DEI 119009

# ‘ACCELERATE’ Public Report

## Acceleration of on-board solar for automotive and electric transportation

Lightyear, Helmond
ECN.TNO, Petten
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Period: 15/04/2019 - 28/05/2021

**Introduction**

This report summarizes the activities, results and conclusions of the Accelerate project. The goal of the project was to demonstrate the viability of a VIPV car. Here the following was taken into account: changing environments for PV, safety of the vehicle and customer demands on reliability, performance and durability.

The design process described in Figure 1 is used, where each work package of the project represents a stage in the development. These stages are based on a standard plan, do, check, act (PDCA) cycle in order to develop a functional, safe, and reliable system that has been tested in the relevant environment and can pass the strict regulations standards.

The project resulted in a close to fully developed VIPV system and fully defined blueprint for the manufacturing process. The developed system will be the basis for the production of Lightyear One cars. This technology will also create key innovations for other integrated PV markets such as BIPV, infrastructure integrated PV, and floating PV.

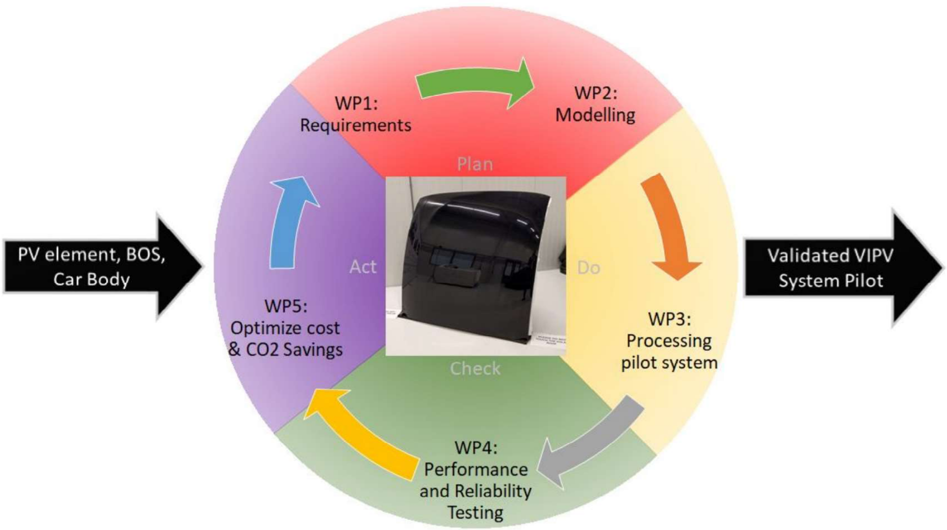


Figure 1 - Design process

**Contents**

**Deliverables**

Every work package consists of several deliverables that are described below. Some of the deliverables were crucial input to continue with other work packages, for example the requirements coming from D1.2 that we're the basis for development in WP3 and validation in WP4. Other deliverables are prerequisites for the final production of the system, such as D3.3 that contains the work instructions for production personnel. This report summarized the conclusions of these deliverables and the main activities done to get to that point.

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| *WP1 - Requirements*<br>● D1.1 - Mid-term report on performance, product and safety requirements. All safety risks identified by making use of HARA, etc. Outstanding questions identified.<br>● D1.2 - Final report on product requirements and safety requirements including: HARA, FTA, etc. Requirements finalized in LY RFLP database, overview of all required norms, NL, EU, outside EU. |
| *WP2 - Modelling*<br>● D2.1 - Mid-term report on FEM thermal and thermomechanical modelling and design rules, with outstanding questions identified.<br>● D2.2 - Final report on FEM thermal and thermomechanical modelling, with link to developments necessary in system and testing protocols as developed in WP3 and WP4. |
| *WP3 - PV system development*<br>● D3.1 - Report on materials, BOM, product and process development for the PV system.<br>● D3.2 - Insulation, housing and integration with LY car.<br>● D3.3 - Work instructions written and made available. |
| *WP4 - Reliability and safety testing*<br>● D4.1 - Reliability test and safety test overview: full test, quick test, quality pass.<br>● D4.2 - Reliability and performance testing of PV system: individual samples and integrated in the LY car.<br>● D4.3 - Safety testing of PV system: individual samples and integrated in the LY car. |
| *WP5 - Optimize supply chain, cost and CO2*<br>● D5.1 - Report on supply chain and final cost optimization.<br>● D5.2 - CO2 impact estimation.<br>● D5.3 - Obtain requirements for LY2. Determine the new technical challenges wrt performance, reliability, safety, etc for LY2. |

**WP1 - Requirements**

A hazard and risk analysis (HARA) has been made according to the automotive ISO26262 standard. The goal was to ensure that a safe PV system shall be fitted to Lightyear Exclusive Series (LYES). This HARA is done by Lightyear and TNO Netherlands. The following safety (SG) goals has been defined to mitigate all the possible risks defined in the HARA:

1. The PV system shall have <60V DC under all circumstances.

*When the voltages could be higher than 60V DC (high voltage) between two differential points in the PV system, then the requirements of UN ECE R100 02 series will apply. In the case of a PV system with voltages above 60V DC, it's not possible to ensure that there will be no high voltage (danger) in any case when the PV panel has a malfunction (for example broken glass).*

2. The DMPPT shall stop tracking when the output cable voltage > 48V DC.

*Battery voltage is 48V, so the DMPPT shall stop working at voltages above 48V DC.*

3. The PV system shall not receive energy back from the battery (SG to battery system and PV system)
4. The DMPPT shall have a safe malfunctioning behaviour (high voltage, temperature, fire)
5. Test PV panel according to UN ECE R43.

*According to UN ECE R43, the PV panel will be seen as one pane made out of glass and plastic. Therefore, the PV panel shall have a component approval according to UN ECE R43 in the category of "glass plastics". The required tests for this type of glass are performed by Lightyear and TNO and based on the test results it seems that a component approval is possible.*

*When the solar panel will go into production, an auditor will audit the production line and the test procedures.*

6. Test PV panel (bonnet) according to the adult/child head impact test procedure described in UN ECE R127 (Pedestrian Safety)

*To ensure no high risk to pedestrians with an impact, the PV panel (bonnet) is tested at Tass International (Helmond) according to some adult and pedestrian head impact points. More tests are needed to ensure that the panel will fulfil the test requirements of UN R127 02 series. However, the first test results look promising. Since LYES will be homologated* *according to the EU M1 small series type approval, these pedestrian safety tests are optional for getting this type approval.*

**WP2 - Modelling**

*Material characterization*

For accurate mechanical and thermo-mechanical modelling it was necessary to characterize several material properties.

*Impact modelling*

In order to understand the impact behaviour of hail or rocks on the solar panel, both analytical and numerical modelling has been performed.

*Hood frame material and bond gap*

A numerical analysis has been carried out for the solar hood, regarding the influence of the thermal expansion coefficient of the hood frame material and bond gap on the tensile stress in the solar panel (among other parameters). If there is a large difference in thermal expansion between the solar panel and the frame, this will lead to large thermal deformations and thermal stresses at the extremities of the operating temperature.

**WP3 - PV system development**

*Product and process development*

The product and the manufacturing process were developed during a series of iterations of designing, manufacturing and testing small (300x300mm) and full size panels.

The temperature profile during the first lamination was optimized taking into account an interplay of different factors.
The electroluminescence measurement was used as a tool to assess the correct working of the solar cells throughout the complete manufacturing process, as well as the IV-characteristic measurement.

Both product and process FMEA were performed at the moment that the maturity of these reached a suitable level.

*BOS: Product and process development*

Dual string converters were developed according to the requirements written in WP1. Each dual string converter can convert solar energy coming from two separate solar panel groups into a 48V battery. Design and validation was carried out up to and including successful vehicle-level tests.

*Documentation / work instructions*

Related to the prototyping of small and full scale solar panels, a list of work instructions was iterated during a series of development cycles. These instructions included the list of production processes, equipment, tooling and materials involved. Every development cycle also included a reporting structure for critical-to-quality characteristics of the products produced, both from an aesthetic and a functional perspective.

**WP4 - Reliability and safety testing**

Every development iteration on both product and process level was validated by a prototyping build. Each build had a specific development purpose that was validated by a number of tests in order to measure the performance of the product in relation to the requirements that were set in work package 1. Here TNO and Lightyear worked together closely in order to execute and analyse the test cycles for each build. In the tables below each purpose, test plan, result and conclusion has been summarized and split into the two main perfomance matrixes: Reliability and safety.

*Reliability testing overview*

With reliability tests the ability of the panels to withstand multiple years of extreme use were tested. An example of this can be seen in figure 7, where extreme vibration combined with a thermal cycling chamber was being used to simulate a life cycle of the product. With each build the interlaying materials were optimized in order to get to a stable system.

Figure 7 - Thermal & vibration test setup

Figure 8 - PV system integrated on the LY One validation prototype

*Safety testing overview*

Since this PV system is being introduced in an automotive application with very mature safety standards, it is of importance to validate that it does not introduce any additional hazards for the user. Together with TNO Automotive safety standards were set on fire resistance, electrical and mechanical safety that were validated with the tests below. Figure 9 for example describes the NCAP head impact test that was performed in order to ensure the pedestrian's safety during a crash.

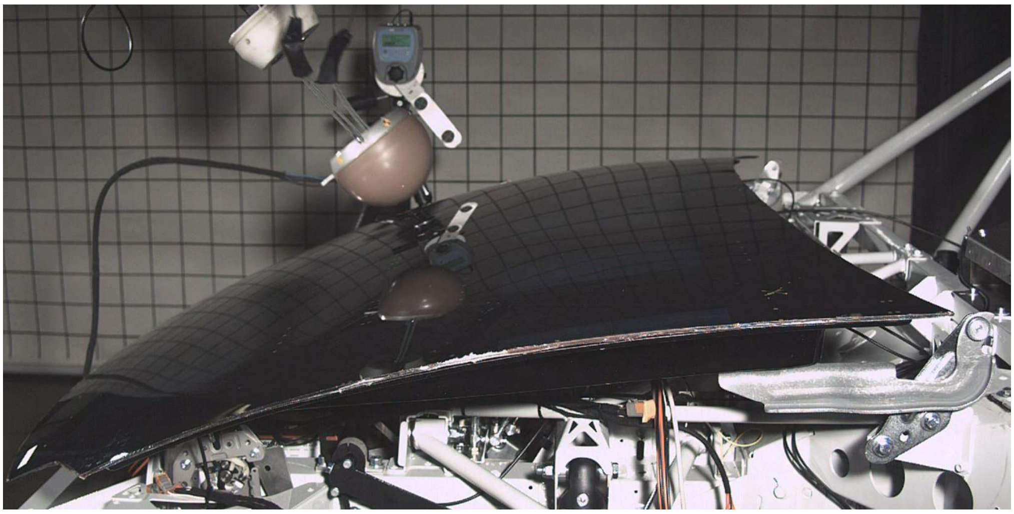

Figure 9 - Pedestrian head impact test

**WP5 - Optimize supply chain, cost and CO2**

*Supply chain and cost optimization*

To reach series production the current prototyping supply chain needed to be optimized. Next to finding the right suppliers, related to the projected volume, to optimise the Bill of Material (BoM) costs, reducing the number of logistical movements (especially of breakable subsystems) is the other main goal to minimize the labour costs, throughput time and overall PV system time costs & technical risk.

Within the context of this project several product combinations are tested with a range of materials coming from, suppliers with a large local content, suppliers with a big low cost country content and suppliers with superior material performance. Within the project the procurement way of working has been followed to fill the sourcing need, approach the market and validate the supplier.

*Life cycle analysis*

In order to create insights in the environmental impact of the VIPV system and therefore create focus areas to optimize material selection, a Life Cycle Analysis was executed. The methodology used was 'Idemat' from Delft university. During the analysis the different materials (and corresponding manufacturing processes) that are present in the system were assessed on several elements, such as: end-of-life scenario, carbon footprint and resource depletion. With the support of the Idemat database the materials were expressed in EUR/m2 'Ecocost'.

## Conclusion & Discussion

The Accelerate project resulted in a close to fully developed VIPV system meant for the Lightyear One production vehicle. During the different development iterations the system proved to be viable on performance, weight, cost and integration capabilities. A blueprint for the manufacturing process has been developed as well that fits the Lightyear business case and is currently under construction. Since the system enables flexibility in scale, it provides the opportunity to transfer this technology to other integrated PV markets such as BIPV, infrastructure integrated PV, and floating PV.

## Dissemination

*Between project partners*

All the reports were shared amongst the project partners throughout the project through meetings and other activities.

*PR activities*

RTL Nieuws - Record voor Nederlandse zonneauto Lightyear One: 710 km op één lading, 08 July 2021
https://www.rtlnieuws.nl/tech/artikel/5240740/nederlandse-zonneauto-lightyear-one-710-kilometer-record-60-kwh-elektrische

RTL Nieuws - DSM en Lightyear werken aan zonnepanelen voor auto's, 14 May 2020
https://www.rtlnieuws.nl/tech/artikel/5122446/dsm-lightyear-zonnepanelen-auto-dak-solar

Tweakers - Het testen van de Lightyear One - Hoe rijdt de Nederlandse zonnecel-EV?, 12 July 2021
https://tweakers.net/video/18254/het-testen-van-de-lightyear-one-hoe-rijdt-de-nederlandse-zonnecel-ev.html

Het Financieel Dagblad - Nieuwe zonnewagen rijdt 710 kilometer op één batterijlading, 8 July 2021
https://fd.nl/ondernemen/1391676/nieuwe-zonnewagen-rijdt-710-kilometer-op-een-batterijlading-mmg1casjlARB

Electrek - Lightyear One prototype delivers 441 miles on 60kWh (+3.45kWh solar) in latest track test, 7 July 2021

https://electrek.co/2021/07/07/lightyear-one-prototype-delivers-441-miles-of-range-on-a-single-charge-in-latest-track-test/

Drivetribe - Ever doubted the Lightyear One's 700 km of range?, 14 July 2021 https://drivetribe.com/p/ever-doubted-the-lightyear-ones-XCYhrdJORiqcy-BWKes5Ig?iid=KcHPh2roRH2jDvxgra635A

Newman, B.K., Regondi, S. Rosca, V., Dekker, N.J.J., Dijken, D., Okel, L.A.G., Goris, M.J.A.A., Di Carlo, D., Kabbaz-Saberi, A., Van Montfort, S., Verschuren, R.M.A.F., Designing PV for the first generation of solar electric vehicles, 37th EU Photovoltaics Specialists Conference (online) September 2020.

Newman, B.K., Here Comes the Sun, University of New South Wales, School for Photovoltaics and Renewable Energy Symposium, Sydney, Australia, February, 2020, UNSW School of Photovoltaic & Renewable Energy Engineering - Bonna Newman - Here Comes the Sun: Opportunities and Challenges for Vehicle Integrated PV.

Newman, B.K. Solar Cars: Opportunities and Challenges, TÜV Module Forum, Köln, Germany, February 2020.

Newman, B.K. How the Netherlands is Making Solar Powered Cars a Reality, University of New South Wales Digital Grid Futures Institute, Sydney, Australia, February, 2020.