V1.1 README

Welcome to the readme of the V1.1. Biosphere Solar's MVP version with a focus on moving towards industry standards. This documentation will include everything you need to know to reproduce, install, and improve the V1.1. This project is licensed under the CERN OHL S, meaning that you must submit any improvements made to the product. This documentation can be sent to team@biosphere.solar. The Biosphere Solar Team is looking forward to your contributions!

V1.1 Product Description

The Biosphere Solar V1.1 is a step up from the V1.0, manufactured for the pilot project at Scheveningen strand with the Municipality of the Hague. V1.1 has increased active area per m2, features bifacial cells, has a more uniform look, and a higher power output. The module also tests an improved edge-seal and the addition of safety foil to the front- and back-glass for post-breakage performance. Still, many aspects of the module are under research, such as thermal profile, IV-curve, Fill Factor, fire rating, and projected lifetime. Therefore, a conservative CTM efficiency of 0.9 is assumed. Note that this module is for research, pilot, and testing purposes, and purchasing these modules will help Biosphere Solar on its mission to bring fair and circular standards to the solar industry and market.

The module comes in 2 sizes, a utility version with 144 cells, and a rooftop version with 120 cells

3D Model

The CAD model of our design can be found here

- V1.1R
- V1.1U

Datasheet

Some key datapoints for the module are found below. The full datasheet can be found here: [1] V1 & V2 Technical Data Sheet & Brochure | Public Data Room | [DRAFT]

Specifications	**Roof**	**Utility**		Cell	Variance	Module Roof	Module Utility	**Other**

Cell type	Aiko 9BB MONO PERC Bifacial c-Si Half-cut	Aiko 9BB MONO PERC Bifacial c-Si Half-cut	Nominal Max. Power (PMax) [W]	3.63	-0.56	392.04	470.448	Maximum System Voltage	1000 V DC
Amount of Cells	120	144	Open Circuit Voltage (Voc) [V]	0.6738	-0.0234	72.7704	87.32448	Operating temperature	-40°C / +85°C
Junction box	3	3	Short Circuit Current (Isc) [A]	6.62	-0.1155	5.958	5.958	Product Guarantee	
Weight [kg]			Maximum Power Voltage [V]	0.58	-0.036	69.6	83.52	Power guarantee (vermogensgarantie)	
Length [mm]	1976	2382	Maximum Power Current [A]	6.255	-0.0925	5.6295	5.6295		
Width [mm]	1134	1134							
Thickness (Without Frame) [mm]	10	10	CTM Efficiency			90%		IV curves	410Wp
Area [m2]	2.24	2.70	Overcurrent protection [A]					LCA score	
Cable Length	2pc 100 mm * 4 mm1	2pc 100 mm * 4 mm2	Fill Factor (FF) [-]	81.40%		73%		Type of connections between cells ?	Stringed, FBC
Connector type	MC4	MC4	Temperature Coefficient (Isc) [%/K]	0.07				Life expentancy	
By-pass diodes	3	3	Temperature Coefficient (IVoc) [%/K]	-0.36				Maximum static load front side	
CO2 footprint:			Temperature Coefficient (Pmax) [%/K]	-0.38				Maximum static load back side	
Product passport/materials used/labeling	Precompliance testing	Precompliance testing	Efficiency percentage	22.00%		19.80%	19.80%	Maximum Hail impact resistance	
Country of Manufacturing	Belgium	Belgium						Certificates (IEC & ISO)	

Frame material	Frameless - Frame Optional	Frameless - Frame Optional							
Kind of construcion	glass - glass	glass - glass						Objective clients (target group)	
Kind of glass used	4mm low-iron tempered solar glass with ani-breakage foil	4mm low-iron tempered solar glass with anti-breakage foil	Max system voltage					Shadow cost?	
Mounting points	Glass/frame clamps	Glass/frame clamps	Limiting Reverse current					IPXX rating?	
Fire rating	TBD	TBD	Watt peak?					Packaging?	

V1.1 Assembly Manual

This chapter describes the process of assembling a V1.1 module

BOM

For this build you will need the following items. Some of these items are unknown

UTILITY Bill of Materials (BOM)													
Part Number	**Part name**	**Category**	**Description**	**Main Material Composition**	**Units**	**Unit metric**	**Weight per unit(kg)**	**Weight Units**	**Total weight**	**Purchaseable unit Cost**	**Total Cost**	**Supplier**	**Reasoning**
F1	Front Glass	Frame	Low-iron tempered glass sheet (4mm).	Soda-Lime Glass	2.701188	m2	2520	0.011	27.23	€16.14	€43.60	Soltech	Ideally, 3.2mm because thinnest affordable tempered size
F2	Back Glass	Frame	Tempered glass sheet with 3 holes	Soda-Lime Glass	2.701188	m2	2520	0.011	27.23	€16.14	€43.60	Soltech	Ideally, 3.2mm because thinnest affordable tempered size
F4	Security Film	Frame	Two 3M S40 Exterior Films	Polyester	2.701188	m2	?	?	?	€145.00	€290.00	Folie Effect	Need to keep the

C1	Bi-facial Perc Cells	Cells	Cells with current collection at the back. HJT or TOPCon cells also feasible	c-Si	144	182x182 M10 cell	0.01	144	1.44	€1.00	€144.00	Soltech	Cells currently used for manufacturer's stringing machine. Ideally IBC, because Europe is leading and planning larger scale manufacturing
S1	Sealant (Everlight Chemicals)	Encapsulation	Sealant material to protect PIB from weathering	Silicone Other unknown substance	0.104496	Liter	0	0	0.00	€10.00	€1.04	Biosphere Solar	Might reduce circularity through mixing with PIB
E1	Tabbing Wire	Electrical	To connect the cells into strings	Tin Flux Copper	267.84	m	0.005	36	0.18	€0.21	€56.25	Soltech	Stringing machine uses standard solder, probably with lead. Replacing with low-temp soldering is an ongoing discussion with manufacturer
E2	Bus Bar Wire	Electrical	To connect the cell strings	Tin Flux Copper	2.835	m	0.05	0.12	0.01	€6.49	€18.40	Soltech	ditto
C2	Cell bed spacer	Encapsulation	Keeps cells in place	PC	1	sheet 2050x1250	1.8	1.000	1.80	€80.14	€80.14	Biosphere Solar	Using transparent polycarbonate
E3	MC4 Connectors	Electrical	Connects module	Plastic Polymer Rubber	2	mc4 connector	0.01	2	0.02	€10.00	€20.00	Soltech	
E4	Cables	Electrical	Connects module	PVC/PE/PP Copper	2	1m cable	0.09	2	0.18		€0.00	Soltech	
E5	Junction Boxes	Electrical	Connection box between busbar wire and cables and contains bypass diodes	Polymer Copper wire Rubber Silicon	3	Junction box	0.15	1	0.15	€2.00	€6.00	Soltech	

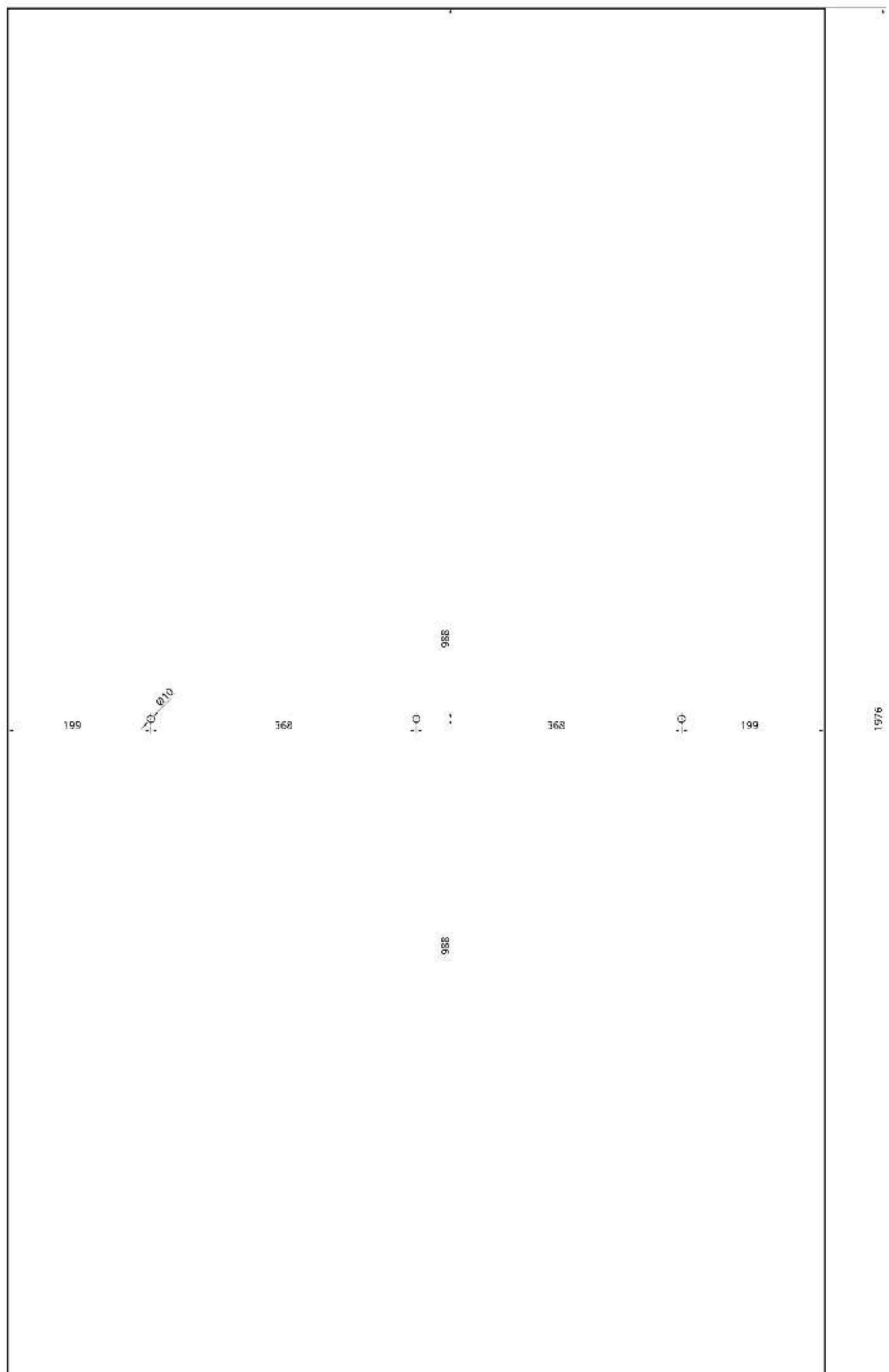
F5	Weather resistant label	Frame	Contains all relevant information conform IEC 61730-1	PVC	1	max 25mm height	-	1		€0.20	€0.20	[Biosphere Solar - Avery]()	
F3	[Aluminium profile]()	Frame (optional)	2x 2m, 2x 1.2m Built around panel for mounting and rigidity	Aluminium	3	pc	?	?	?	€24.49	€73.47	Biosphere Solar - XXL Direct/Hornbach	Could be a good standardised profile, still quite expensive
TOTALS									58.23		€776.69		

ROOFTOP Bill of Materials (BOM)													
Part Number	**Part name**	**Category**	**Description**	**Main Material Composition**	**Units**	**Unit metric**	**Weight per unit(kg)**	**Weight Units**	**Total weight**	**Purchaseable unit Cost**	**Total Cost**	**Supplier**	**Reasoning**
F1	Front Glass	Frame	Low-iron tempered glass sheets (4mm)	Soda-Lime Glass	2.240784	m2	2520	0.009	22.59	€16.14	€36.17	Soltech	Ideally, 3.2mm because thinnest affordable tempered size
F2	Back Glass	Frame	Tempered Glass	Soda-Lime Glass	2.240784	m2	2520	0.009	22.59	€16.14	€36.17	Soltech	Ideally, 3.2mm because thinnest affordable tempered size
F4	[Security Film]()	Frame	[Polyester]()	Polyester				?	?	€145.00	€290.00	Biosphere Solar - Folie Effect/3M	Need to keep the
C1	[Bi-facial Perc Cells]()	Cells	Cells with current collection at the back. HJT or TOPCon cells also feasible	c-Si	144	182x182 M10 cell	0.01	144	1.44	€2.00	€288.00	Soltech	Cells currently used for manufacturer's stringing machine. Ideally IBC, because Europe is leading and planning larger scale manufacturing

S1	Sealant (Everlight Chemicals)	Encapsulation	Sealant material	UV-cured Sealant		Liter	0	0	0.00	€10.00	€10.00	Biosphere Solar	Circular, low energy to apply, does not require heat treatment, can be cured using UV, does not require silicone, is also an adhesive, includes dessicant
E1	Tabbing Wire	Electrical	To connect the cells into strings	Tin Flux Copper	0	m	0.005	36	0.18	€0.21	€0.21	Soltech	Stringing machine uses standard solder, probably with lead. Replacing with low-temp soldering is an ongoing discussion with manufacturer
E2	Bus Bar Wire	Electrical	To connect the cell strings	Tin Flux Copper	0	m	0.05	0.12	0.01	€6.49	€6.49	Soltech	ditto
C2	Cell bed spacer	Encapsulation	Keeps cells in place	PC	0.000	m2	1.8	0.000	0.00	€3.00	€3.00	Biosphere Solar	Using transparent polycarbonate
E3	MC4 Connectors	Electrical	Connects module	Plastic Polymer Rubber	2	mc4 connector	0.01	2	0.02	€10.00	€20.00	Soltech	
E4	Cables	Electrical	Connects module	PVC/PE/PP Copper	2	1m cable	0.09	2	0.18		€0.00	Biosphere Solar	
E5	Junction Boxes	Electrical	Connection box between busbar wire and cables and contains bypass diodes	Polymer Copper wire Rubber Silicon	3	Junction box	0.15	1	0.15	€2.00	€6.00	Soltech	
F5	Weather resistant label	Frame	Contains all relevant information conform IEC 61730-1	PVC	1	max 25mm height	-	1		€0.20	€0.20	Biosphere Solar - Avery	

F3	Aluminium profile	Frame (optional)	Built around panel for mounting and rigidity	Aluminium	6220	mm	?	?	?	€0.01	€60.93	Biosphere Solar - XXL Direct/Hornbach	Could be a good standardised profile, still quite expensive
TOTALS									47.15		€757.16		

The holes in the back glass should be made according to the below specifications. This is for the Rooftop module. The horizontal dimensions for the Utility module are equal. In the vertical axis, the holes are centered.



988
Ø10
199
368
368
199
1976
988
1134

Tools Needed

You will need the following tools

- ☐ Tool Box
- ☐ Camera
- ☐ Multimeter
- ☐ Gloves
- ☐ Goggles
- ☐ Safety Shoes
- ☐ Extension cord
- ☐ Scissors
- ☐ Rulers
- ☐ Glass washing soap
- ☐ Glass washing cloth
- ☐ Squeegee
- ☐ Foil application wiper tool
- ☐ Cutter
- ☐ Soldering Station
- ☐ Solder Wire
- ☐ Flux pen
- ☐ Fume extractor
- ☐ Caliper
- ☐ Masking tape
- ☐ Duct tape
- ☐ UV Lamp
- ☐ Extruder tool edge seal
- ☐ Caulk gun
- ☐ Heat gun

Assembly Steps

The assembly is sunny side up, following the steps below. The times given are for an assembly of 3 V1.1R modules with 3 people in a semi-automated factory.

Preparation Beforehand

- load all tools and materials
- produce the necessary cell strings using a stringer
- prepare the bussing tapes according to the technical drawing
- prepare jigs for placing the bussing tapes

- cut the frames
- make sure there is enough fuel to travel to the production location
- prepare food

We left at 6, which ensured our arrival around 9:00. Staying at the production location the night before is also a possibility.

Preparation on Arrival

Upon arrival, prepare by setting up the work area. For us this took 30 minutes ⏱ 00:00:00

STEP 1: Back Glass Washing

[30 Minutes] ⏱ 00:00:00 | 1 Person

STEP 1: Glass Washing.MP4

The glass can be washed using a glass washing machine, or by hand

STEP 2: Bussing tape attachment, leads attachment, hole sealing

[1 Hour] ⏱ 00:00:00 | 1 Person

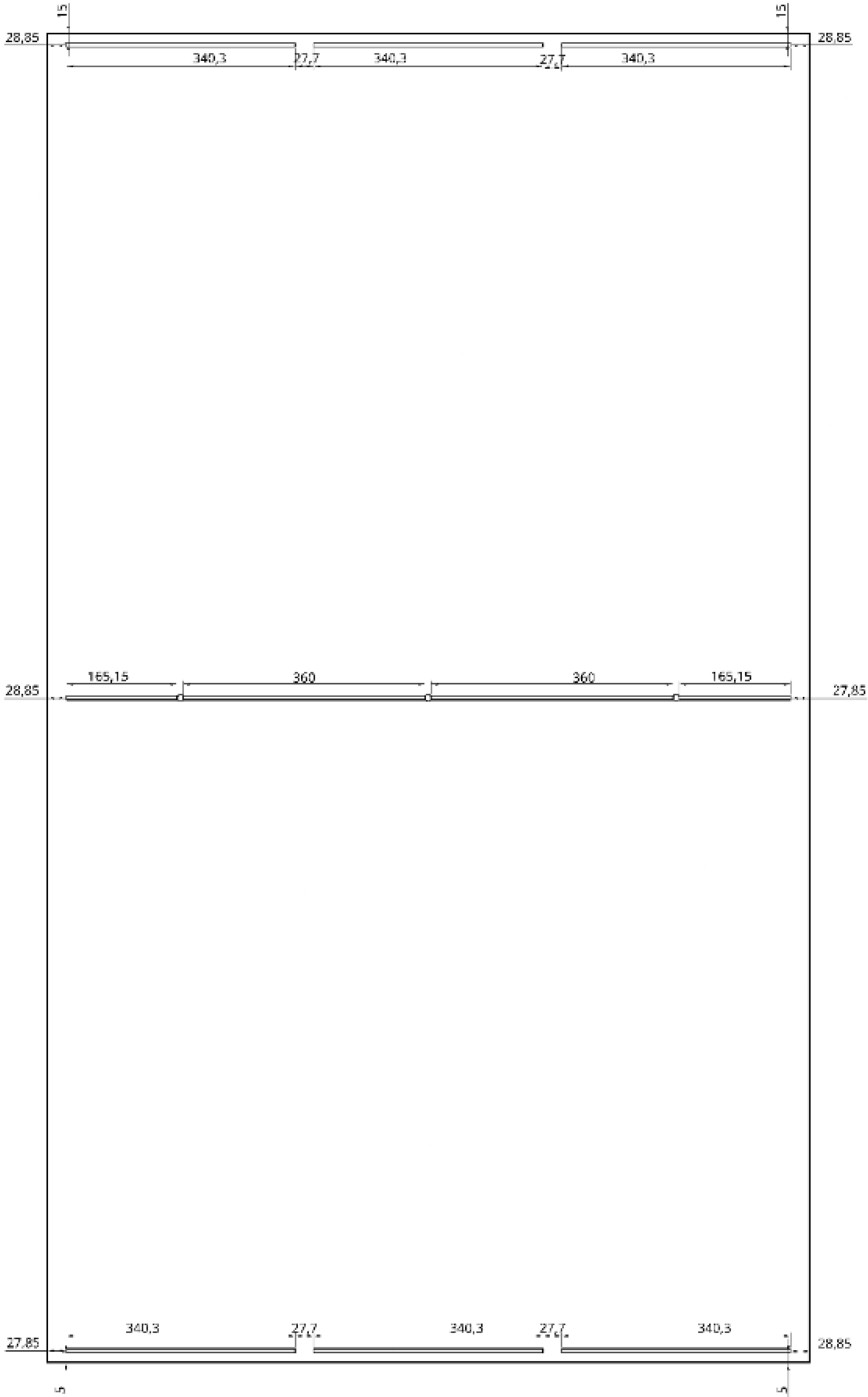
STEP 2: Bussing Tape Attachment 1.MP4

STEP 2: Bussing Tape Attachment 2.MP4

STEP 2: Bussing Tape Attachment 3.MP4

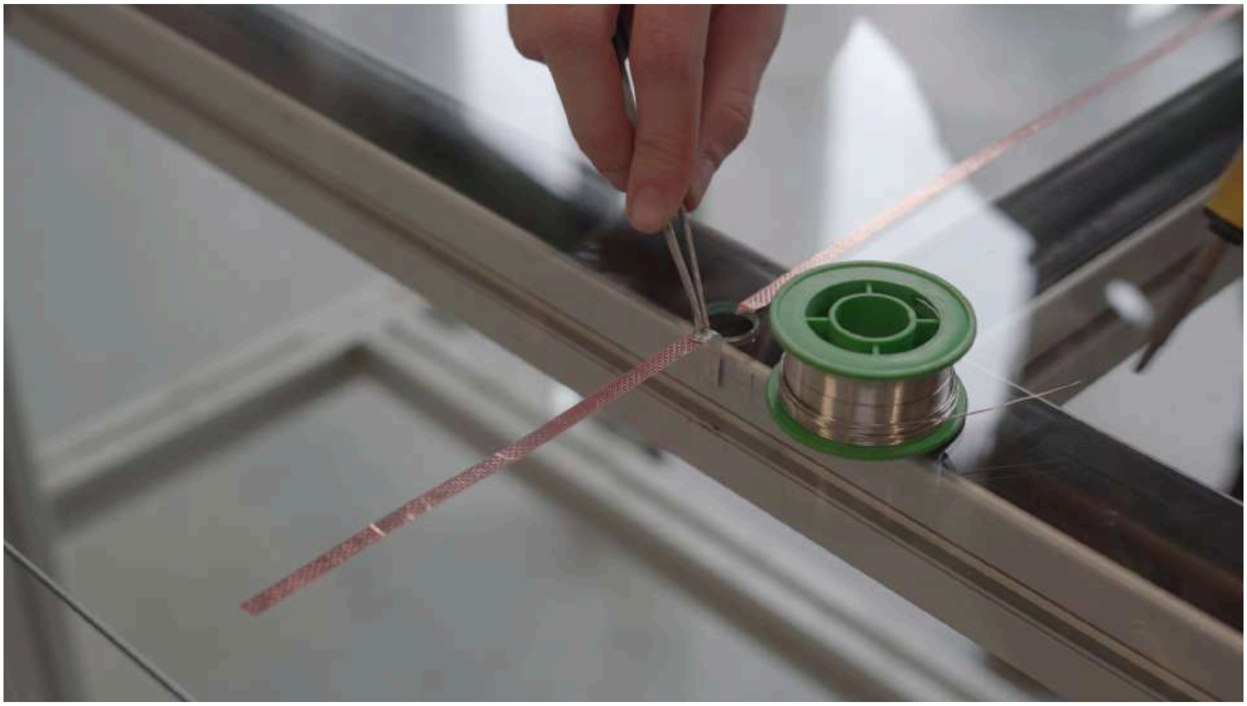
STEP 2: Bussing Tape Attachment 4.MP4

Attach the bussing tape according to the following technical drawing. For this, a jig can be used

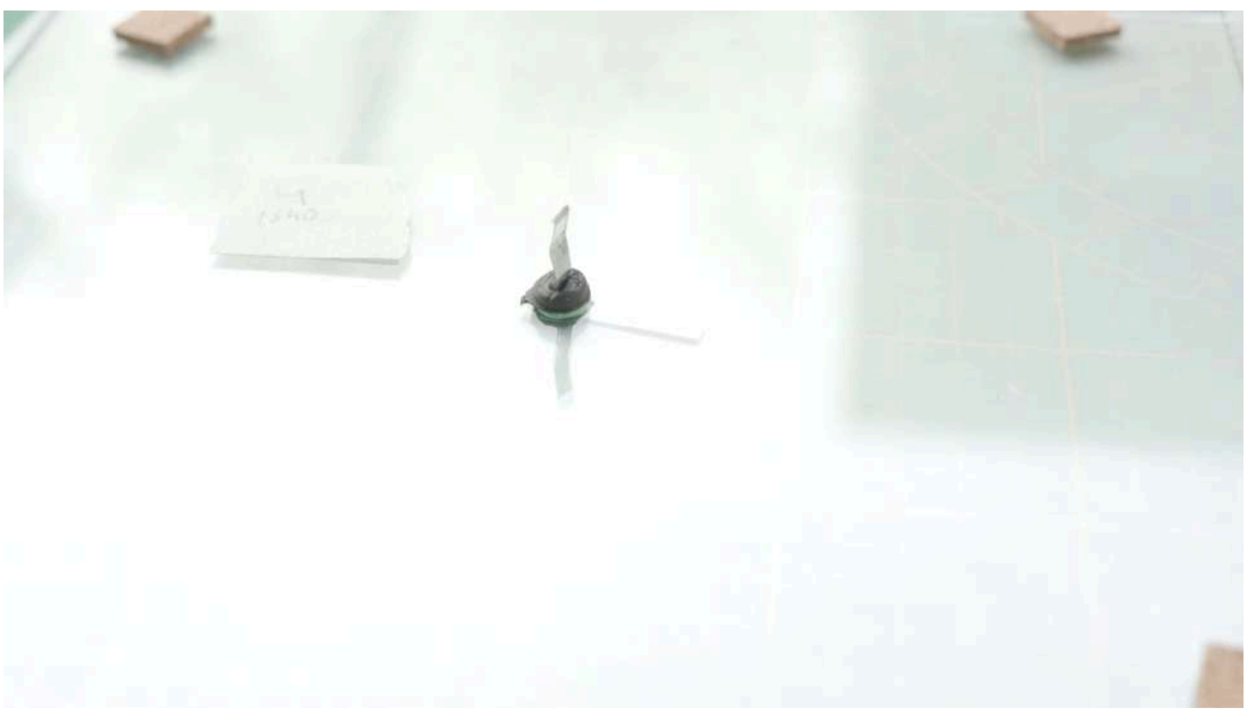

15
15
28,85
28,85
340,3
27,7
340,3
27,7
340,3
165,15
360
360
165,15
28,85
27,85
340,3
27,7
340,3
27,7
340,3
27,85
28,85
15
15

1:4

Attach 3cm pieces of bus bar to the bussing tape, going through the holes



seal the hole with PIB, ensuring no short-circuit. (this picture shows only one bus bar through the hole, in reality it's 2)



STEP 3: Back foil attachment

[45min] ⏱ 00:00:00 | 1 Person

STEP 3: Back foil attachment 1.MP4

STEP 3: Back foil attachment 2.MP4

STEP 3: Back foil attachment 3.MP4

Flip the assembly

Place the foil over the glass and cut out the foil around the glass holes, making sure the hole is smaller than the junction box, that will cover it after.

The S40 foil is attached to the bottom side of the back glass. The side with foil becomes the bottom of the module

The foil is attached by spraying the glass with lots of soapy water, then pulling off the film from the foil and simultaneously unrolling the foil on the glass. Once it is aligned with the glass edges, squeeze out the soapy water

STEP 4: Junction box soldering

[20min] ⏱ 00:00:00 | 1 Person

Put the wires through the slits in the junction boxes and solder, with the cables facing outwards. (keep in mind that the polarity chosen here determines the cell polarity, and the orientation of the module)

Temporarily secure the junction box to the glass with tape

Flip the assembly back to sunny side up

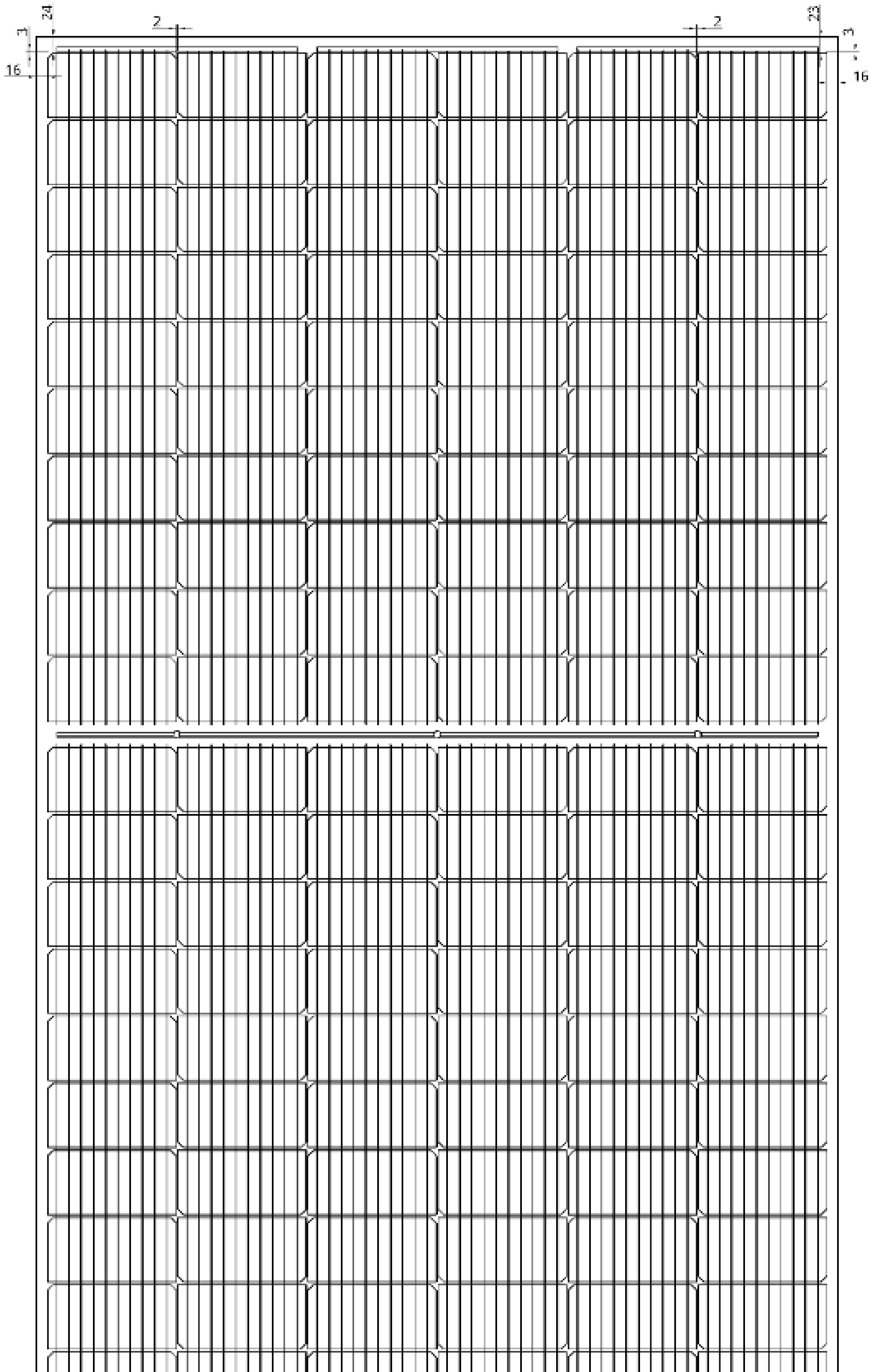
STEP 5: Cell string placement and bussing

⏱ 00:00:00 | 1 Person

STEP 5: Cell String Placement 1.MP4

STEP 5: Cell String placement 2.MP4

Add the cell strings, ensuring a series connection according to the following technical drawing. Check, according to the cell polarity and the polarity of the junction boxes that the cells are placed in the correct orientation.


24
3
16
2
2
23
3
16
16
3
23
2

Solder cell stings to the bussing tape using ample flux and solder wire. Ensure that the total solder assembly does not exceed 1mm in the z axis

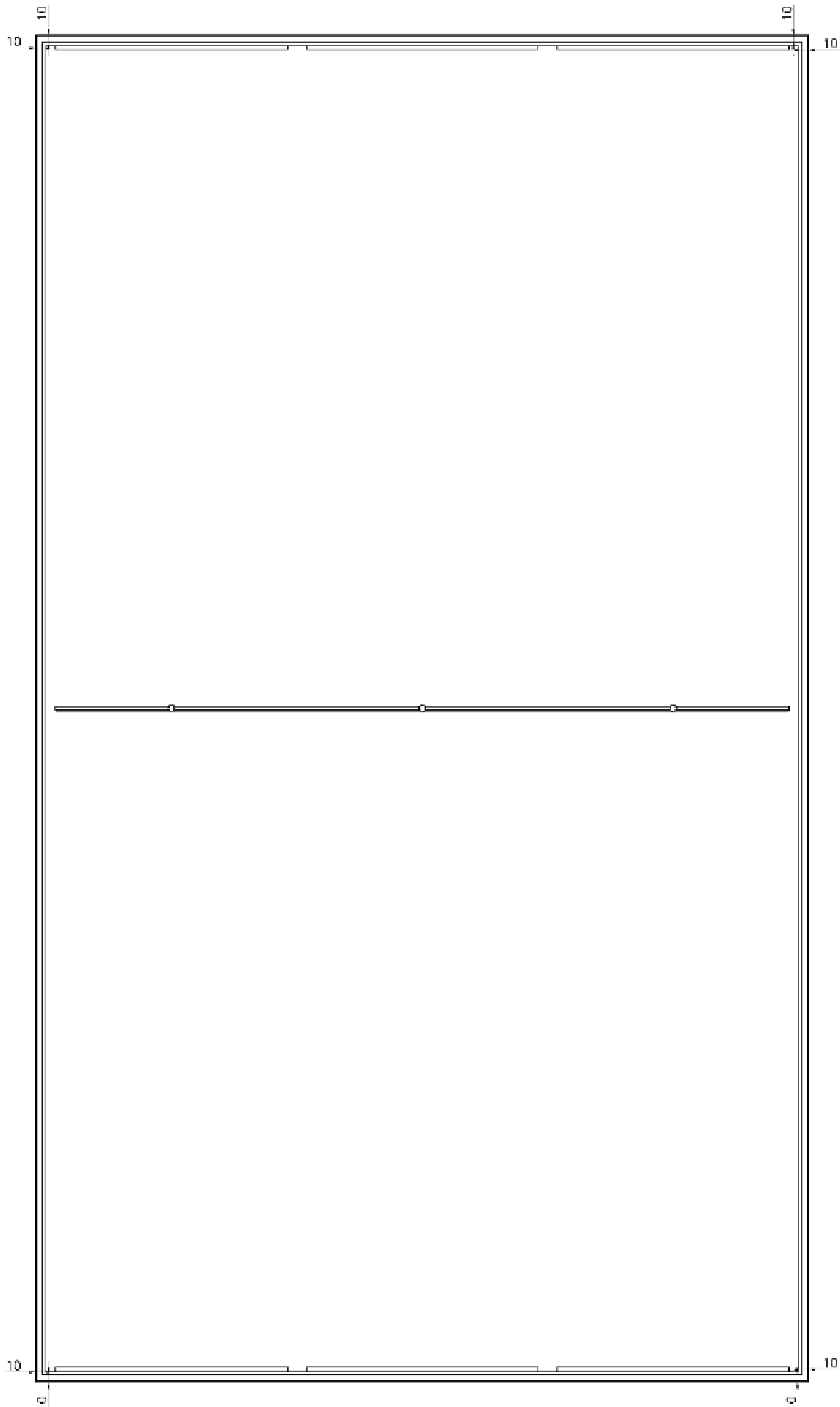
STEP 6: Inner frame and edge seal placement

⏱ 00:00:00 | 1 Person

STEP 6: Edge Seal Placement 1.MP4

STEP 6: Edge Seal Placement 2.MP4

Place the inner frame according to the following technical drawing


10
10
10
10
10
10
10
10

Add the edge seal around the edge to ensure 10mm width after pressing. (Everlight or PIB)

STEP 7: Front glass washing and placement

⏱ 00:00:00 | 3 Person

STEP 7: Front Glass Placement.MP4

Wash the front glass and place it on the module top

Clean off any excess sealant and tape off the edge to prevent spilling

STEP 8: Edge seal curing and IV test

⏱ 00:00:00 | 1 Person

For Everlight: Cure the module edges with the UV lamp for 60 seconds

For PIB: heat (130°C) and press the module edges using the roller (add some spacer wood since the roller cannot go below 10mm

Mark the serial numbers of each module. Take the IV curve without front foil, noting the serial number

STEP 9: Front foil attachment

⏱ 00:00:00 | 2 Person

Place the front foil on the front glass

STEP 10: IV Test

⏱ 00:00:00 | 1 Person

Take IV curves to compare the performance before and after foil, marking the serial number

STEP 11: Framing

⏱ 00:00:00 | 1 Person

Put caulk in the frame

Attach the frame

STEP 12: Junction Box Potting

⏱ 00:00:00 | 1 Person

Put sealant into the junction box

STEP 13: Silicone Curing

Wait

V1.1 Disassembly Manual

1. Identify broken elements through visual inspection. (Optional) Establish broken elements through EL
2. Prepare replacement strings (2mm spacing, 10BB bifacial half cells, 12 or 10 cells per string)
3. Remove frame by applying pressure at frame corners
4. Place sucker on front glass and apply slight lift pressure
5. Cut edge seal. With some PIB heat can help, but if heat can be avoided it's better since it also makes the PIB sticky, allowing it to re-adhere and stick to tools. Pull the front glass up while cutting to avoid re-adherance.
6. Lift front glass off
7. Desolder and remove broken strings
8. Place and resolder new strings
9. Apply new sealant if necessary
10. Re-attach frame using silicone bond

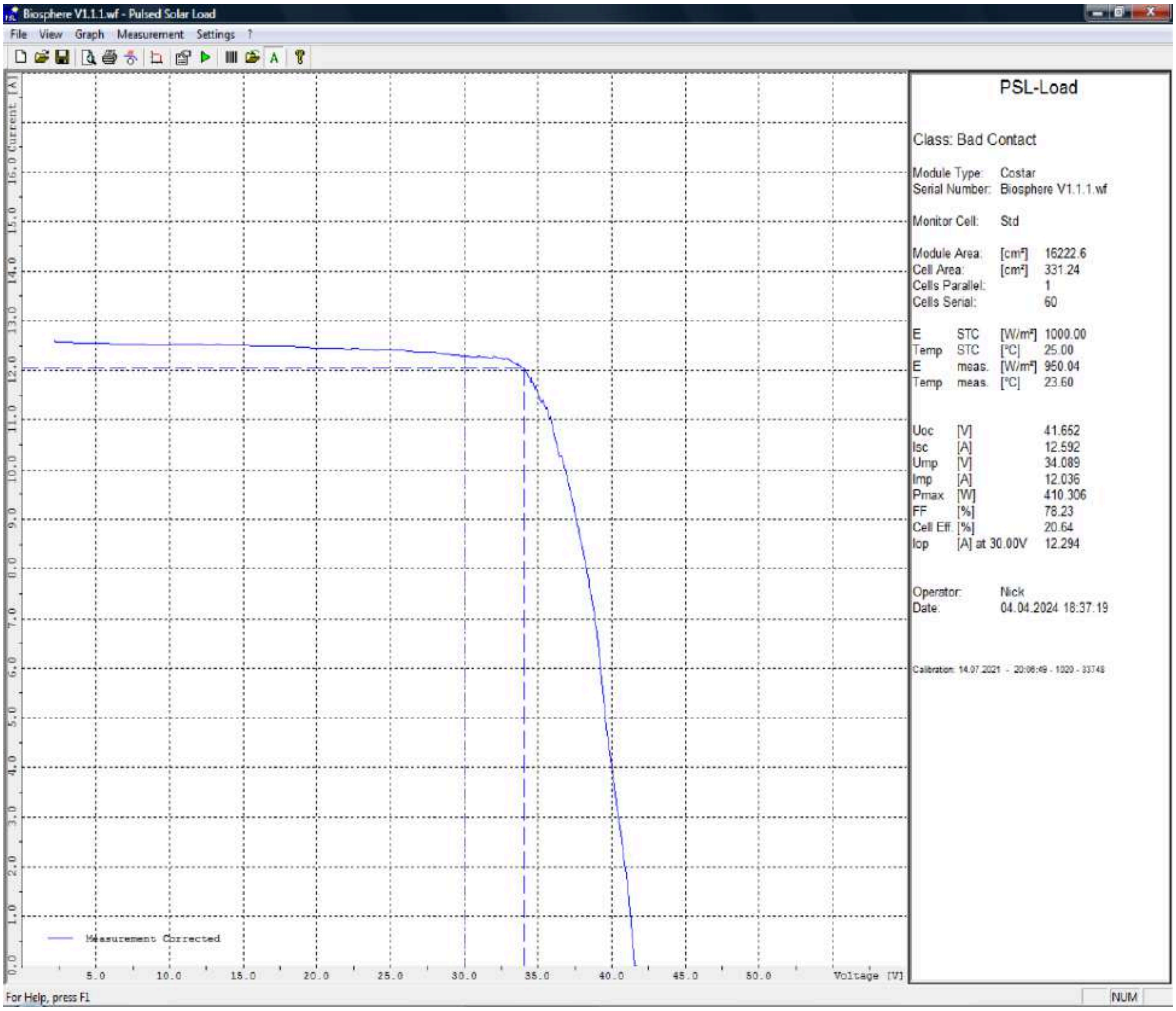
Test Results

We will need to get CE certified sooner than later, for that we will have to send a report to a recognized notified body who approves our self-audit.

Performance & IV Curve

The IV curve looks fine, not great. The Wp value is decreased from about 423 to 410 due to the addition of the S40 safety foil.

All results here: 🗀 V1.1 IV Tests

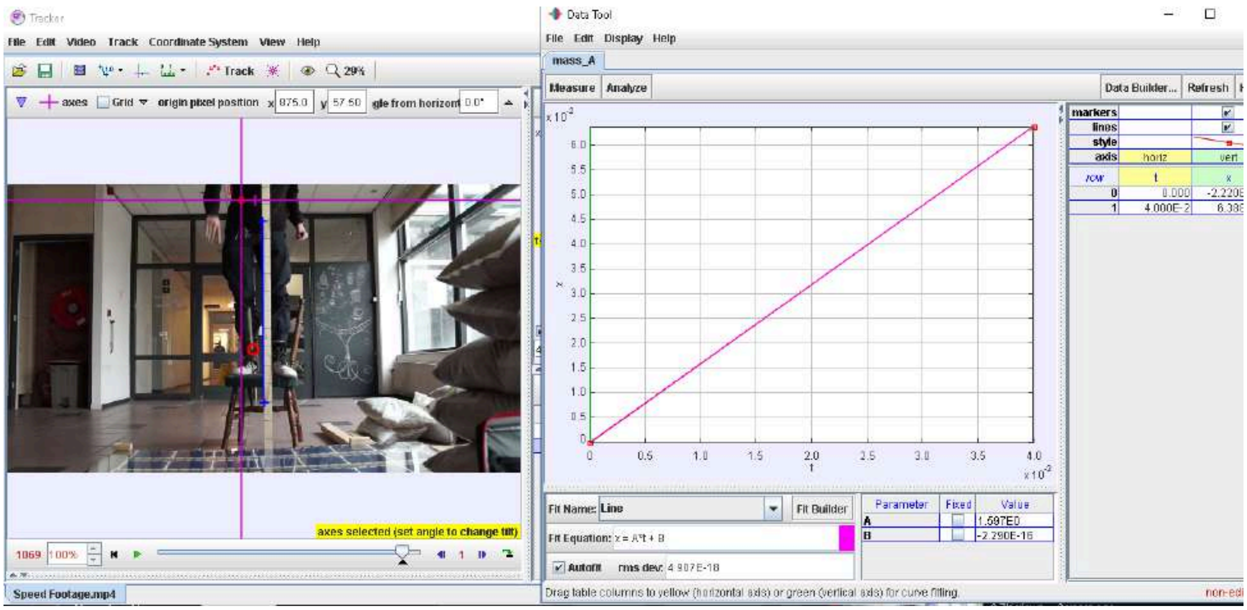


Outdoor Test [TO DO]

Breakage Test

The breakage test was performed on a repaired version of the V1.0 with 4mm tempered glass on both sides. Both the front and rear tempered glass panes have the 3M S40 safety foil applied on the exterior face. The [full video about this process is available on our youtube channel](#)

The breakage was performed using a 40mm steel bearing. Using the footage, analysed in Tracker, it is estimated the ball was thrown at 1.597 m/s^2. However, with a low framerate of 25fps and long exposure, this value is not highly accurate (only one frame was usable for measurement). The weight of this bearing is 197g (CALCULATED)



The result was that the panel held together. Some cells did break. Especially the cell next to the impact point broke in many pieces, but also other cells broke. It should be noted that cells in this module are constrained in a cell bed with vertical edges on the sides, which may cause breakage during bending. The bend in the module was severe.

Post-Breakage Rigidity In Frame [TO TEST]

Damp Heat Test [ONGOING]

The damp heat test was carried out using a steamer oven, which reaches X% relative humidity. The samples tested are with 2 pieces of tempered glass, with dimensions of 280x280 mm. The oven is timed at 8 and 10 hour slots, taking pictures every 200 hours with a total test time of 1000 hours. They are sealed around the edge with different types of sealant. In addition, the back glass has a hole, which is sealed with different types of sealant, and capped off with a junction box, to simulate the back of V1.1 module. The samples have orange silica beads inside which decolor in case of moisture ingress.

- Sample 1: has everlight UV cured sealant. This seal failed 2 times after 8 hours. Most likely due to improper curing
- Sample 2: has Kömmerling Helioseal 101 and PVS silicone. TO TEST

Post Breakage Damp Heat [TO TEST]

EL images

EL images are completed with all the panels with an IR camera. For the roof version it was done at 40V and the utility version around 45V. There are some shaded cells and microcracks showing that we need to improve the design of the cell bed, but one of the modules will have the strings replaced. See images here:

V1.1 EL

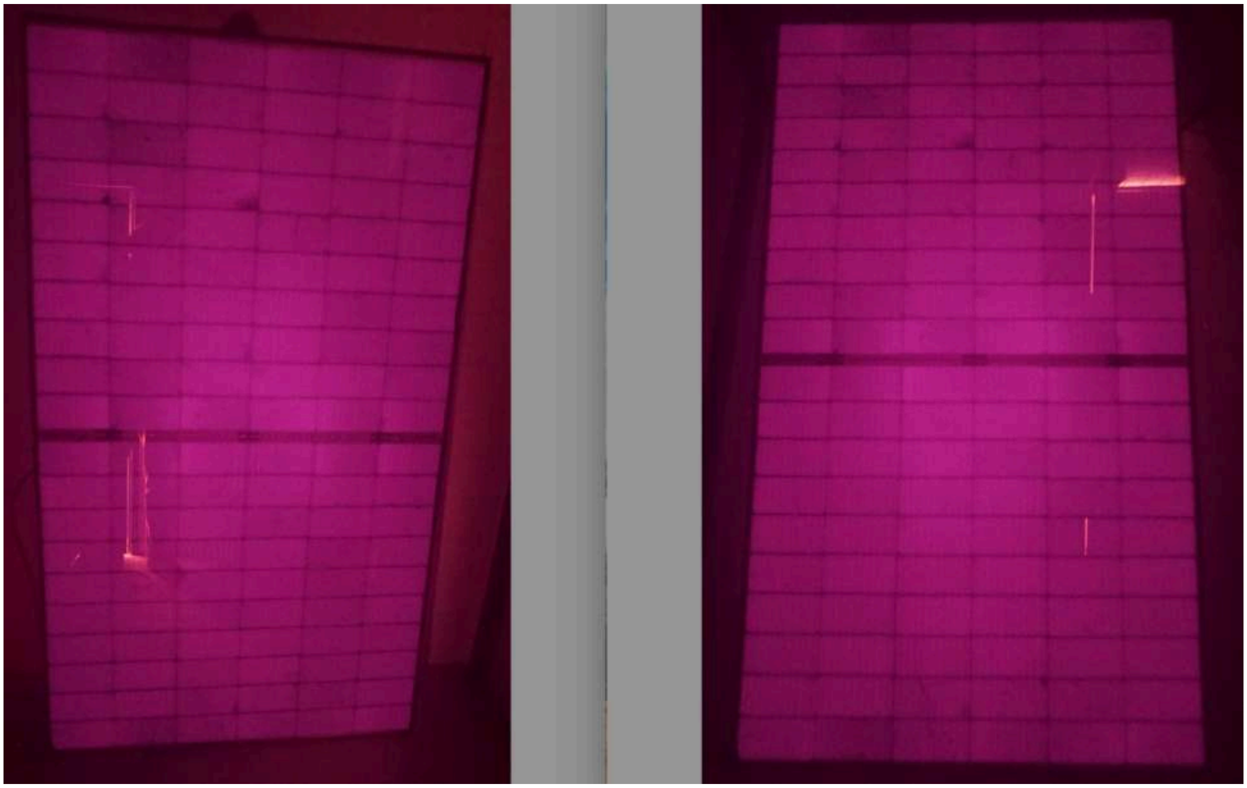
Static Mechanical Load

The static mechanical load test is carried out using an evenly distributed load of 550kg for the V1.1R and 661kg for the V1.1U

Frameless

Mounted in portrait mode using valk pro glass clamps at 50 cm from the top and bottom of the module glass, with 57 cm in between.

EL before (left) and after (right) for V1.1.1R



Framed

Mounted using VDV mounting clamps in landscape mode.

--> Utility scale FRAMED failed with the clamps on the sides. The frame fell out way before reaching 600kg.

Insulation Test

Insulation tests were conducted on both rooftop and utility versions up to 500V and both with and without frame.

V1.1 Insulation Test.xlsx

UV Research [TO DO]

The S40 foil blocks 99% of the UV, PIB is UV resistant, the Everlight seal is cured by UV. Mechanical properties of recycled PET degrades after long UV exposure (Vasylius et al., 2023) and even with normal UV stabilized PET (backsheet) degrades from UV and moisture (Gok et al., 2015). The PET cellbeds are only a temporary solutions.

Fire Safety Research

S40 foil

S40 foil is tested for EN 13501 Behavior to exposure to fire in buildings. Polyester is extremely hard to catch fire (flame retardant) and when it does catch fire it melts rather than burns. Solvent based pressure sensitive acrylic (PSA) is flammable but not sure what type of PSA is in the foil.

Improvements to be Made

Post Breakage Foil

This module has two sheets of foil to keep the glass together after breakage. The advantage of this foil is that module circularity is improved since modules with broken glass can be returned in one piece. Moreover, this foil may reduce the chance of breakage by softening the blows.

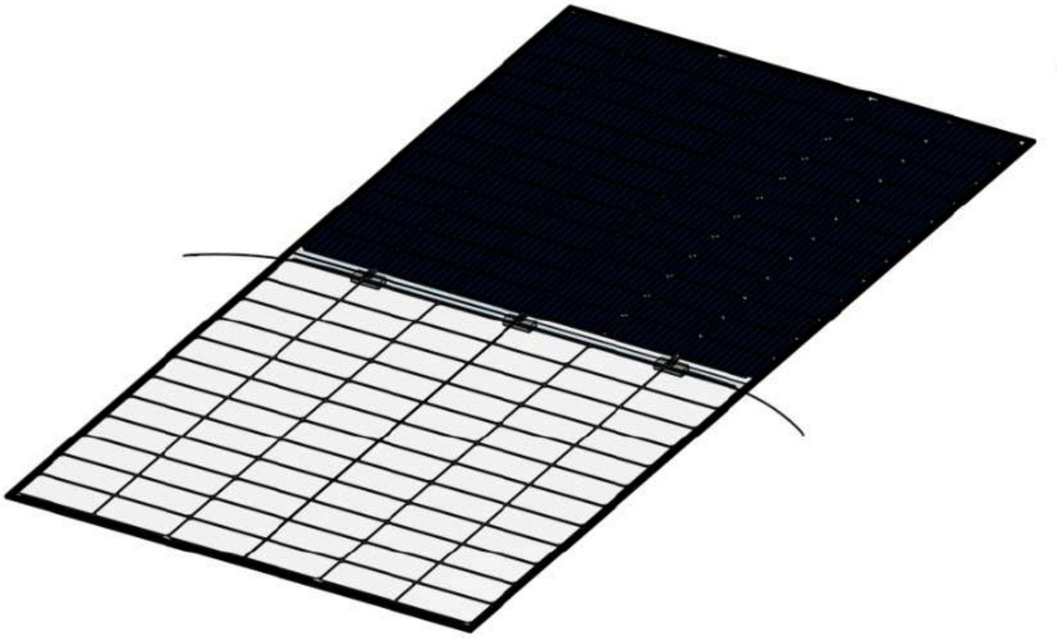
The foils used in V1.1 were 3M S40. We also looked into 3M PPF. The advantage of S40 is its high strength. PPF could also be a good option since it doubles as an anti-reflective and anti-soiling coating.

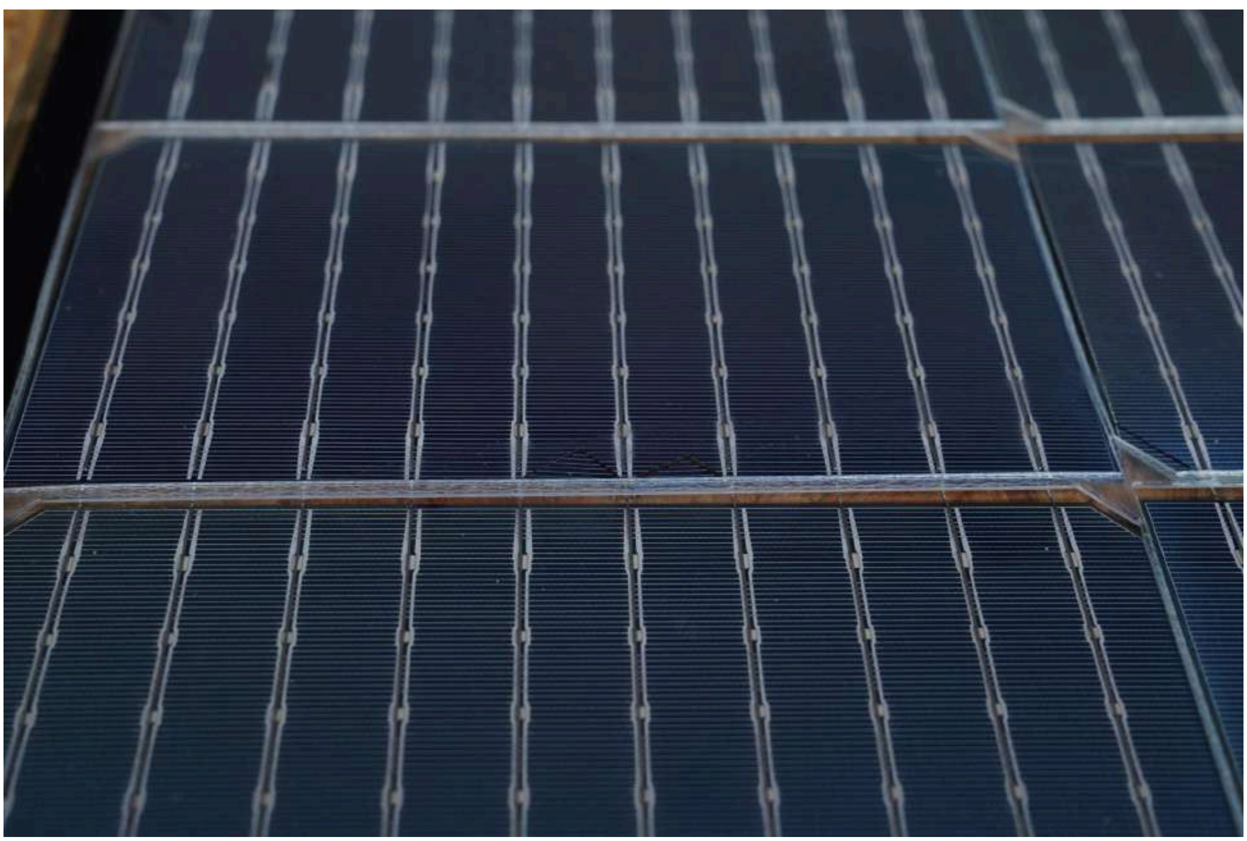
The downside of these foils is that they come with a very high price of about €130,-/m at scale. We would need about 4 meters of this foil per module. Therefore, their use is not economically feasible at this point. Another minor downside is their impact on performance, since they contain UV-blocking agents. Our IV-curve measurements showed a +/-10Wp drop in performance with the S40 foil. The PPF was not tested.

The next step is to find alternative suppliers for such foils at a more feasible price. Additionally, a cost-benefit analysis needs to be done to assess the need for such foils.

Spacers

The first prototype (V1.1.0U) of this module series had PETG spacers between all cells. However, due to inaccuracies these would sometimes overlap with the cells. The pressure from the heavy glass placed on top of the spacers would cause the cells to chip and shatter.





Subsequently, copper tape was used to replace the bus bars and stick the cells to the back glass. In addition, a PETG spacer was added around the perimeter to ensure spacing between the glass sheets before completion of the sealing. These solutions largely solved the issues, while still keeping the cells in place really well. However, the final modules still showed cracks in the cells, and our manufacturer raised concerns that this module would not pass a dynamic mechanical load test.

The proposed solution is to add spacer glue dots through precision UV cured adhesive deposition on critical points between the cells. These can be cured before the front glass is placed to maintain easy disassembly of the front glass. Alternatively, these can be cured after the front glass is placed to bond the front and back glass together. This may improve the overall mechanical rigidity of the module, especially when moving to thinner glass.

Precision Sealant Deposition

Currently, the sealant deposition, especially that of the UV-cured sealant , was messy and resulted in variable seal widths, as well as spillage of the sealant material over the cells. This will be improved in future versions using a CNC paste printer. Such a device could also be used to carry out the above-mentioned glue-dot deposition.

Weight

This will be further improved in V1.4, using thinner glass. The target is a total module weight of <25kg, to ensure 1 person can carry the module within health and safety regulations. This weight can only be reached by using 2mm glass..

Efficiency

This will be further improved in V1.2, using liquid encapsulation to tackle the issues of thermal and optical continuity.

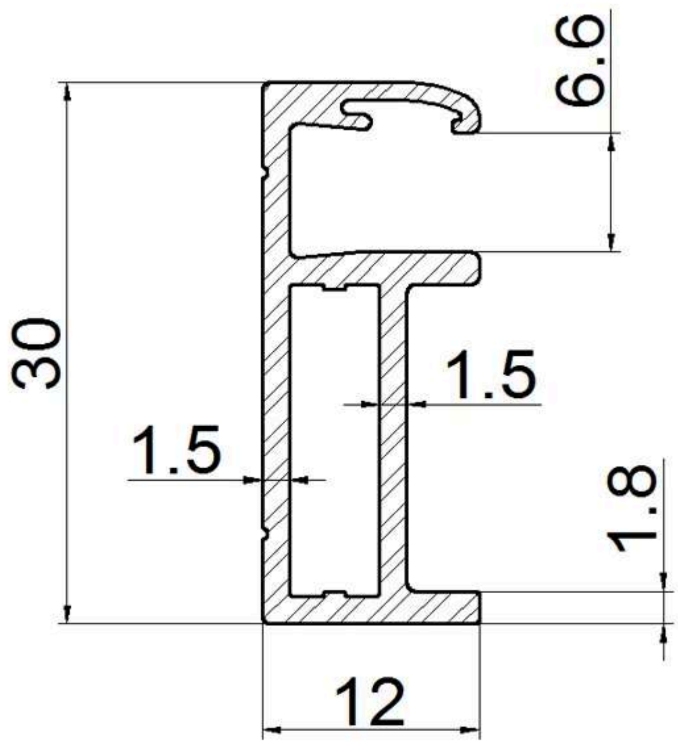
Scale up

Three V1.1 panels were produced in Soltech within a full day. At this rate we cannot scale up because most of the production processes are not (semi-)automated. Only the stringing of cells and glass washing are. In addition, Soltech only has the capacity to produce around a maximum of 100 panels per day. We are contacting larger PV manufacturers to help us scale.

Frames

The frames for the V1.1 are not standard solar frames. They were used because they were accessible, fit our modules and easy to assemble. However, they cannot withstand the static mechanical load test. They slid off the glass sheet possibly due to poor sealing and long standing edges on the mounting points. Standard solar frames can secure panels with 4-8 mm thickness but the V1.1 were 10 mm thick (for example, the 6.6 needs to be 10 or we need to reduce our module thickness).

Therefore we should look into more options such as custom made solar frames while also reducing the module thickness to around 8 mm.



CE marking

Not directly related to the components but an important step before being fully IEC 61215 certified is to have a CE marking for a certain level of quality assurance for users. This entails self-audited reports on IEC testing done with the current version. Even though it is self-audited, it needs to be approved by a notified body. Therefore the next step is to contact a notified body and send them our report for testing and ensuring we comply with IEC 61730 as it contains the most important requirements for safety.