Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

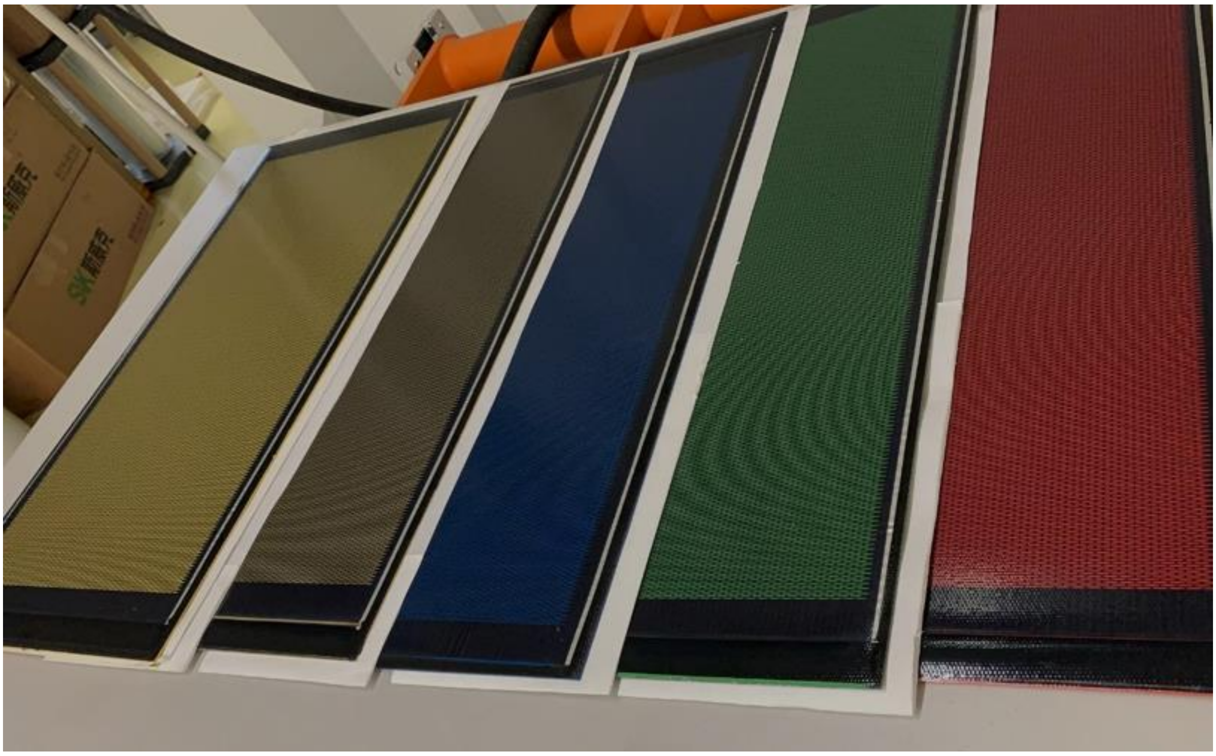
Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

Final report

PanelPV

Sandwich panels with integrated PV with freedom of size and color



Source: Flisom AG

Date: 21.12.2020

Location: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

Subsidy recipients:
Flisom AG
Gewerbestrasse 16, CH-8155 Niederhasli
www.flisom.ch

Authors:
Patrick Reinhard, Flisom AG, patrick.reinhard@flisom.com
Ulfert Ruehle, Flisom AG, Ulfert.ruehle@flisom.com

SFOE project coordinators:
Herr Stefan Oberholzer, stefan.oberholzer@bfe.admin.ch
Herr Karin Söderström, karin.soederstroem@bfe.admin.ch

SFOE contract number: SI/501698-01

Summary

The goal of this project was the development of a coloured sandwich Photovoltaic (PV) panel based on Copper-Indium-Gallium-Diselenide (CIGS) thin film PV. This was done in collaboration with external partners having expertise in building coloured sandwich PV panels, mainly in the Netherlands, in framework of a SOLAR-ERA.NET project (http://www.solar-era.net). Flisom was to provide the suitable PV foils and developing all processes required for proper sample exchange and integration into this new product. The developed product should finally be demonstrated in a small façade installation to be set-up at the site of a project partner (TNO or Panelen Holland) in the Netherlands.

Sandwich panels are generally used in construction, especially for façades, but can also be used for roofing applications. They have a defined structure which includes an insulation layer enclosed within two outside layers of different materials and properties. Generally one of the outside layers is suitable for external use with resistance against environmental impact. The inner "outside" is a mechanical protection and stabilizer against damage but will not be exposed to environmental influence.

In this project PV foils have been integrated, meaning laminated, with the outside layer of the sandwich panel becoming the back sheet (BS) of the PV panel in combination with the insulation and inner protective layer. A suitable BS has been identified, and the required lamination process successfully demonstrated, together with required environmental testing of the final product.

As PV panels generally shos only a dark, almost black colour, translucent PV films were developed to allow for colour coming from the outside of the sandwich panel. Translucence was achieved by structuring the PV foil with a laser process in such a way as to create a high number of small enough voids; in that way the human eye cannot resolve individual patterns and perceives only on coloured surface. 50% transparency with remaining 40% of the original electrical performance was demonstrated. This is an impressive achievement, especially in view of the often observed shunting that can be induced by such laser patterning steps.

The foils provided by Flisom for the demonstrator have finally been processed at TNO. Reproducibility issue in the laser patterning process and sample exchange procedures of such translucent foils have however resulted in demonstration modules with poor electrical performance. Still, it was decided to laminate them at Flisom, so as to allow the consortium to at least build some demonstration modules, focusing on the aesthetics effect.

Discussions are ongoing between the partners to go for another round of sample exchanges, beyond the end of the project, in order to achieve functional products, that could be installed and electrically connected. Business case for such products is underway at Panelen Holland, based on the inputs provided by Flisom. One main cost unknown for such products remain the laser process yield and speed, which can only be estimated very roughly at this early stage. The TNO tool is a lab-tool equipment. Extrapolation based on Flisom's experience indicates that the target of 100 Euros/m^2 for such panels could be achieved. Commercial implementation still requires some development, especially in view of scalability of the laser process and price point-of-view in increasingly competitive market for Building Integrated Photovoltaics (BIPV).

Zusammenfassung

Ziel dieses Projektes war die Entwicklung eines farbigen Sandwich-Photovoltaik (PV)-Moduls auf Basis von Kupfer-Indium-Gallium-Diselenid (CIGS) Dünnschichttechnologie. Die Entwicklung erfolgte in Zusammenarbeit mit externen Partnern, die über Fachwissen im Bau von farbigen Sandwich-PV-Paneelen verfügen, hauptsächlich in den Niederlanden, im Rahmen eines SOLAR-ERA.NET-Projekts

(http://www.solar-era.net). Die Firma Flisom hat die geeigneten PV-Folien bereitgestellt und alle Prozesse entwickelt, die für einen Probenaustausch und die Integration erforderlich sind. Das entwickelte Produkt sollte schliesslich in einer kleinen Fassadeninstallation demonstriert werden, die am Standort eines Projektpartners in den Niederlanden aufgebaut werden sollte.

Sandwich-Module werden im Allgemeinen im Bauwesen eingesetzt, insbesondere für Fassaden, können aber auch für Dachanwendungen verwendet werden. Sie haben einen definierten Aufbau, der eine Dämmschicht umfasst, die von zwei Aussenschichten mit unterschiedlichen Materialien und Eigenschaften umschlossen wird. Eine der Aussenschichten ist für den Ausseneinsatz geeignet und widerstandsfähig gegen Umwelteinflüsse. Die innere «Außenseite» ist ein mechanischer Schutz und Stabilisator gegen Beschädigungen, wird aber keinen Umwelteinflüssen ausgesetzt.

In diesem Projekt wurden PV-Folien integriert, d. h. laminiert, wobei die äussere Schicht des Sandwich-Moduls in Kombination mit der Isolierung und der inneren Schutzschicht die Rückwand (BS) des Moduls bildet. Eine geeignete BS wurde identifiziert und der erforderliche Laminierungsprozess erfolgreich demonstriert, zusammen mit den erforderlichen Umwelttests des Endprodukts.

PV-Module zeigen in der Regel eine dunkle, fast schwarze Farbe. Für Gebäudeanwendungen wurden in diesem Projekt transluzente PV-Folien entwickelt, um eine Farbgebung der Aussenseite des Sandwich-Moduls zu ermöglichen. Die Transluzenz wurde erreicht, indem die PV-Folie mit einem Laserverfahren so strukturiert wurde, dass ein Raster von vielen kleinen Löchern entsteht; auf diese Weise kann das menschliche Auge keine einzelnen mehr Muster auflösen und nimmt nur eine einheitlich farbige Oberfläche wahr. Es wurde eine Transparenz von 50% bei verbleibenden 40% der ursprünglichen elektrischen Leistung nachgewiesen. Dies ist eine beeindruckende Leistung, da mit solche Laserstrukturierungsschritten die Gefahr von elektrischen Kurzschlüssen in der PV-Folie besteht.

Die von Flisom für den Demonstrator zur Verfügung gestellten Folien wurden schließlich bei TNO bearbeitet. Probleme bei der Reproduzierbarkeit im Laserstrukturierungsprozess und beim Austausch von Proben solcher transluzenten Folien haben zu einer verminderten elektrischer Leistung geführt. Dennoch wurde beschlossen, diese Folien bei Flisom zu laminieren, damit das Konsortium zumindest einige Demonstrationsmodule bauen kann, wobei der Schwerpunkt auf dem ästhetischen Effekt lag.

Derzeit laufen Gespräche zwischen den Partnern, um nach Projektende eine weitere funktionale Produkte zu entwickeln, die installiert und elektrisch angeschlossen werden können. Ein Business Case für solche Produkte ist bei Panelen Holland in Arbeit, basierend auf den von Flisom bereitgestellten Informationen. Unsicherheiten bei den Kosten für ein solches Produkt bilden die Ausbeuteund die Geschwindigkeit des Laserprozesses (Laborgerät) und können in diesem frühen Stadium nur grob abgeschätzt werden. Eine Extrapolation auf Basis der Erfahrungen von Flisom zeigt, dass das Ziel von 100 Euro/m^2 für solche Paneele erreicht werden könnte. Die kommerzielle Umsetzung erfordert weitere Entwicklungsarbeit, insbesondere für Skalierbarkeit des Laserprozesses, mit Blick auf einen zunehmend wettbewerbsorientierten Markt für gebäudeintegrierte Photovoltaik (BIPV).

Résumé

Le but de ce projet était de développer un module photovoltaïque (PV) en sandwich coloré basé sur la technologie des couches minces de diséléniure de cuivre, d'indium et de gallium (CIGS). Le développement a été réalisé en collaboration avec des partenaires externes ayant une expertise dans la construction de panneaux PV sandwich colorés, principalement aux Pays-Bas, dans le cadre d'un projet SOLAR-ERA.NET (http://www.solar-era.net). La société Flisom a fourni les films PV appropriés et a développé tous les procédés nécessaires à l'échange d'échantillons et à l'intégration. Enfin, le produit développé devait être démontré dans une petite installation de façade, qui devait être installée sur le site d'un partenaire du projet aux Pays-Bas.

Les modules sandwich sont généralement utilisés dans la construction, notamment pour les façades, mais peuvent également être utilisés pour les toitures. Ils ont une structure définie comprenant une

couche isolante entourée de deux couches extérieures ayant des matériaux et des propriétés différents. L'une des couches extérieures est adaptée à une utilisation en extérieur et résiste aux influences de l'environnement. L'intérieur "extérieur" est une protection mécanique et un stabilisateur contre les dommages, mais il n'est pas exposé aux influences de l'environnement.

Dans ce projet, des films PV ont été intégrés, c'est-à-dire laminés, où la couche extérieure du module sandwich, en combinaison avec l'isolation et la couche de protection intérieure, forme la feuille de fond (BS) du module. Un BS approprié a été identifié et le processus de laminage requis a été démontré avec succès, ainsi que les essais environnementaux requis pour le produit final.

Les modules PV présentent généralement une couleur sombre, presque noire. Pour les applications de construction, des films PV translucides ont été développés dans ce projet pour permettre la coloration de l'extérieur du module sandwich. La translucidité a été obtenue en structurant le film PV avec un procédé laser de manière à créer une grille de nombreux petits trous ; de cette manière, l'œil humain ne peut pas résoudre les motifs individuels plus nombreux et ne perçoit qu'une surface uniformément colorée. Une transparence de 50 % avec 40 % de la puissance électrique d'origine restante a été démontrée. C'est une réalisation impressionnante, car avec de telles étapes de modelage au laser, il y a un risque de court-circuit électrique dans le film PV.

Les films fournis par Flisom pour le démonstrateur ont finalement été traités à TNO. Des problèmes de reproductibilité dans le processus de modelage par laser et dans l'échange d'échantillons de ces films translucides ont entraîné une réduction des performances électriques. Néanmoins, il a été décidé de laminer ces films à Flisom afin que le consortium puisse construire au moins quelques modules de démonstration, en se concentrant sur l'effet esthétique.

Des discussions sont actuellement en cours entre les partenaires pour développer un autre produit fonctionnel qui pourra être installé et connecté électriquement après la fin du projet. Une analyse de rentabilité pour ces produits est en cours chez Panelen Holland, sur la base d'informations fournies par Flisom. Les incertitudes quant au coût d'un tel produit sont le rendement et la vitesse du processus laser (appareil de laboratoire) et ne peuvent être estimées que de manière approximative à ce stade précoce. Une extrapolation basée sur l'expérience de Flisom montre que l'objectif de 100 Euro/m2 pour ces panneaux pourrait être atteint. La mise en œuvre commerciale nécessite des travaux de développement supplémentaires, en particulier pour l'extensibilité du processus laser, en vue d'un marché de plus en plus concurrentiel pour le photovoltaïque intégré aux bâtiments (BIPV).

Take-home messages

- A process for coloured photovoltaic panels has been developed within an international consortium based on translucent photovoltaic foils based on Copper-Indium-Gallium-Diselenide (CIGS) technology.
- Electrical functionality was demonstrated as well as the stability upon environmental testing. 50% transparency with remaining 40% of the original electrical performance was achieved.
- The laser process to create the void pattern in the CIGS foil to obtain translucency can be carried out without shunts being created.
- Ideas exist for turning such an approach into a marketable product for Building Integrated Photovoltaics (BIPV), but there are some challenges to overcome.

Contents

Summary 3

Zusammenfassung 3

Résumé 4

Take-home messages 6

Contents 7

Abbreviations 8

1 Introduction 9

1.1 Background information and current situation 9

1.2 Purpose of the project 9

1.3 Objectives 9

2 Procedures and methodology 10

3 Results and discussion 10

3.1 WP1: Development of Design and Process for Integrated Façade Panels 10

3.1.1 Description of adhesion tests 11

3.1.2 Results of tests 14

3.1.3 Results of second testing round 16

3.1.4 Progress of façade modules 18

3.2 WP2: Process Development for Translucent PV Foils 21

3.2.1 Principle of translucent PV foils 21

3.2.2 First results of laser process by Sunpartner 21

3.2.3 First results of laser process by TNO 25

3.2.4 Use of colourless PI 27

3.2.5 Latest results of laser process by TNO (developed second half of 2019) 28

3.3 WP3: Realization of coloured demo-façade 30

4 Conclusions 35

5 Outlook and next steps 37

6 National and international cooperation 38

7 Communication 38

Abbreviations

CIGS	Copper-Indium-Gallium-Diselenide
BIPV	Building Integrated Photovoltaic
BS	back sheet
DH	damp heat
Al	Aluminium
EPD	electrophoretic deposition

1 Introduction

1.1 Background information and current situation

The main objective of the PanelPV project is the development of visual attractive façade elements, which produce solar electricity at an acceptable, market conform cost level. The project aims at the development of new facade elements with integrated PV based on sandwich panels made by Panelen Holland and Copper-Indium-Gallium-Diselenide (CIGS) Photovoltaic (PV) foil made by Flisom. In the project, these two products should be combined into new power generating façade elements. A technology has to be developed to make the PV foil translucent, such that the integrated product appears to have the same colour as the underlying sandwich panel. This gives the producer of the sandwich panel full freedom in colour or print selection.

The project should result in the fabrication of a demo façade in which several sandwich panels with different colours will be integrated and electrically interconnected.

1.2 Purpose of the project

At the current market situation Building Integrated Photovoltaic (BIPV) is still a new, expensive and often customized solution which for price reasons will not or cannot be accepted by many potential customers. Further, the dominant colour black which is currently delivered with many PV solutions is not very well accepted by architects and home owners likewise.

To integrate PV in buildings alternate solutions which offer flexibility in colour and reduction in price need to be develop to open the door for a higher acceptance in the building integrated market. Creating a product which will offer the benefit of standardization and the flexibility of colour is the driving motivation behind this project. Standardized solutions will lead to reduced costs for the customers and in combination with the choice of colour the path for a widely accepted innovative product is paved. The benefit of high market acceptance on the other hand will lead to increased demand of a standardized product leading to further reduced manufacturing cost.

The innovative combination of two available technologies will enable a BIPV product offering different colours based on a standard façade cladding system like the one from Panelen Holland. Multiple cladding materials like colour coated metal sheets or composite material panels offering a wide choice of colours are used. These panels will be combined with optically translucent PV foils based on Flisom's CIGS thin film PV foils. The translucence of the generally opaque PV foils will be achieved removing all coatings in parts of the active PV foil using a specific laser process.

1.3 Objectives

The major goal of the project is the development of a novel façade element consisting of a sandwich panel with integrated translucent PV of a power output of at least 50 W/m^2. These panels can be manufactured in different colours and are easily integrated in façades. Proof of concept of this new product will be done installing a façade of at least 3 m^2 using integrated sandwich PV panel in different colours with a power of around 50 W/m^2. The cost goal for the new product manufactured in mass will be 100 €/m^2 on top of the facade without integrated PV. This additional cost will offer a Return of Invest (ROI) in the range of 5 to 8 years depending on the geographical area and the electricity prices of the installation if the generated energy is used for self-consumption.

A business plan collectively developed by Flisom and Panelen Holland will line out the commercialization of the innovative product showing a clear path to the market.

2 Procedures and methodology

Development of the integrated façade element was executed following individual work packages (WPs).

In WP1 the design and lamination process of the integrated PV façade element will be developed. The panel structure of Flisom's standard product is very well defined and includes multiple films laminated together. In the project different materials potentially usable as back side film, also called back sheet (BS), need to be identified. Having a wide variety of colours available is equally important as showing good adhesion to the encapsulation foil used in manufacturing Flisom PV panels. Testing specific material combinations for sufficient adhesion requires measurement of adhesion on multiple samples after different stages of aging. Further, test panels will be manufactured using the relevant back sheet material to undergo environmental test for evaluating long term stability of the electrical and mechanical stability of the PV panels. These tests and the manufacturing of test panels will be done by Flisom. PV panels with relevant back sheet material will then be finished to integrated sandwich panels at Panelen Holland to see if this final manufacturing process has a detrimental effect on the electrical performance of the PV panel.

WP2 focuses on development of a laser process enabling to make translucent PV foils based on Flisom's standard deposition process for CIGS films. The challenge is the partial removal of active PV material in defined sections. The human eye is not able to separate individual structures with "small" dimensions at a distance of a meter or more. The laser process must not cause any damage to the remaining semiconductor material leading to reduced electrical performance of the final translucent PV film. In particular, the laser can cause shunt resistances reducing the low light performance and thus lowering the annual production of electrical energy.

Ideally, the power of a solar film will decrease linearly with the amount of surface area removed from the opaque substrate. At a translucence of 50 % the power of the solar film will be half of the opaque version. The goal is to achieve at least 40 % of the original power at 50 % transmission rate.

In WP3 finally a demo installation of at least 6 real size panels with different colours using a proven BS material and PV films with 50% transmission will be realized. The premises of Panelen Holland will host this demo as a showcase for customers.

In addition to the technical demonstration, commercialization of the product is of equal importance. Therefore, Flisom and Panelen Holland will develop a business plan how large-scale production of these panels can be realized and how the market will be conquered.

3 Results and discussion

The results presented here are a summary of all activities performed during the project, with stronger focus on those delivered and led by Flisom AG.

3.1 WP1: Development of Design and Process for Integrated Façade Panels

In WP1 work started with adhesion tests of different materials being potentially useful for façade cladding elements and which can also be used as back sheets for PV modules.

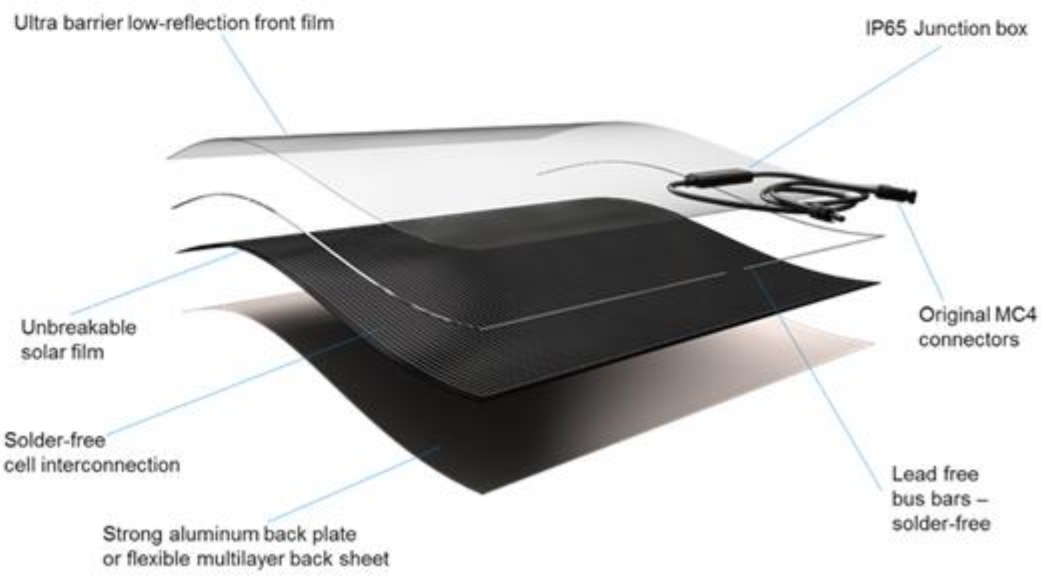


Figure 1: Exploded view of Flisom modules without encapsulant

The structure of a Flisom CIGS thin film PV panel is shown in Figure 1. However, in the figure the foil adhering the different layers together, the so-called encapsulant, is not shown for ease of understanding. Different materials can be used as a BS, from very flexible to even rigid. This material gives the module its specific mechanical characteristic. There are two very important material properties, which are required:

1. The BS needs to have good adhesion to the encapsulant to make sure the bond will last for many years.
2. The BS must be a good barrier against moisture penetrating from the environment inside the module and causing degradation. Also, this barrier function must be good enough to ensure stable electrical performance for more than 25 years.

To ensure that these stringent requirements are fulfilled extensive testing of adhesion and barrier function is required.

Flisom has gained experience that any metallic BS will fulfil the barrier function required to withstand environmental impact for more than 25 years. Therefore, for metallic materials the critical test is adhesion between the surface of the metal sheet coating and the encapsulant. In addition, in case of non-metallic materials time consuming damp heat (DH) tests are required to test electrical and mechanical stability of encapsulated submodules against the impact of moisture. Testing conditions of the DH test are 85 % relative humidity at 85 °C for 1000 h.

In a first, round Flisom received eight different material samples from Panelen Holland, which have been prepared for adhesion testing. The test follows a multi-step process, which takes 6 weeks minimum to test for aging influence. After execution of the tests, the adhesion will be measured using a pull force tool and the resulting force will be documented.

3.1.1 Description of adhesion tests

For adhesion testing samples of the correct size have to be prepared before the tests can commence. The samples in use have a size of 52 x 150 mm (see Figure 2).

The sample of BS material will be laminated to a stack of Flisom's standard encapsulant and BS. Using the pull force tool the adhesion of the encapsulant to the sample material will then be measured (see Figure 5). During the test the tool will apply an increasing force on the bond until the bond breaks open.

Once the bond is open the pull force is continuously pulling upwards for a certain distance. As the bond is already broken the two test materials will separate under the permanent influence of the pull force. The test result with the Pull Force Tool leads to two different values – the peak and the plateau value. The peak value indicates the force required to break open the bond between two test samples. The plateau value indicates the force required to spread the already broken bond under continuous influence of pull force. The adhesion value measured this way is given in N/cm. An exemplary test result is shown in Figure 3&4.

Figure 2: Sample for adhesion tests

Also, the quality of the break will be evaluated. Good adhesion is characterized with a cohesive fracture indicating that the adhesion is stronger than the adhesive material and the adhesive in use limits the load. In case of a cohesivefracture the adhesive is coming off the bonded material. In case the adhesive force is strong enough for the application the bond is considered good enough and the adhesive can be used in combination with the tested material. The aspired minimum pull force value for Flisom is 5 N/cm, a value above 10 N/cm is considered very good.

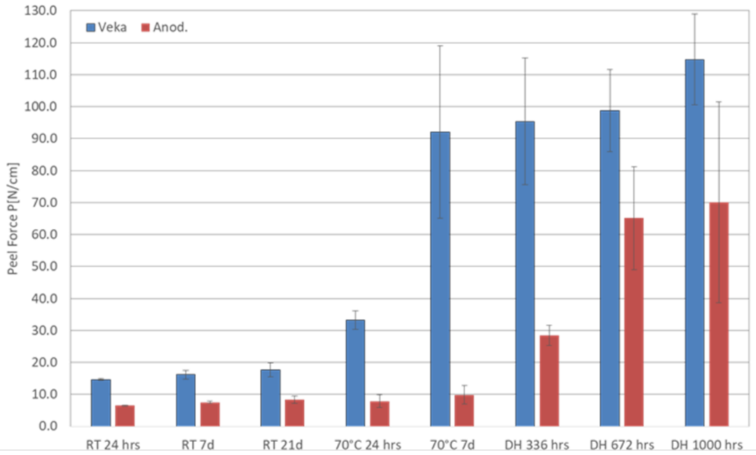


Figure 3: Adhesion between encapsulant and two different BS material

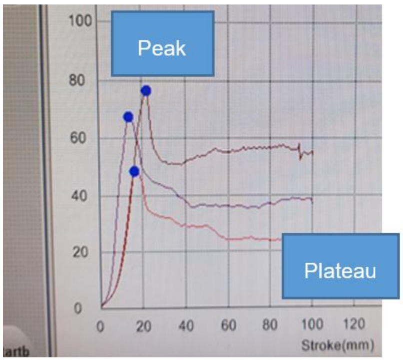


Figure 4: Exemplary pull force measurement data for three samples

Figure 5: Adhesion measurement with Pull Force Tool

Test	days
24h RT	1
7d RT	7
21d RT	21
24h 70°C	1
7d 70°C	7
7d 85°C	7
Damp Heat 336 hours	14
Damp Heat 672 hours	28
Damp Heat 1000 hours	42

Table 1 Test sequence of adhesion test

A complete sequence of adhesion tests consists of multiple steps including aging under different environmental conditions. The detailed steps are listed in Table 1. To get some statistics, 4 samples of the same material have been prepared and tested for each step up to 1000h DH. For the final result the average value of these 4 samples is taken.

3.1.2 Results of tests

In the first round all samples sent by Panelen Holland except of one made of composite material (wood & resin) have been tested for adhesion, and some of them have shown good initial values. One challenge was for some material the unstability under environmental stress of DH.

Figure 6 Sample after 6 weeks of DH shows strong unacceptable bend

Unfortunately, the material is mechanically not stable under environmental stress of DH. Being exposed to a high temperature for such a long time (1000 h) caused the samples to bend. The result is clearly visible in Figure 6.

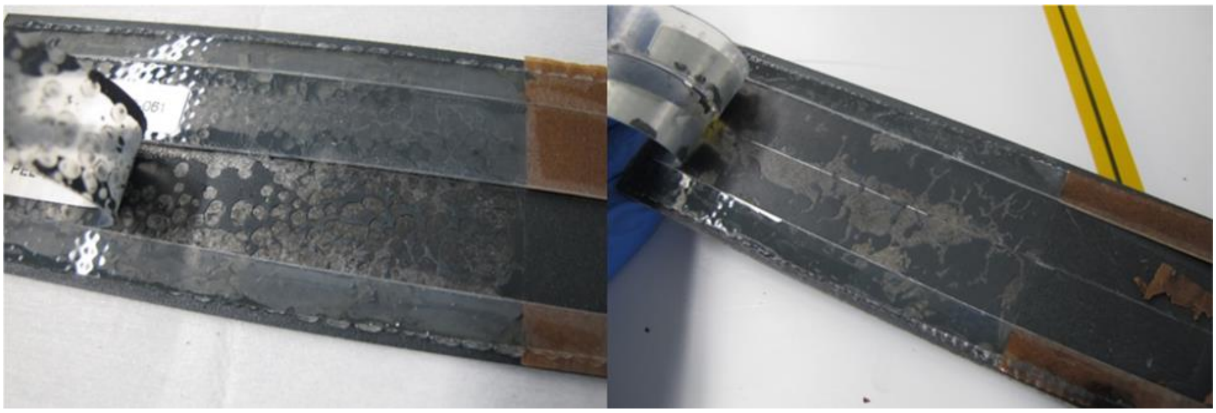


Figure 7 Tests samples with powder coating after 672h (left) and 1000h (right) DH

Adhesion of coated steel and Aluminium (Al) samples however, have low values right after lamination. Although adhesion improves during the testing sequence the final measurement after 6 weeks of DH again show low values. This result is quite disappointing, as it will limit the available of coatings substantially. A summary overview of the values is found in Figure 8. In case of the powder coating used on steel and Al the low adhesion after DH test is related to a general decomposing of the coating in the laminated area. The adhesion test showed that the coating itself lost its ability to withstand the pull force and developed signs of a cohesive break. This is nicely demonstrated in Figure 7 where samples after 672 and 1000 h of DH are pictured.

At the end out of the seven tested material samples only anodized Al is really usable. Wooden composite material has not been tested for doubts about the suitability of this particular material due to its high content of wood fibres mixed with an undefined phenol raisin.

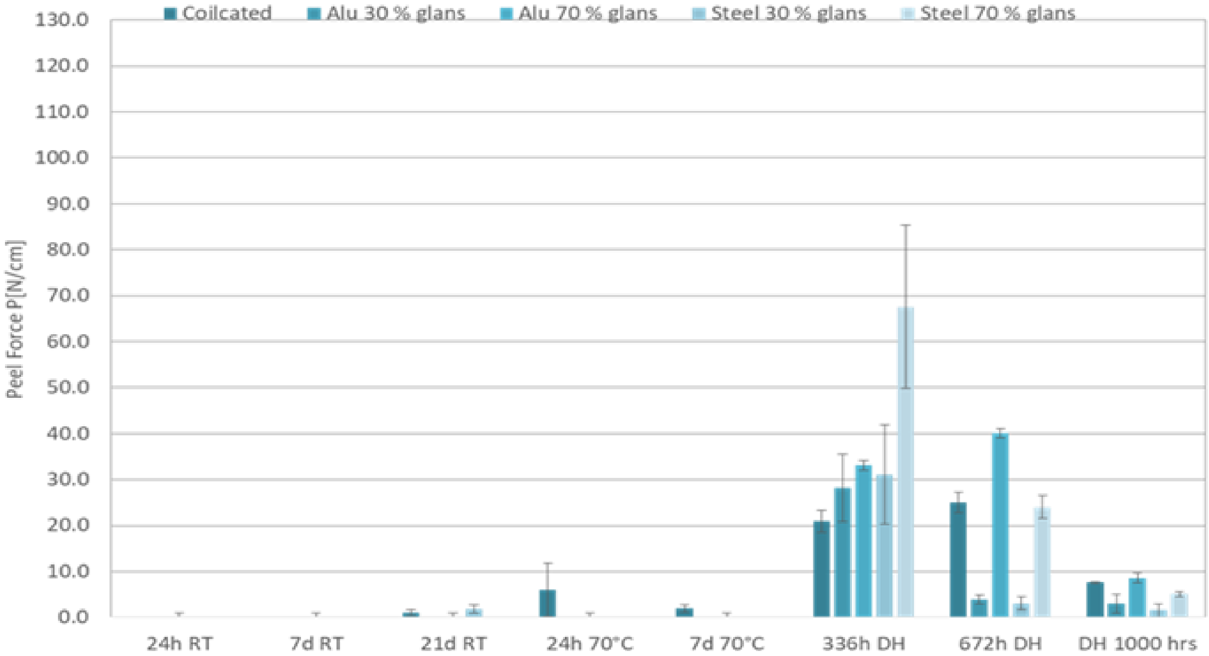


Figure 8: Adhesion test results for different coated metal samples

3.1.3 Results of second testing round

Given the first results a second round of other material samples was prepared by Panelen Holland and sent for adhesion testing. In this case different type of coatings on steel and Al have been sent. In addition anodized Al samples in different coloured have been received by Flisom as well.

Testing during this second round was done not only using Flisom's standard but also alternative encapsulant material from other suppliers as well as other encapsulation materials. This expanded testing sequence originates in the need to reduce manufacturing cost and thus alternate suppliers and materials have to be evaluated for future usage.

Flisom's experience with anodized Al so far was only positive, therefore this set of samples was not tested during this second round. In the first trial all powder coatings on steel or Al have shown bad adhesion and therefore it is most important to find a combination of encapsulant and metal coating with sufficiently strong adhesion.

The best adhesion was measured on coatings done by Electrophoretic Deposition (EPD) in combination with most of the tested encapsulants. However, there are different encapsulants of the same manufacturer, which did not work with all coatings. Promising candidates have been identified, that include a composite material. This is a very common material used in façade cladding systems besides metals. This material is a composite containing wood fibres in conjunction with phenol resin embedded within a hard outside material offering UV protection and good resistance against environmental influence. These panels are available in a wide variety of colours and thus are the ideal material for a low cost façade cladding system. In the second shipment samples with the dimension for full size modules have been sent in two colours to test the environmental stability of active modules in the climate chamber. Although samples of this material were sent before it was not considered because of doubts about the ability of the material to withstand the harsh conditions of the DH test. However, according to Panelen Holland it is one of their favourite façade materials therefore those samples also went through adhesion testing as well as DH with modules.

The adhesion between encapsulant and composite material samples turn out to be acceptable as the measured values are above the minimum of 5 N/cm and increase over time at room temperature (RT), elevated temperature, and DH. Even after 1000 h of DH the adhesion is still very good.. Regarding the electrical stability of modules against environmental impact Flisom has repeatedly tested metal BS for their suitability and also passed the critical tests of the International Electrotechnical Commission (IEC). In case of the composite material there is no knowledge about the long term stability against DH. Therefore tests with a number of modules manufactured of 1 PV foil, so called 1x1 modules, have been started. Exemplary the two samples shown in Figure 9 are shown. In both cases a black frame at the perimeter can be seen. This is an edge seal (ES). The ES is a protection against ingress of humidity between front sheet (FS) and BS from the sides made of a butyl containing black tape, which is quite visible and thus contradicts the goal of the project to develop a uniformly looking coloured PV panel. For aesthetical reasons one sample was prepared without edge seal (not shown). To improve the aesthetics of the panel the trial without edge seal was started.

The results of these DH tests showed that the starting performance was comparable for all modules above 30 W (>11 % eff.). Effects of the DH are seen already after one week being really detrimental after 3 weeks, therefore testing was halted then. The samples without edge seal shows the worst result, indicating the need of this side barrier. In case of the modules with edge seal the results are not explicit but clearly not acceptable for a product used as PV module.

Figure 9: Two 1x1 modules using wooden-composite BS with ES. On the right side the cross contact is covered for aesthetic reasons.

As the composite material is very important for façade cladding systems a test has been done to improve the DH behavior of modules using this BS material. The hypothesis is that this material allows excessive penetration of humidity causing damage to the PV foil and thus degrading electrical values. In a first test a panel whose back side was covered using an Al plate and sealing it around the edges with Al coated plastic foil was prepared. This set-up will block humidity to some extend and will give an indication if more protection against moisture will help. This sample (see Figure 10) was then placed in the DH chamber and results are shown in Table 2. Although the drop in power is still too high for PV panels the Al coverage shows a clear improvement indicating that the protection against moisture ingress is showing some positive effect. Further improving the barrier of those panels requires lamination of an Al foil on the back and around the edges. This is the best option to attach an effective barrier against moisture.

Table 2 DH results of composite material sample with Al back

Status	Remaining Power
Initial	100 %
1w in DH	97 %
3w in DH	81 %

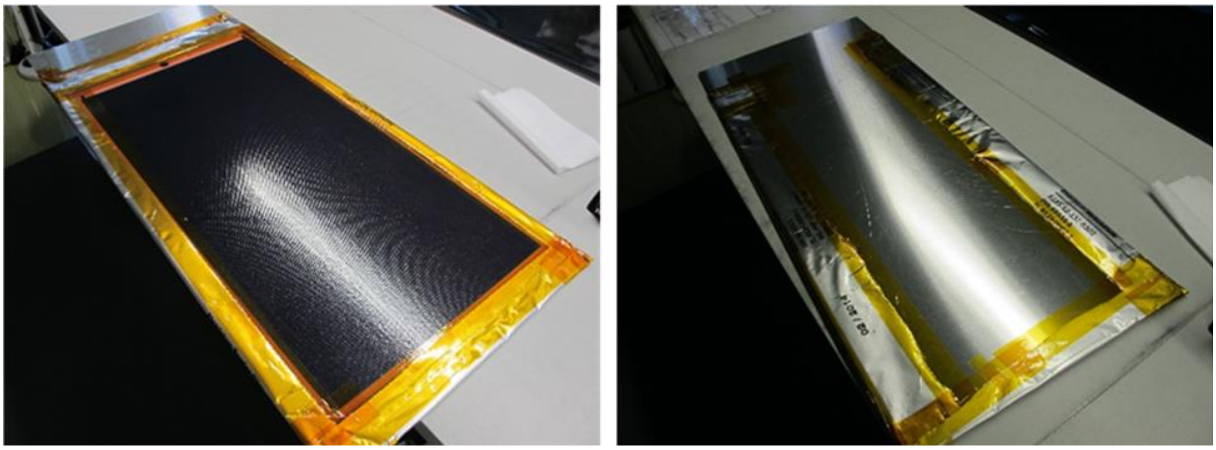


Figure 10: Sample with Al protection against moisture ingress

3.1.4 Progress of façade modules

In preparation of the demo façade, which must be installed as a delivery of WP3 the design of the module used for the façade has to be developed between Panelen Holland and Flisom. The goal is to have dimensions relevant for the construction industry and not deviating too much from standard dimensions used by Flisom. It was decided to follow Flisom's standard 2x1 eMetal modules. eMetal modules are a class of Flisom products where the backsheet consists of a metallic plate (typically aluminium or steel). In case of 2x1 modules 2 PV films of 74 x 37 cm size are connected and laminated together onto a sigle metallic backsheet to form one module.

Equipment dimensions at the project partners Sunpartner and TNO limits the size of the translucent film to 30 x 30 cm. To keep the outside dimensions of sandwich panels with opaque and translucent PV films the same the solution as shown in Figure 11 was chosen with fixed dimension of 160 x 40 cm. In this case the active area of the modules with translucent films are smaller as the width is limited to 30 cm. The length of 150 cm is about the same than for the opaque reference films.

First reference modules of this size using black anodized BS have been manufactured to demonstrate the ability that it is possible to manufacture this product. An example is shown in Figure 12.

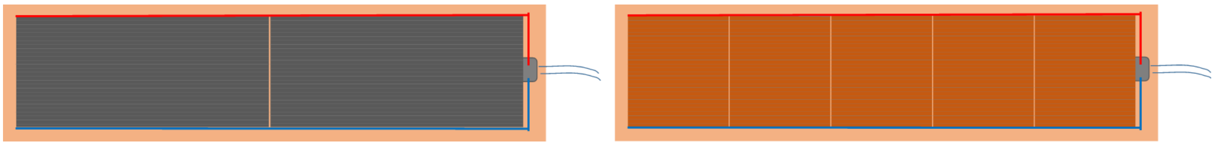


Figure 11: 2x1 reference module (left), 5x1 module with translucent film (right) at same dimension of 160 x 40 cm

Figure 12: 2x1 reference module using black anodized Al BS. Left is front, right is back side.

In addition to these modules based on a metal BS also several modules with only one PV film, so called 1x1 haven been manufactured with composite material as BS. Figure 9 shows photos of examples in two different versions. The left has the cross contact connecting the bus bars from each side towards the center uncovered. In the right photo this cross connector is covered with a black sheet for aesthetic reasons. For the final design of the façade elements Flisom together with Panelen Holland have to define a solution how to hide the cross connector and ES area as both cannot be made translucent and will disturb the optical impression of a uniformly coloured surface.

One of the deliveries of this project is manufacturing a complete sandwich panel including insulation which is bonded to the BS by Panelen Holland. A module with composite material BS has been chosen for this kind of demonstration and Panelen Holland added the insulation and an inside layer at their premises. To check if there is a negative influence of this final process step the module power was measured before sending it to Panelen Holland and after receiving the panel back with the insulation attached. Applying the insulator and inside layer does slightly affect the electrical performance of the panel. This is shown in Table 3 and further optimization of the process is needed to reduce this loss. The good news however, the power is only affected a little.

Table 3: Electrical results of integrated sandwich panel

	Power	Eff./SM
Pre-lam	32.30	12.0%
Laminated	32.17	11.9%
With foam	30.84	11.4%

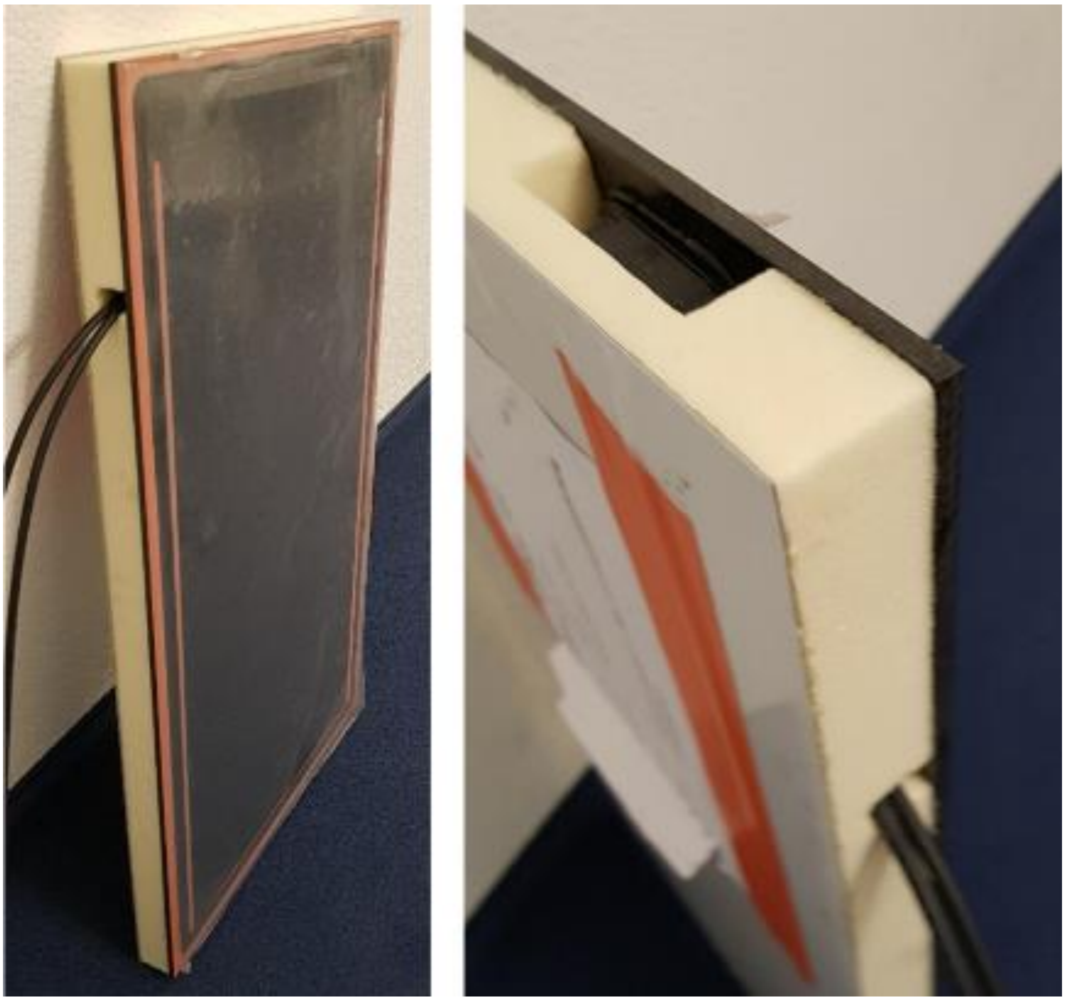


Figure 13: View of a finished sandwich panel based on composite material BS

Environmental testing was planned to ensure stability of the modules for long-term use. In order to gain more insights for different materials, the consortium has decided to ignore adhesion values at this time and to prepare samples on different BS material for environmental testing based on IEC 61646. Ignoring adhesion values is not against IEC 61646 because modules will be inspected against mechanical damage and delamination after testing. This inspection will show any critical mechanical damage directly related to the environmental test. DH results have been done with different BS discussed above: all metal sheets behave in a similar manner as the standard Flisom products, showing no major impact of the change of backsheet. Composite material BS however would need further optimization, for which initial solutions have shown some positive results already (Al-back coating).

3.2 WP2: Process Development for Translucent PV Foils

3.2.1 Principle of translucent PV foils

The major tasks of WP2 is the development of the laser process removing the active PV layers to create translucent openings in the PV foil. To explain the principle of this approach a schematic is the best option. Figure 14 shows the important details. On the left side it is shown that all the active layers have to be removed to ensure only the transparent substrate is left. Ideally, also the substrate will be removed leaving a hole in the foil. On the right side a possible arrangement of a hole pattern giving transmission is shown. The hole structure will become invisible to the human eye if the dimensions are smaller than 500µm and the distance is more than a meter. The eye then only sees a mix of the colour of the BS and the opaque section of the foil.

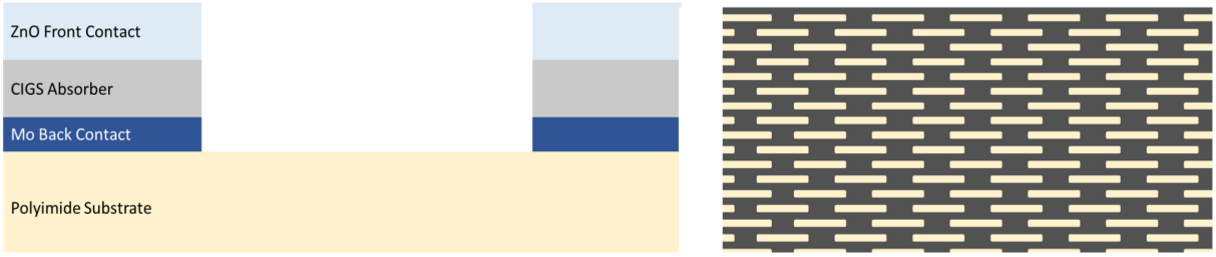


Figure 14: Schematic showing how translucence will be achieved, left: detailed structure of layers (not to scale), right: hole pattern to achieve translucent areas within opaque PV foils

3.2.2 First results of laser process by Sunpartner

Development of the laser process to create the translucence was the responsibility of the project partners Sunpartner and TNO. As the equipment available at both partners is limiting the size of the workpiece Flisom had to design a special PV foil with dimension of 30 x 30 cm. In the production process the dimension of the PV foil is defined right after the coating of the Molybedenum back contact (Mo BC) during execution of the first laser scribe line the so-called P1 line in the Mo layer. The dimension are different form standard production thus a designated roll was coated to manufacture these PV foils. Samples of these 30 x 30 PV foils have been sent to both Sunpartner and TNO for process development.

During 2018 Flisom learned that the PV foils require special storage conditions to ensure electrical stability over a longer period. This degradation effect only happens with un-laminated film and was not detected with finished modules laminated according to the standard procedure.

The mentioned instabilities have affected the samples of the first shipments and caused degradation of the material over time. However, despite the degradation of this first shipment the determined results are very useful to judge the quality of the laser process.

Sunpartner developed process conditions on their laser set-up to remove the opaque layers and achieved successful results as shown in Figure 15. The PV foil is clearly transparent having a transparency of approx. 20 %. The Polyimide (PI) substrate material used by Flisom is transparent but has a yellowish colour therefore, the transparency seen in the photo is less than the 12 % related to the laser pattern. According to Sunpartner's measurement the transmission of the PI foil is only around 55 % darkening the translucent part of the PV film significantly. The yellowish colour of the PI has to be overcome and two ways are possible. First: replacing the yellowish PI by a clear version of the material. This approach requires testing if colourless PI material is available and will work for Flisom's deposition process. Second: Find a way how to remove not only the active layers on top of the PI substrate but also to remove the PI substrate in the area of the laser shot, an interesting challenge for the development of a laser process.

Figure 15 Test sample of laser process by Sunpartner

Sunpartner has developed four different process settings (A, B, C, and D) of a laser ablation process removing the active PV layers from the PI substrate. For the ablation of the layers a laser spot size of 0.9 mm is chosen and thus diameter of the translucent spot is in the range of 0.9 mm. Further details of these process settings are not known to Flisom. The sample seen in Figure 15 was manufactured using the settings of process C leading to the best results. In case of Process A and B a lot of material re-deposition inside the laser spots is collected, which reduces transparency and is likely to create shunts within the module structure. In the case of Process B the edges are also very rugged as the microscopy photos of Figure 16 show, further increasing the risk of adding shunt resistance (R_{sh}), which will reduce the electrical performance. Both process settings are considered not suitable for the purpose of creating translucent PV films and have not been further evaluated.

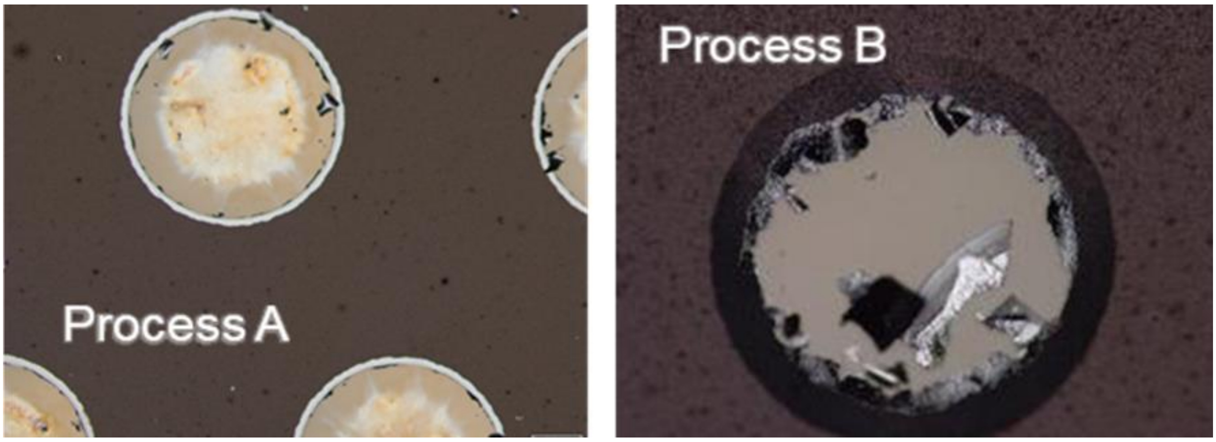


Figure 16: Process A and B leading to unacceptable ablation results. Laser spot 0.9 mm

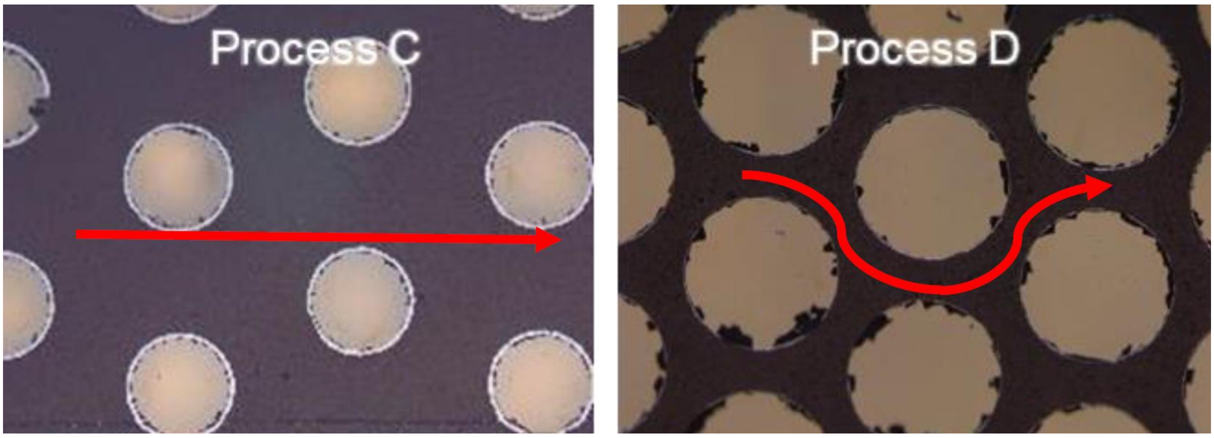


Figure 17: Process C and D giving good results. Transparency for C is 15% for D is 55%. Laser spot 0.9 mm, red arrows indicating path of photo current

Looking at microscopy photos of Processes C and D the differences in appearance are quite obvious in comparison to Process A and B. The different transparency achieved is also easy recognizable in Figure 17. In both cases the edges look clean and no re-deposition of material inside the spot could be found. This was checked using Energy Dispersive X-ray Spectroscopy (EDX) analysis, which allows finding traces of different elements. Process D has a higher spot density leading to a higher transparency of the foil. Comparing photos of Process C and Process D it is obvious that increasing spot density leads to an elongated path of the photo current. The longer travel of the generated photo current causes an increase in Ohmic losses caused by the limited conductivity of the Zinc-Oxide (ZnO) front contact. This Ohmic loss is indicated as an increase of the series resistance (Rs) of the modules, which can be determined during electrical measurements.

In Table 4 electrical values of three modules are shown before and after (indicated by “PP” (post process) after the serial number) the laser ablation process creating the translucent spots.

Table 3 :Electrical values before and after ("PP") laser ablation process by Sunpartner

Module	Eff	Rsh	Rs	FF	Isc	Voc	Pmax	PV after ablation
Module 113-2	5,25%	119,04	25,20	31,45%	0,128	8,66	0,334	72%
Module 113-2PP	3,30%	101,87	37,27	30,13%	0,104	8,08	0,264	
Theoretical	3,75%							
	-12,6 %		X 1,5		-19%	- 7 %	- 21 %	
Module 113-3	5,22%	142,37	51,48	33,02%	0,135	9,34	0,418	74%
Module 113- 3PP	3,34%	144,96	69,37	28,67%	0,106	8,80	0,267	
Theoretical	3,87%							
	-14 %		X 1,3		-22%	- 6 %	- 36 %	
Module 113-4	6,58%	245,68	19,42	43,77%	0,143	8,41	0,527	74%
Module 113- 4PP	4,17%	211,21	28,80	39,72%	0,110	7,65	0,333	
Theoretical	4,87%							
	-14,5%		X 1,5		-23%	- 9%	- 37 %	

At this point it needs to be highlighted that during storage before processing the modules degrade as measurements by Sunpower show in Figure 18. This degradation is the reason for an already low starting efficiency prior to the ablation process and the effect was already mentioned above. In case of the modules listed in Table 4, about 26% of the PV layer have been removed by laser ablation. The efficiencies measured after the ablation process are approx. 13% less than theoretically expected. The reduction of measured Isc after ablation is in the expected range given the reduction of the active PV layers by approx. 26%. As very positive can be noted that the shunt resistance (Rsh) does show a slight drop only, a sign that the laser process does not add any additional shunt path. A lower Rsh would reduce the output power of the module, especially during times of low light intensity as power is used up inside the module and not delivered to the contacts. The higher as expected drop in efficiency (Eff) and thus power is mainly related to the increase of Rs.

Unfortunately, after these first positive results Sunpartner was not able to present any further progress due to entering insolvency procedures.

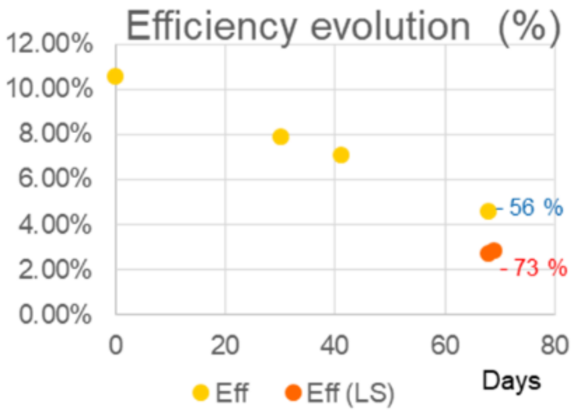


Figure 18: Efficiency degradation of PV foil over time due to storage

3.2.3 First results of laser process by TNO

Besides Sunpartner also TNO is working on development of their own laser process technology, which may be different from Sunpartner's approach. Since the withdrawal of Sunpartner the success of this development has become critical and also caused some delay in progress in 2018 as catching-up by TNO to the same technological status of Sunpartner was required. So far no details have been presented by TNO about the process as this has become a patent application.

Figure 19: Test sample with approx. 20% transparency by TNO

The process developed by TNO is leading to very promising and different results than the process by Sunpartner. Besides removing the active PV layers the TNO process is also able to completely remove the yellowish PI in the laser spot creating a fully transparent hole. A sample can be seen in Figure 19, which in comparison to Figure 15 is completely transparent without a yellowish haze. These transparent shots are very important as they solve the issue of removing the yellowish haze without the usage of colourless Polyimide. As shown in Table 5 the electrical measurement of the first tests show good results. The loss of current (Jsc) of approx. 16% is in very good agreement with the transparency of approx. 20%. Voc remains unchanged, which indicates not a big increase in shunts. The drop in shunt resistance (Rsh) as well as the increase in series resistance (Rs) clearly indicates that further optimization of the laser process is required to reduce the drop in Rsh and optimization of the hole pattern to minimize Rs.

Table 4: Electrical values before and after ("Translucent") laser ablation process by TNO

	Before ablation	After ablation	Difference After/Before
V_{oc} (V)	35.20	34.69	99%
J_{sc} (mA/cm^2)	25.66	21.57	84%
FF	0.536	0.471	88%
Eff (%)	7.68	5.59	73%
Rsh (Ω*cm^2)	8.98	5.76	64%
Rs (Ω*cm^2)	225	361	160%

TNO also did a study to find out which transparency can be achieved using different hole patterns. Having holes of 2 mm diameter a random pattern only allows for 30% translucence, which is not enough. Pattern with higher hole densities and respectively higher translucence can only be reached using a regular structure. Figure 20 shows three different possible hole patterns. The possibility of smaller hole pattern has not been evaluated during the first development round. To achieve 50% transparency reduced hole diameter can be a requirement and has to be evaluated. Further it is important to study the effects of different shapes lake long holes as it is shown in Figure 14.

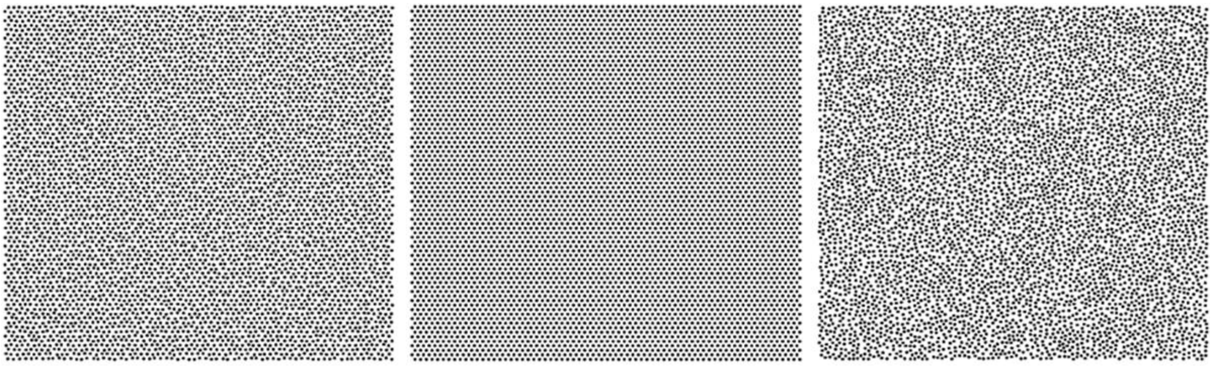


Figure 20: Samples of different hole pattern to evaluated (L – hexagon pattern with random placement, M – hexagon pattern, R – completely random pattern)

In addition to development of the laser process TNO laminated first samples to demonstrate the colouring effect using translucent PV foils. Two back sheets made of anodized Al in the colours Copper and Red provided by Panelen Holland were used together with two different samples of PV foil – both with a 20% random hole pattern. In case of the colour Copper the hole diameter is 2mm and in the case of Red the hole diameter is 2 – 4mm. Photos of these demonstrators can be seen in Figure 21. Colour Red has a low contrast between the colour and the PV foil therefore the colour effect is less pronounced than in the case of the much brighter colour Copper. For higher translucent samples even with dark colours the optical impression of the colour will become very dominant although the colour will always be dimmed by a “shadow” from the black PV foil.

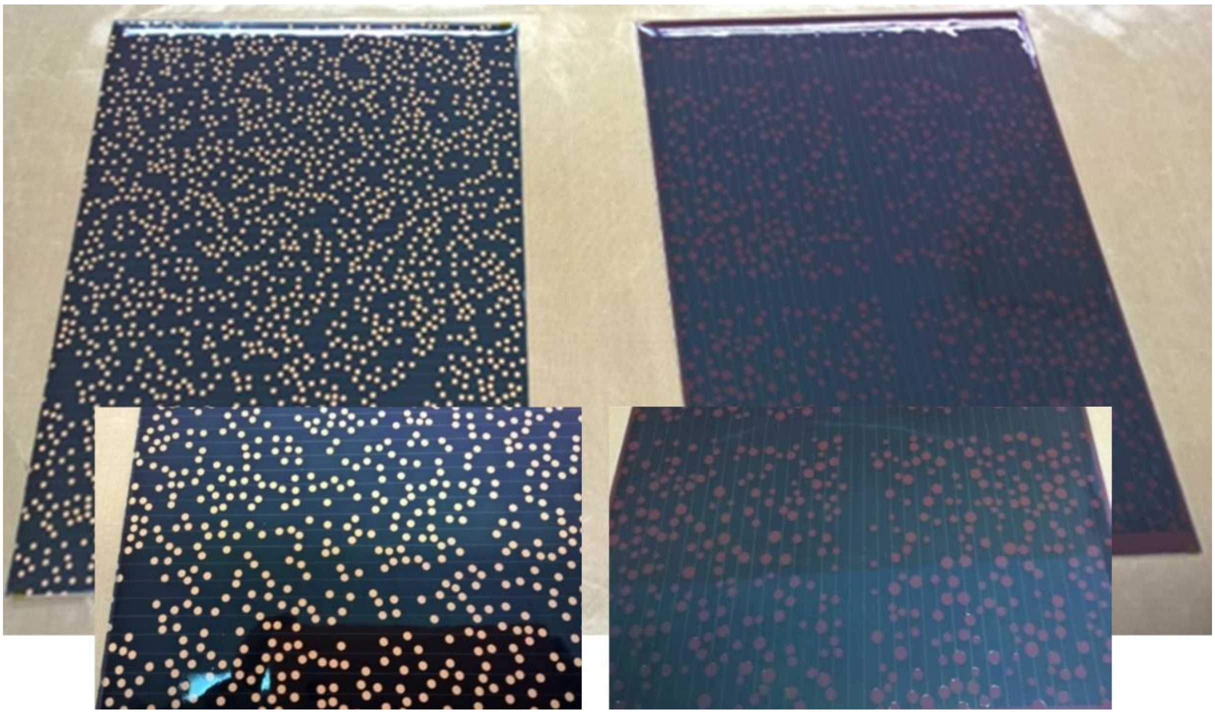


Figure 21: Laminated demonstrators to show colour effect with translucent PV foil.

3.2.4 Use of colourless PI

On regards of colourless PI Flisom was going through an intense market research to find suppliers of this special kind of material. Manufacturers of colourless PI have been identified and contacted. However, at this time the material is not commercially available on the market in larger quantities. The suppliers have been able to send small scale test samples, but not enough to manufacture a larger quantity of PV foils using roll-to-roll deposition tools. In addition to availability colourless PI has very different material properties compared to the standard yellowish product. The critical differences are mainly mechanical strength and usable temperature range. Both parameters are important for Flisom’s process as substrate temperatures during the CIGS deposition process are in the range of 450°C, very high for a polymeric material. Clear PI does not allow such high temperatures. Also sufficient mechanical strength is required at these high substrate temperatures to ensure reliable foil transport under defined transversal and longitudinal tension without the risk of rupture of the foil. Testing small samples for suitability cannot be done at Flisom as available equipment works only roll-to-roll and not with small size samples

The laser ablation process developed by TNO is able to completely remove the PI leaving a clean and transparent hole in the film and the need to transfer the deposition processes from standard to colourless PI is gone. Activities on this regards have been stopped for the time being and will resume if the need for this approach becomes obvious.

3.2.5 Latest results of laser process by TNO (developed second half of 2019)

After the first results by TNO achieved very important and promising results achieving almost 50% translucent PV foils. Optimizing the laser process and testing different hole shapes has resulted in a translucence ration of almost 47.4% on an area of 85x85 mm. The overall size of the sample is 100x100 mm but not the entire area was treated with the laser to leave a small border needed for mechanical stability during handling. A photo of the laminated sample is shown in Figure 22 with a red square indicating the 85x85mm area.

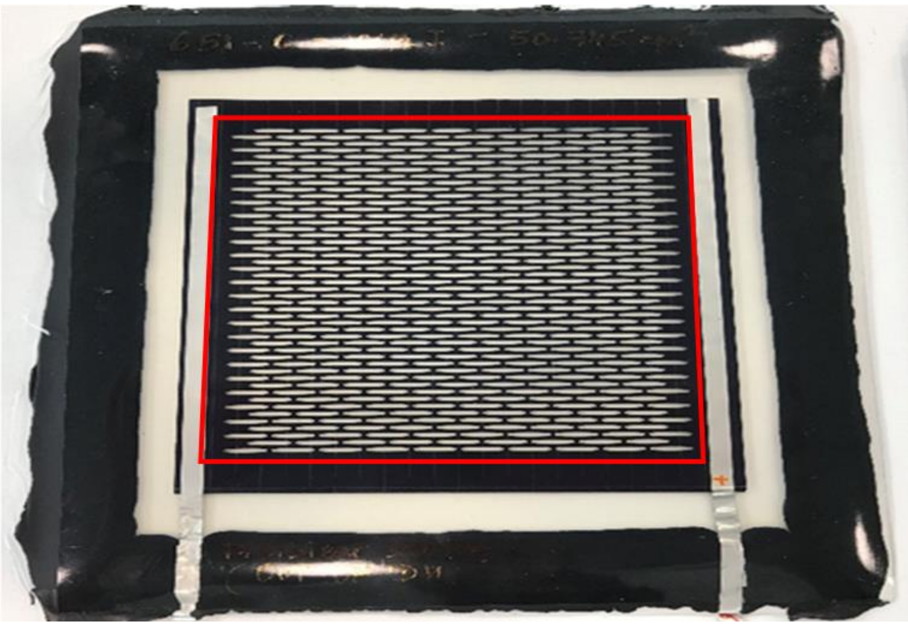


Figure 22: Laminated sample with optimized pattern – 47.4% translucence on 85x85mm area (area inside red square)

Table 5: Percentage change of electrical parameters of 2 translucent samples with optimized pattern

	651B Post Lamination	651C Post lamination
Jsc	62%	61%
Voc	103%	109%
FF	95%	102%
η	60%	67%
Rs_light	177%	178%
Rsh_dark	91%	330%

Electrical results in percentage between before and after laser process are given in Table 6. The measurements shown in the table are post lamination as heavy curling of the PV foils after laser processing required lamination to achieve a flat measurable surface. The results of Table 6 indicate very good electrical performance after the laser process without signs of increased shunting related to the laser process.

In addition first translucent samples have been laminated between two standard Flisom FS and placed in a climate chamber to perform DH test on the modules. After 300h of 85°C/85% relative humidity (RH) no degradation of electrical performance was measured.

3.3 WP3: Realization of coloured demo-façade

In this work package, the main goal is to design and develop a façade that includes sandwich panels with integrated PV. The demo façade will be located at the facilities of Panelen Holland in Oosterwolde, NL. This partner is leading this work package, together with Kiwa BDA which advises on regulations and certifications. An example of modified certification sequence is shown in the flowchart below (figure 23). This flow chart has been created for the voluntary CE marking of building products, and is valid for a change of backsheet. In parallel, full investigation of the building requirements in the Netherlands was overtaken, including product properties, Dutch building decree or EN Eurocodes and national annexes. In case of commercial use of such sandwich panels, the certification requirements are therefore known and could be achieved within short time. It was not the scope of this project to go up to certification, as no budget was planned for it.

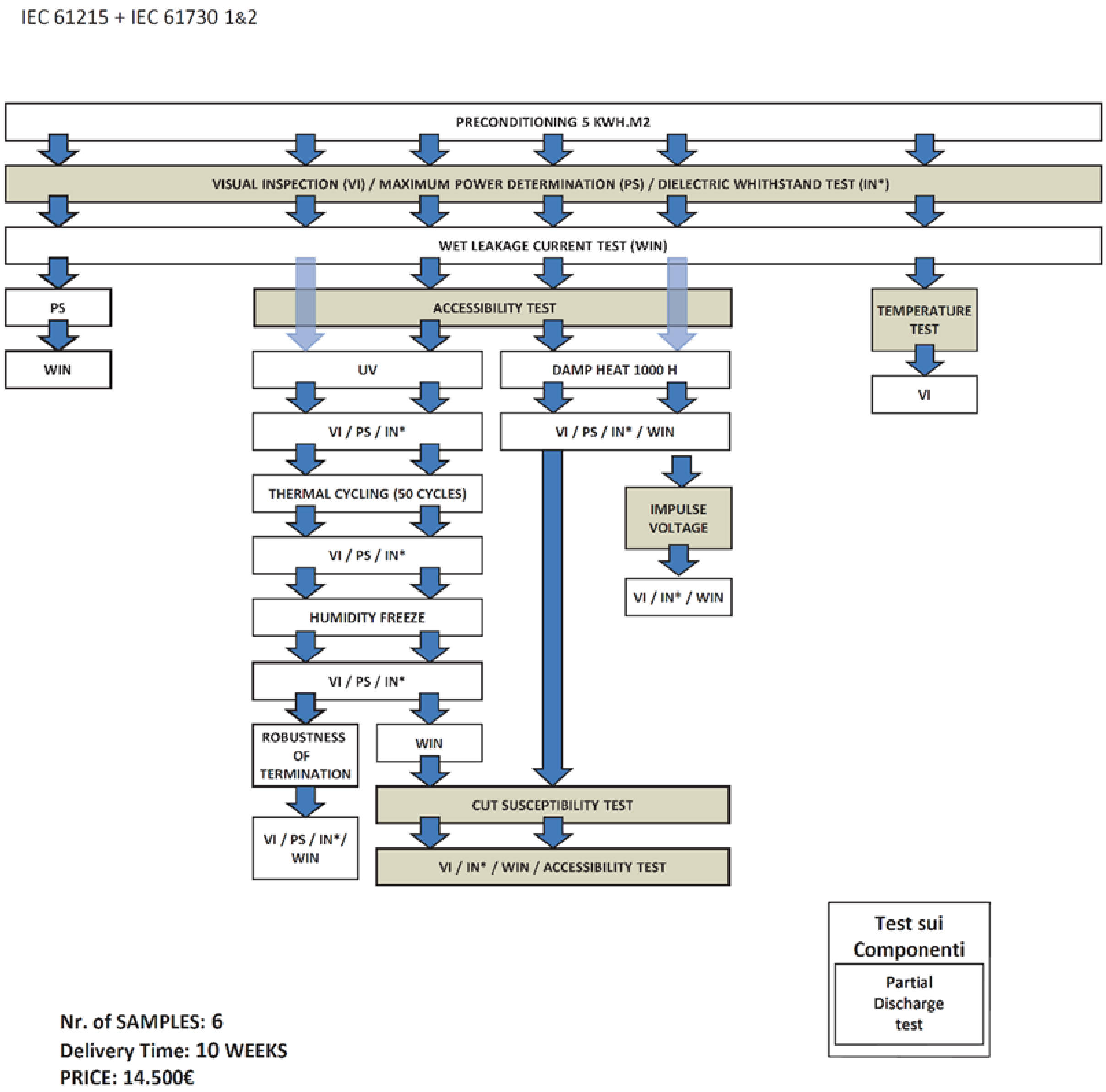


Figure 23: Modified IEC testing sequence that would be required for certification of modules with modified backsheet.

Based on all inputs and discussions of WP1-WP2, the design of the panels has been finally chosen as below, with following requirements (figure 24):

- Keep Flisom standard submodule width – 374mm
- Adapt length as suitable for the demo and the laser tool
- Reduce dead area at edge to maximum 14mm – determine system voltage depending creeping distance according to IEC.

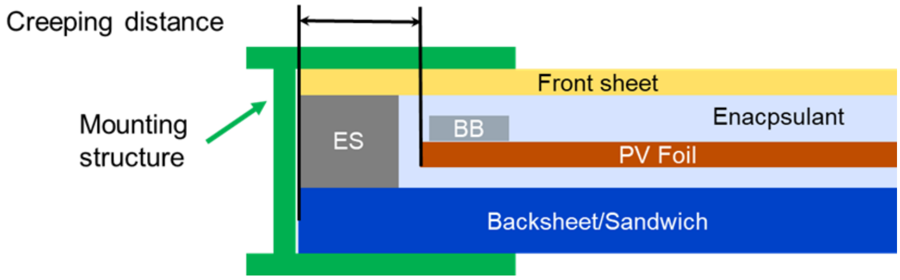


Figure 24: Sketch of agreed module structure for demonstration modules

Submodules have been produced at Flisom at end of 2019 in different batches, and provided to TNO for laser structuring. Due to the COVID situation in 2020 and also a downtime of the laser equipment at TNO, the processing has been delayed significantly. The modules provided have been sent back to Flisom in Q3 2020 only, and have been shown only very poor electrical performance. The exact reason for this poor electrical performance is not understood at this stage, but could be linked to the thin encapsulant used for first lamination at TNO (needed for avoiding curling after lasering – example shown in figure 25) and the rolling of the modules upon shipment. Pictures of laminated prototypes are shown in figure 26, together with the IV curve before and after lamination (figure 27), confirming the poor electrical performance (Voc should be > 40 V).

Figure 25: Translucent submodules, showing some bending due to modified residual stress after laser patterning. This requires TNO to laminate already partly the modules before shipping back to Flisom for proper handling and characterization.

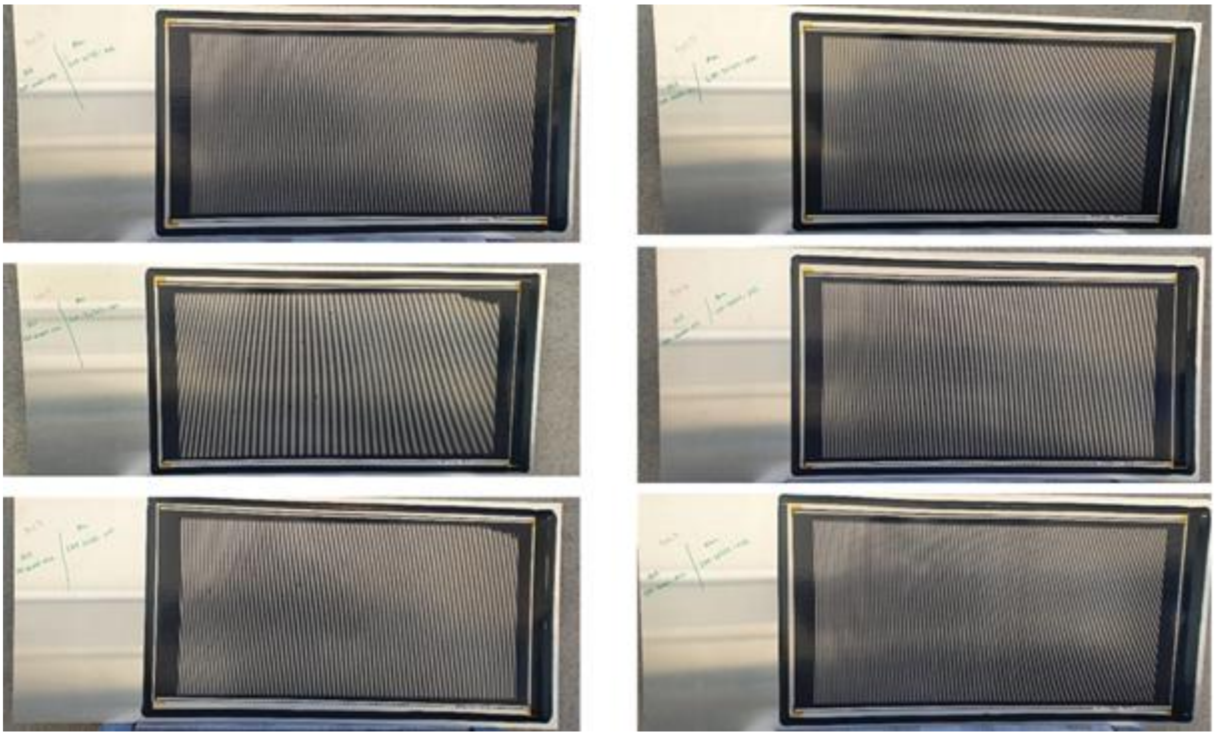


Figure 26: Pictures of prototypes laminated at Flisom on a metal sheet after structuring. Some missing patterning on individual modules on edges is linked to a software error at TNO partner and has been fixed for preparation of the demonstrators.

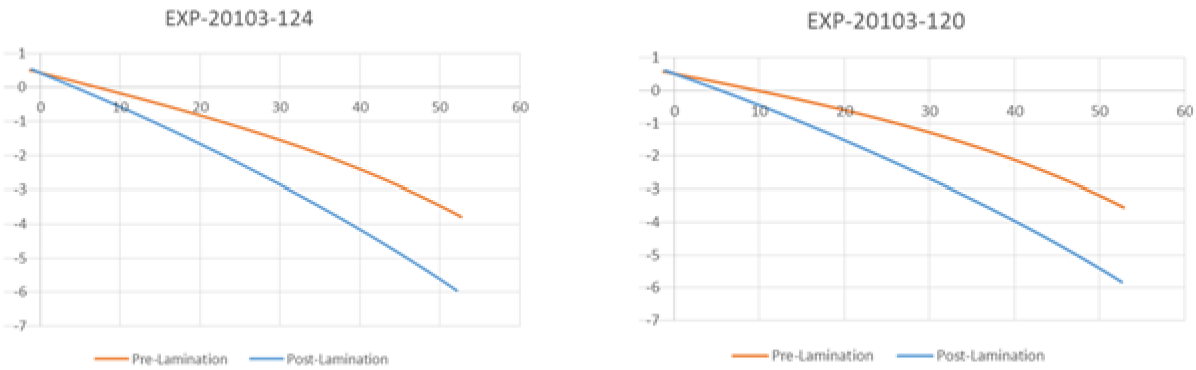


Figure 27: IV curve of 2 submodules (others were not giving any IV response). X-axis is the voltage, and should in good functioning modules give at least 40 V.

In order to investigate the reasons for low performance in more details, Flisom has attempted in August 2020 to provide again some submodules to the partner, that should be sent back this time flat packaged in foil bag evacuated and purged with N2. It is possible that the rolling of the fragile foil causes some damage, especially on the more fragile foil due to laser process. However, due to issues with the baseline process at Flisom in that month (linked to experiments/development) and other urgent customer orders to fulfil, no new submodules have been provided since then. Discussions are still ongoing with TNO to provide them additional submodules as bilateral cooperation beyond the end of the project to tackle this issue. TNO however also has had issues with their laser process in latest attempts, observing irregular detachment of CIGS from the foil outside of the patterns/holes that reduce the efficiency significantly. Looking with a microscope suggests that this could originate from microcracks.

Due to the strong delay of the project and lack of functional material, it has been decided to use the non-working submodules anyway and process them further up to a final product. The main goal is here to demonstrate the aesthetics of such a product. It has been decided to make 11 elements with following dimensions: (7 pieces with 768 x 388 mm, and 4 pieces with 768 x 762 mm) so as to fit to the demo façade size at Panelen Holland (4 standard size panels of 1x1.6m2 of cSi). Figure 28 shows examples of the frames upon which the modules are to be installed.

Figure 28: Frames with space for 4 small panels (top) and 8 big panels (bottom). Produced modules will be distributed accordingly.

Lamination of the submodules has been finished at Flisom on different coloured back sheets in November 2020 and shipped on 08.12.2020. Final lamination by our partner Panelen Holland will be done most likely in January 2021.

10 modules have been produced, as combination of 1x1 and 2x1. PV parameters are shown below. As explained above, severe shunting of the modules has been observed, likely due to transportation. The modules will therefore not be electrically active, but at least the demonstrator will allow to obtain a good impression of the aesthetics. Figure 29 shows the coloured modules before shipment from Flisom.

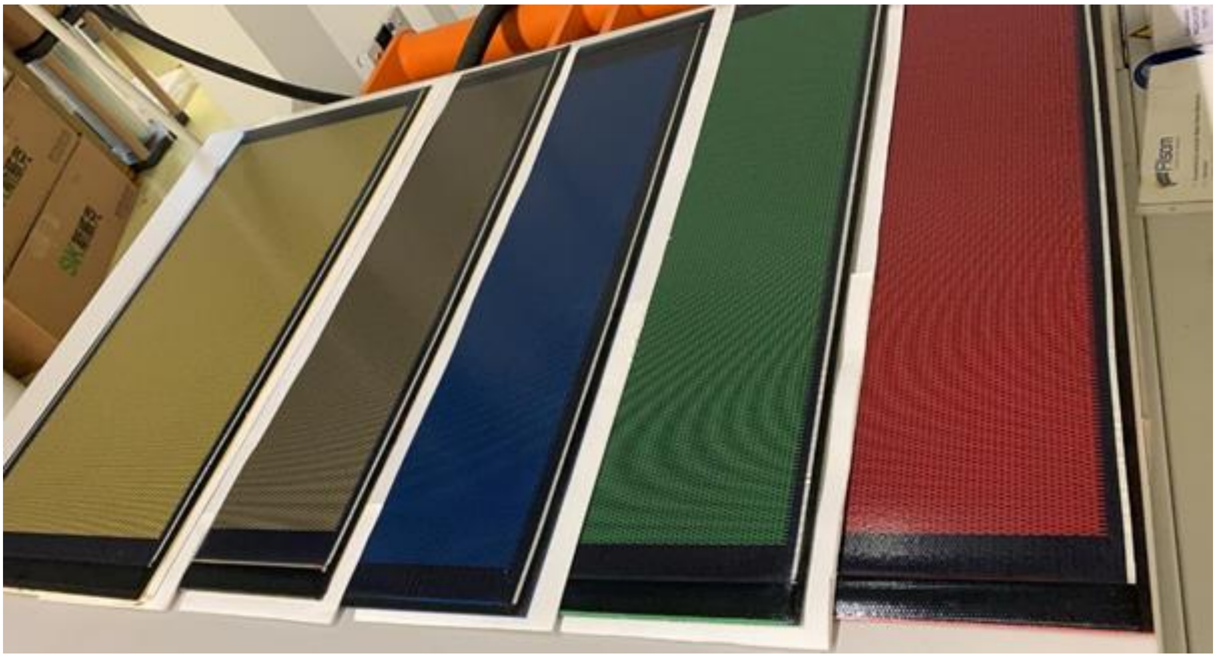


Figure 29: Semi-transparent modules laminated onto colored back sheets from Panelen Holland.

MOD-NR	Power	Rsh	TYP
EXP-20103-130	**0.24**	**25.8**	**1x1**
EXP-20103-128	**0.16**	**25.92**	**1x1**
EXP-20103-129	**0.209**	**20.25**	**1x1**
EXP-20103-131	**0.191**	**20.76**	**1x1**
EXP-20485-227	**0.131**	**19.24**	**1x1**
EXP-20485-228	**0.143**	**31.65**	**1x1**
EXP-20103-104	**0.509**	**43.85**	**2x1**
EXP-20103-106			
EXP-20103-107	**0.594**	**44.15**	**2x1**
EXP-20103-103			
EXP-20103-105	**0.647**	**38.37**	**2x1**
EXP-20103-108	**voc 9.910**	**isc 0.260**	
EXP-20103-127	**0.002**	**61.25**	**2x1**
EXP-20103-128			

A business case for such products has been worked out by Panelen Holland, based on inputs of Flisom. The detailed business plan is available in Dutch only, and will be finalized after making pictures of the final sandwich panels.

It was found that the competition on these type of panels is big in the market of enamelled glass. These panels with integrated pv-foil below the enamel ensure a constant color of the surface. The approach followed in this project has in comparison, even with 50% transparency, a loose of color, which is an issue in façade-building. Architects usually keep by their colors and do not accept any large variations.

From price perspective, as a first estimation, Flisom estimates that such structured films laminated onto a colored backsheet could be provided to PanelPV at a prices of 100 EUR/m^2. Further cost reduction might be possible by developing the laser process of TNO to make it compatible with manufacturing requirements (speed, yield) and optimizing the panel layout (dead area; FS and BS material).

Such a prices is not expected to be a showstopper per se; but the lack of a commercial partner who can laser the submodules of Flisom at affordable cost and within acceptable time frame is the main challenge. Panelen Holland has so far not been able to sell any project due also to limited size of available modules for demonstration. The sandwich panels they make are custom made and have to fulfil the requirements of measurements from ca. 200 x 300 mm size until 2000 x 4000 mm size.

To make this product a success, they expect the need for an even more transparent foil, a dedicated laser-partner in vicinity of a Flisom production facility (or at Flisom itself), and the possibility for Panelen Holland to take care of the lamination onto the backsheet by themselves. This would cut most of the transport and lead-time. Lead times for such projects should not be longer than 10 weeks, with possibilities to order panels from 1 piece until a few hundred, all in different sizes. Their conclusion is that we have succeeded in making the product that was originally requested, but at this stage this is not the type of product that the market wants or is ready to pay for.

4 Conclusions

The achieved results are evaluated based on the status of deliverables and milestones defined in the proposal. Delays in execution of the work of about 1 year have been accumulated due to different events (production issue at Flisom in summer 2018; insolvency of Sunpartner in 2019; equipment downtime at TNO in 2020; COVID-19 crisis in 2020), but most deliverables and milestones have been reached, and if not, proper explanation provided.

An overview of deliverables, milestones, and the status of WP1 are listed in Table below.

Activities/ Tasks	Status
WP1: Development of Design and Process for Integrated Façade Panels	
M1.1: Integrated PV sandwich panel, submodule efficiency after integration ≥ 12%, dimension of submodules are ≥ $0.2m^2$ (30.06.2018)	Done.
D1.1: Demo panel: Sandwich panel with integrated opaque PV foil, submodule efficiency ≥ 12%, dimension of submodules are ≥ $0.2m^2$ (30.06.2018)	Done
D1.2: Report on degradation tests of sandwich panels with integrated opaque PV foils (31.10.2018)	Done
WP2: Process Development for Translucent PV Foils	
M2.1: Laser process developed for translucent CIGS module: transparency > 50%, efficiency at least 40% of original opaque sub module (31.07.2018)	Done
M2.2: CIGS solar module grown on PI foil with a transparency ≥ 90%, cell eff. ≥ 12%, dimension approx. 0.5 cm^2 (30.04.2019)	Not done – Activity stopped due to laser process able to remove PI foil itself
D2.1: Translucent CIGS mini module on foil of at least 10x10 cm^2 with 50% transparency and ≥ 40% of its opaque efficiency (31.10.2018)	Done
D2.2: Transparent CIGS module integrated with a sandwich panel showing the colour of the front plate of the sandwich panel, efficiency of the submodules ≥ 5%, dimension of submodules are ≥ $0.2m^2$ (30.04.2019)	Done
D2.3: Report on results of degradation studies of translucent CIGS modules integrated with sandwich panels (31.10.2019)	Done
WP3: Realization of Coloured Demo-Façade	
M3.1: Translucent PV foils, depending on results of WP2, will be selected for panels to be integrated in demo façade of ≥ 3 m^2 dimension with submodules of ≥ 5% efficiency	Done
D3.1: Design for demo façade of at least 6 real sized sandwich panels of at least 3 different colours. Modules will be electrically connected to an inverter and provide a power of at least $50Wp/m^2$ per submodule, dimension of demo façade ≥ 3 m^2 (31.10.2019).	Partially done – Modules not connected (low electrical performance)
D3.3: Develop business plan for market introduction of integrated coloured façade elements (31.10.2019).	Done

In WP1, deliverable 1.1 have resulted in the sandwich panel based on composite BS. This was a good achievement and progress towards reaching the project goal of manufacturing integrated sandwich panels based on composite or other BS material without reduction in the electrical performance. Their behaviour in climatic chamber has also been investigated, showing no significant showstopper in their behaviour compared to standard back sheet. However, some optimization is required to reduce ingress through composite BS, for which alternative solutions have been tested already.

WP2 progress has mainly been impacted by insolvency of Sunpartner. TNO has however been able to demonstrate very good progress. Translucent PV foil with little effect on the electrical performance have been shown, and in a second round of development work by adapting the shape of openings in the PV foil TNO was able reach a transparency of almost 50% on an area of 85x85mm with minimal loss on electrical performance beyond the removed active area. The laser process developed by TNO creates fully transparent holes removing not only the active PV layers but also the yellowish substrate. This is a big advantage as the need for a PV foil using colourless PI is gone. With the achieved results the goals of D2.1 and D2.2 have almost been reached. Technologically there is no indication that the goal cannot be reached. The first results on degradation studies of translucent laminated PV foils are also a good indication that electrical stability of the modules is not harmed as long as the encapsulation is able to withstand the environmental impact. Drawbacks in this project are more linked so far to irreproducibility of processes at this early development stage, but we do not anticipate any issue on long term.

WP3 progress has not resulted in a final demonstration façade with functional modules due to issues during the manufacturing and sample exchange of the batch of translucent modules planned for the installation. However, in a first experiment, the initial prototypes had shown good electrical results, indicating that there should be no showstopper to realize such façade in future. Demonstration panels without electrical function are however under processing at the moment of writing this report, with the objective to demonstrate the aesthetics of such products. Remaining work is mainly the pending final sandwiching at the final Dutch partner, expected latest by mid-December. In parallel, Flisom is in discussion with TNO to continue the collaboration so as to provide functional modules beyond the end of the project.

A final business plan has been prepared by the Dutch partner. The expected cost of 100 Euro/m2 is achievable, which was the initial target of the project. Main unknown in computing the cost of translucent submodules laminated on a back sheet from Panelen Holland are the laser process cost and lead-time. As of now, they do not expect the product to be suitable for the market, especially due to i) change of color compared to competition with enamelled glass, ii) long lead time of submodule supply due to missing partner for lasering at industrial scale, iii) and limited flexibility in design as per usual customer requirements in this sector.

5 Outlook and next steps

In view of the overall project results, there is high confidence that producing sandwich panels based on translucent CIGS modules of Flisom with acceptable efficiency reduction and stability are technically feasible. Only showstoppers seen at this stage might come from i) laser process yield and speed, ii) business plan outcome (customers not willing to pay the price for the given efficiency).

Before implementation of such a product onto the BIPV market, several improvements are required:

- The laser process must be tested further for robustness and implementation into manufacturing environment, so as to ensure low enough manufacturing cost. At this stage, all process parameters are with TNO, and it should be defined how such manufacturing could look like for Flisom in future.
- The handling procedure for large area foils must be optimized to ensure that the translucent submodules survive electrically until the lamination onto the coloured backsheet.
- The certification of final product must be done; it was not planned as part of the project.

- A functional installation must be proven, so as to show to customers the viability of such products. Flisom, TNO and Panelen Holland are assessing how to prepare a new batch of modules in coming months.
- The business case must be refined carefully in view of the continuously evolving BIPV market requirements. Whether Flisom will invest in providing such a technical solution depends to a great extent on the willingness of Panelen Holland to provide such product. In case of no interest from their side, Flisom will however still have a choice to approach other building-element providers.

6 National and international cooperation

The consortium of this Solar-era.net project is international. Besides Flisom no other Swiss partner is involved. Unfortunately, after the drop-out of Sunpartner the remaining partners are only Swiss and Dutch.

For Flisom this international cooperation is very important for development of this particular product. Only through the combined activities the complex task of creating translucent PV foils was started as Flisom itself does not have the means to do this process at this time. The final product itself is clearly in the interest of Panelen Holland, which is also doing the final production steps manufacturing a full sandwich panel. For Flisom the process of manufacturing partially finished product and sending it to a customer for completion nicely fits in the understanding of being a technology company providing solutions to the customer but not necessarily the final B2C product.

Successful development of this product will open a big market for Flisom PV foils being installed in many facades in the Netherlands, as well as any other geographical area were Panelen Holland is having distribution channels. In addition to Panelen Holland Flisom will be able to find other potential partners in Europe and worldwide being able to integrate translucent PV films with their coloured façade elements.

At this point it is also important to highlight the good and long cooperation between TNO and Flisom. Both have been successfully working together in different international projects in the past and the cooperation in this project is based on this experience and trust.

7 Communication

So far no special communication was done for this project. Once the product and a commercialization strategy are successfully developed it makes sense to communicate to the international public and market via press release in relevant print and online publications for regenerative energies and construction about this new option for BIPV.