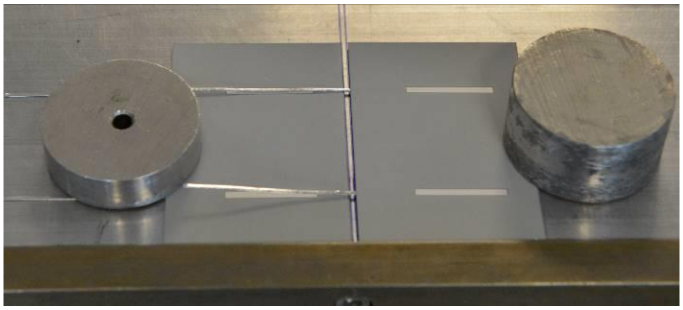

Step 5: Stack the finished cells

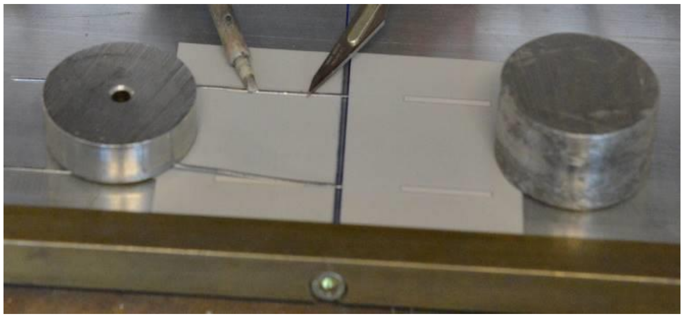
Figure 5: Tabbing sequence.

Stringing
Take a long hotplate with markings that allows you to control the distance between cell bits. Recall the spacing between cells should be 2mm and in this step this parameter is fixed. To solder a string of cells, follow these steps with reference to Figure 6:

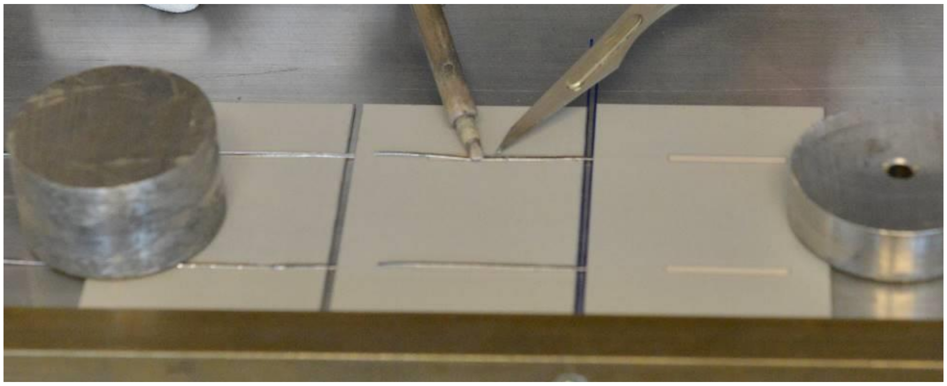
1. Put the soldered cell bits sunny side down with the ribbons all facing the same direction. Place the ribbons of adjacent cells on top of the neighboring cell and placed it with the desired distance. *(Here the aesthetics of the module starts!).*
2. Solder the ribbons to the back of the cell at the dedicated busbar marks by sliding the solder iron over the ribbon. Note that what we are doing here is simply connecting the emitter (n side) of one cell to the base (p side) of the next.
3. Continue this process until the cell string is of the desired length.



Step 1: Place cell bits sunny side down



Step 2: Solder the ribbon to the backside at the busbar markings



Step 3: Adjust the paper weights and continue soldering the next cell

Figure 6: Stringing sequence

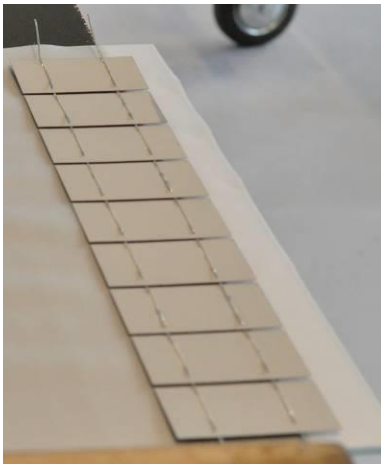


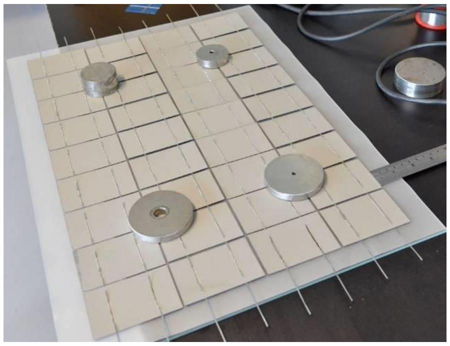
Figure 7: Example of finished string

Layup and String Interconnection

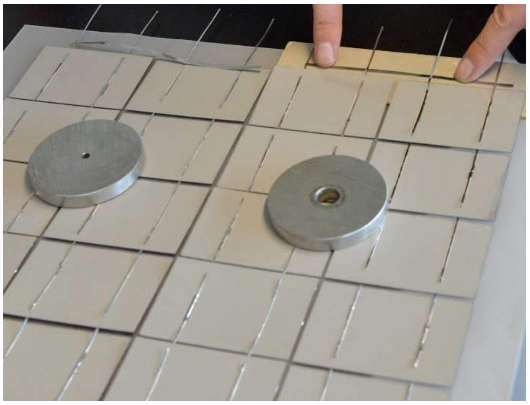
Now it's time for the module layup and connecting the cell strings. Follow these steps with reference to the figures below.

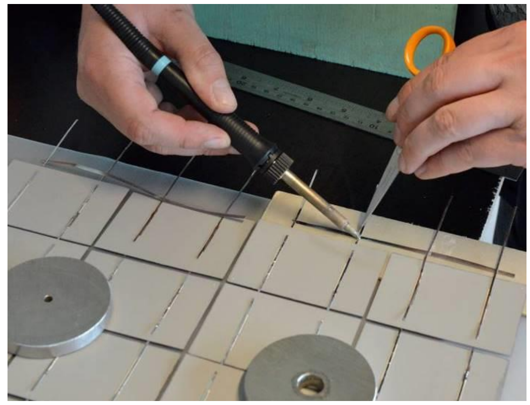
1. Clean the glass with isopropyl alcohol, and cut two pieces of EVA to the size of the glass.
    a. Cutting EVA, backsheets and other foils, should be done with a sharp knife using only **one** knife slide, cutting all the way through the foil in the first go.
2. Put the first layer of EVA on the glass. Place the individual cell strings on this EVA/glass surface. Once all substrings are placed on the EVA/glass surface, make the final alignment before soldering the strings together. *(Crucial for the final module appearance.)*
3. Connect the strings with interconnection ribbon. Solder to the interconnection ribbons at the end of the strings. Place these according to your design and use a cover plate to not melt the EVA.
4. For aesthetic purposes you can choose to cover the interconnection strings with some interlayer material. Here you need an extra peace of EVA corresponding to the size of the interlayer.
5. Put the second layer of EVA on the module using the same procedure as in Step 2.
6. Cut a piece of backsheet that is 2 cm larger than the glass on each side (to protect the membrane of the laminator).
7. Peel back the EVA and backsheet where the junction box will go (electrical outlets). Cut a fine slit in both the EVA and backsheet and wrap the ribbons out through these slits.
   Tape these ribbons to the back sheet using the green tape – specially made for this purpose.

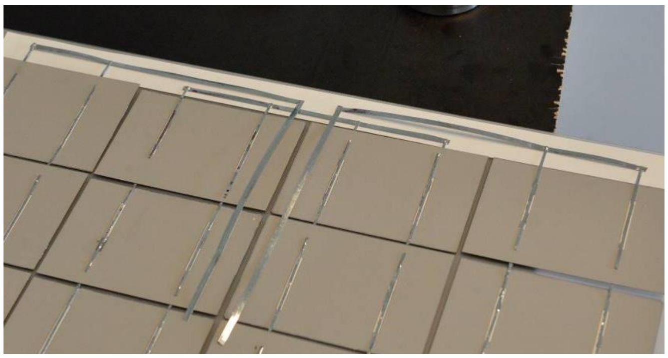
Step 1: Clean the glass

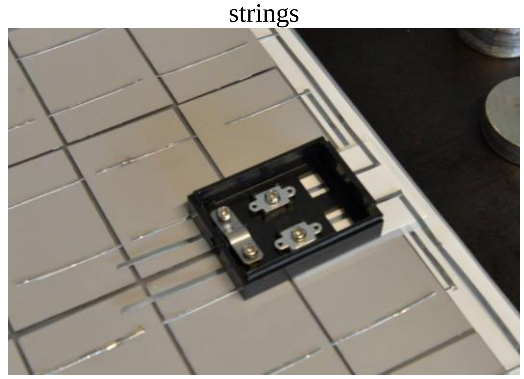


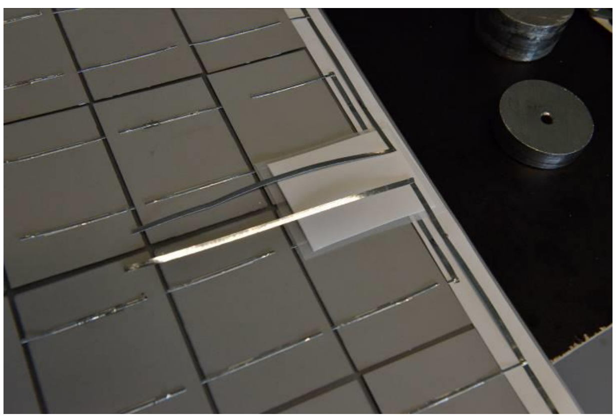
Step 2: Adjust the string placement


Step 3: Align the interconnectors before soldering

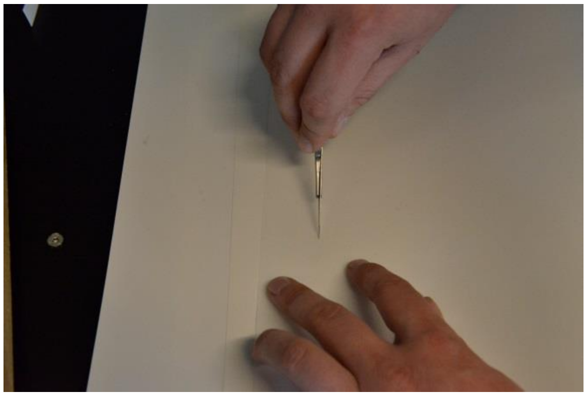

Step 3 (cont.): Solder the interconnectors to the strings


Step 3 (cont.): Assess the electrical outlet

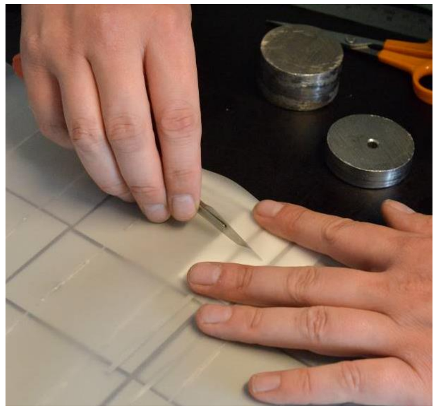

Align and check the junction box position


Step 4: Details of the interlayer insulator and EVA

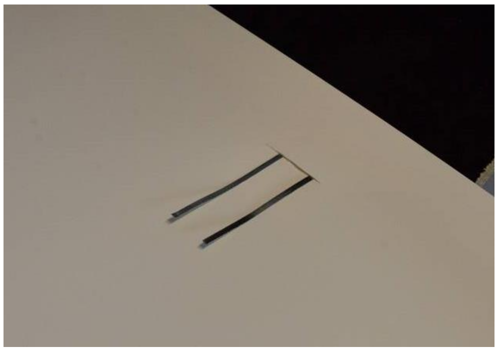

Step 5: Place the 2nd sheet of EVA on the module



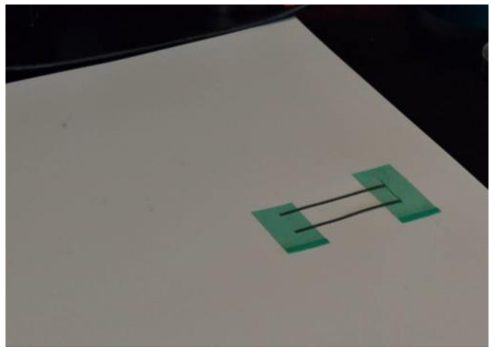
Step 6: Cut a piece of backsheet with 2cm extra width. Put the backsheet on top of the 2nd EVA and fold the back sheet and EVA back. Use the slits in the EVA as ruler for the slits in the backsheet.



Step 7: Cut slits in the EVA for the outlets



Step 7(cont.): Bring the ribbons through the slit



Step 8: Placement of green tape

Lamination

Your module is ready for the laminator. Prior to the lamination cycle it's a good idea to test the module measuring open circuit voltage (Voc) with a multimeter (Figure 8).

- Make sure the laminator has done an empty cycle prior to lamination to get all the air out of the vacuum lines (to be done by instructors).
- Adjust the lamination cycle to the specifications of the EVA (to be done by the instructors).
- Place the module into the laminator (glass down). Put the fiberglass cover over the module and run the lamination cycle.
- After the cycle is complete the top of the laminator will rise up (Figure 9). Use welding gloves if you are taking the module out of the hot laminator. **The module will have a temperature of around 150 ºC**, so let it cool a little prior to any further processing.

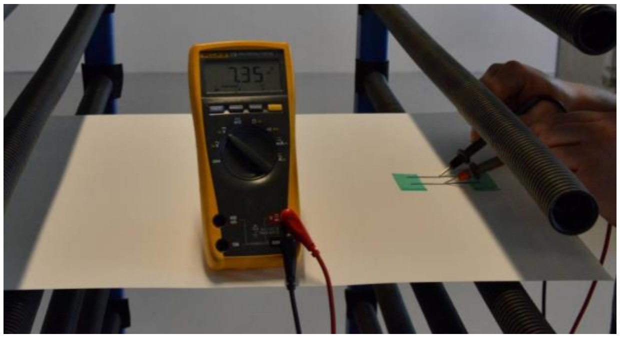


Figure 8: Open circuit voltage measurement with DMM

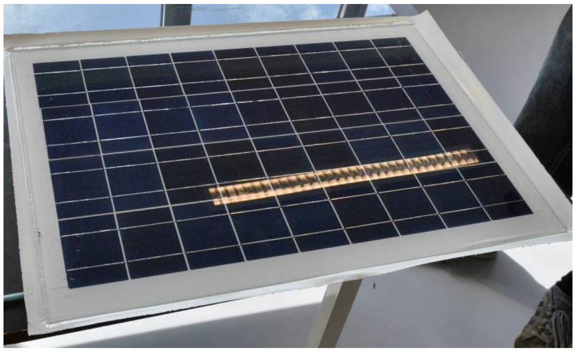



Figure 9: Laminator lid rising up after lamination cycle (left) and laminated module ready for trimming (right)

Trimming, Junction Box, and Framing

Have an instructor assist you with the final steps:

- Trim the excess backsheet and EVA off the edges. Use a special razor blade knife to trim the module.
- Mount the junction box over the ribbons from the module.
- Glue the junction box to the backsheet with silicone seal.
- Attach the wire with banana plugs to your module junction box.
- Frame the module according to Michael Graversen's advice.

3. Presentation

Suggestion for the presentation:

- Present you module design and you thinking behind it.
- Include your module dimensioning table.
- A drawing of your module
- A picture of your module.
- Your personal experience from the fabrication.
- Performance metrics of your module including EL image.
- Conclusion