WHITE PAPER

WAVELABS LED SUN SIMULATORS:
Moving Electric Vehicles Towards Solar Power

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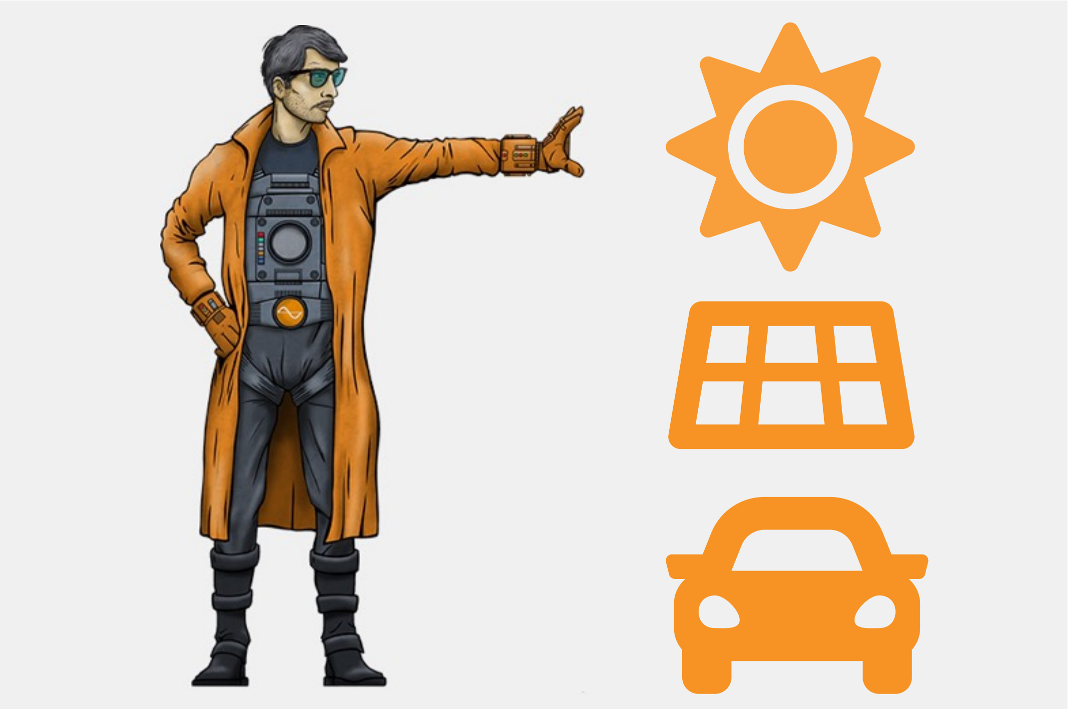

ABSTRACT

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The electric vehicle industry is growing rapidly. Limited availability of charging points, long charging times and small vehicle batteries are causing some EV owners "range-anxiety" and are stopping many other customers from buying an EV in the first place. Research shows that under favorable conditions, VIPV can reduce the number of required charging moments by 50%. Several start-ups and research institutes are evaluating vehicle integrated photovoltaic solar panels (VIPV).

The key challenges that need to be solved for VIPV are:

1. STC testing of non-accessible/built-in modules
2. Optimization of power yield under driving conditions
3. Performance prediction/degradation over time
4. Reliability testing of modules in road traffic conditions

In this whitepaper, WAVELABS investigates the challenges that VIPV may be facing. We examine how the use of our LED sun simulators can help solve some of the problems ahead. We are considering applying for patents specifically in the VIPV space. Therefore, this whitepaper does not list our proposed solutions publicly. If we were to publish our solution ideas here, we would not be able to patent them later.

If you are interested in discussing your specific challenges, please reach out to us and we will be happy to help!

WAVELABS LED sun simulators:
Moving electric vehicles towards solar power

In the process of moving our society towards 100% sustainable energy use, transportation and mobility are among the major industries in desperate need of reform. The good news: Electric vehicles (EVs) are forming the foundation that makes an energy transition in the mobility sector even possible. Modern battery technology is now powerful enough to make this happen at a reasonable cost to consumers. However, charging points are not as readily available as they should be, and the charging process still takes much longer than simply refueling at a gas station. This can lead to "range anxiety" among drivers of EVs. One approach to alleviating this anxiety may be to integrate solar panels into the body of an EV, which charge the battery whenever the sun is shining. This is called vehicle integrated photovoltaics or VIPV.

VIPV technology is being developed by many large and small companies and research facilities the world over. WAVELABS is the premier manufacturer of LED sun simulators in the world. More than 33% of global PV cell manufacturing capacity has a WAVELABS SINUS tool installed in the fab. We are motivated to take on the next big challenges that solar is facing because we are determined to see a 100% sustainable energy future become a reality.

Several challenges of VIPV have been very well documented by the research of Dr. Bonna Newman and team at TNO (Netherlands). A lot of the information in this article was obtained from a presentation held by Dr. Newman at the TÜV PV Forum 2020 Cologne (Feb. 2020) and presentation slides obtained while attending the event.
You can watch a similar presentation at UNSW on YouTube:
https://www.youtube.com/watch?v=3SK_yq0IdKA

What is a solar vehicle?

Solar vehicles are electric vehicles, which are, at least partially, powered by solar energy as a type of fuel for their propulsion. Solar vehicles are equipped with photovoltaic (PV) cells, which are integrated into the vehicle body and have the function of converting sunlight into electrical energy. This energy is stored directly in the vehicle's battery. We often speak of VIPV: Photovoltaics integrated in vehicle or PVIV: vehicle integrated photovoltaics. The terms are synonymous.

WAVELABS

What are benefits of VIPV?

The benefits of integrated PV are increased range, reduced CO2 emissions, potential cost savings of € 200-350 per year and, most importantly, the reduction of required charging moments.

Research shows that in locations with a lot of sunlight hours, charging moments can be reduced by about 50%. This is a game changer in terms of the usability of EVs for daily commuting activity! Data shows that, in the summer, some drivers will not have to plug in their vehicles to charge for a span of 4-5 months! This could mean that adding solar power to an EV may become a powerful unique selling proposition for car manufacturers.

Benefits summary (Europe)

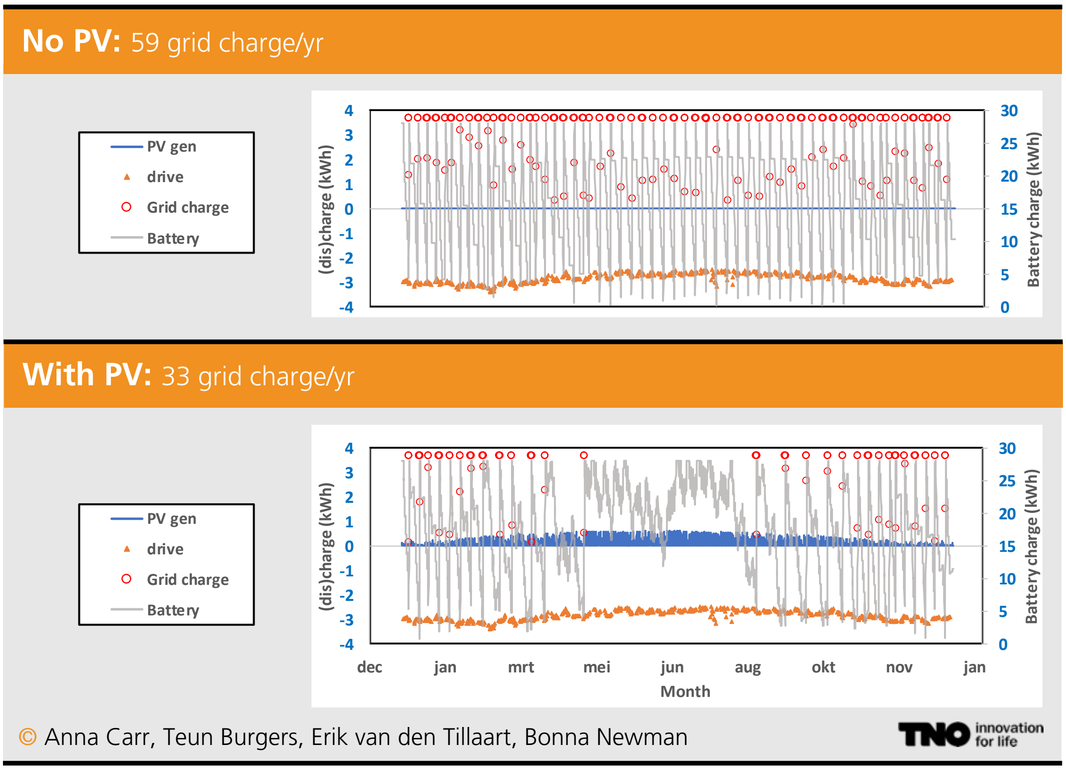
Location	Energy demand [kWh / year]	Potential PV Generation (% of energy dem.)	Reduced Grid Dependence (CMs)	Savings (/year)	CO_2 (/year)
Maastricht	1486	53%	56%	€ 234	273 kg
Madrid	1518	80%	32%	€ 354	410 kg
Stockholm	1537	48%	62%	€ 218	254 kg

- Simple driving profile – 10k km/year commuting
- Conservative charging strategy
- Grid charging cost - € 0.30 / kWh
- CO_2 emission factor, grid consumption – 0.5 kg-CO_2/kWh
- Irradiance data from 2018

© Anna Carr, Teun Burgers, Erik van den Tillaart, Bonna Newman

TNO innovation for life

Effect of solar charging (NL)



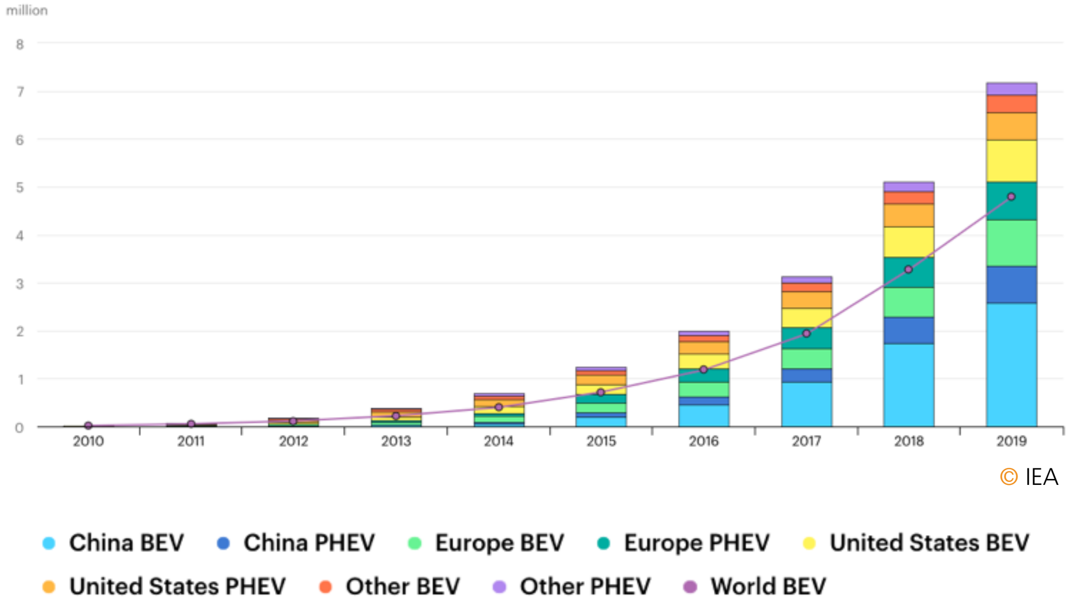
What is the market for EVs and specifically VIPV solutions?

Everybody knows the story of Tesla, which is, if nothing else, forcing the hand of legacy car manufacturers to also deploy more and more EVs on the market. Additionally, there are start-ups which center their EV design on the advantages that VIPV brings. SonoMotors (Germany) and Lightyear (Netherlands) are the most famous examples in Europe.

From a usability standpoint, PV integrated in vehicles makes perfect sense. With the increasing maturity of VIPV technology, it is only a matter of time until it will find more and more adoption in EVs. The demand for electric vehicles is increasing exponentially, topping 7 million in 2019, as the IEA report shows.

Global electric car stock, 2010-2019

The exponential growth of the EV sector combined with the advancing maturity of VIPV technology will lead to a huge demand for VIPV solutions later this decade.



Notes:
PHEV = plug-in hybrid electric vehicle | BEV = battery electric vehicle.

Sources:
IEA analysis based on country submissions, complemented by ACEA (2020); EAFO (2020c); EV-Volumes (2020); Marklines (2020); OICA (2020); CAAM (2020)
https://www.iea.org/reports/global-ev-outlook-2020

Who is in the VIPV field?

TOYOTA: Hybrid Prius

- Japan, 2019
- VIPV on the roof
- 180 Wp
- +3 km per day

© Toyoto Deutschland GmbH

HYUNDAI: Sonata Hybrid

- VIPV on the roof
- Korea, 2019
- 205 Wp
- +3,6 km per day

© hyundaimotorgroup.com

VIPV PLAYER

Who is in the VIPV field?

SonoMotors: Sion, Prototype, BEV

- Germany, 2019
- VIPV all over the roof, hood, sides, 1.2 kWp
- Mono-Si
- Max. +34 km per day

© Sono Motors GmbH

Lightyear: Lightyear One, Prototype, BEV

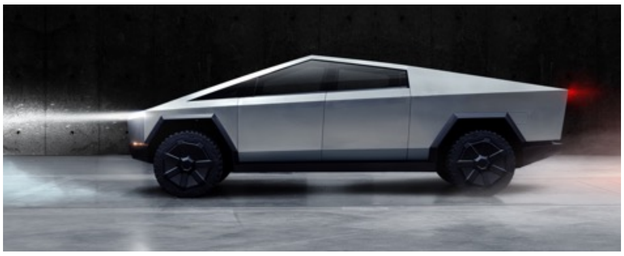
- Netherlands, 2019
- VIPV cover roof and hood, 1.25 kWp
- Mono-Si
- Max. +12 km per hour

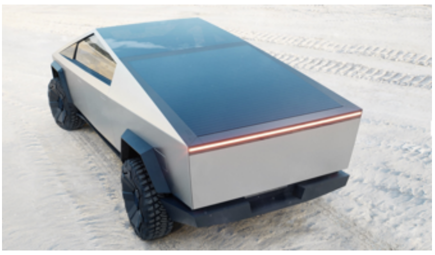
© Lightyear.one

Who is in the VIPV field?

Tesla: Cybertruck with optional solar tonneau cover

- **USA, 2020**
- **Max +15 mi per day**
- **VIPV Tonneau cover ~500 Wp**
- **Area: ~2,5 m²**





© Tesla.com

What about Tesla's plans to create a 1,000-mile battery?

The battery capacity of the TNO calculation is 30 kWh and the estimated commuting range is 10,000 km per year. The underlying specs are in line with a Nissan Leaf. Scaling up the battery to achieve a range of 1,000 miles would mean that a battery with a capacity of 280 kWh would be needed.

Assuming the same driving parameters as before, a car that had to be charged 59 times per year would only have to be charged 7 times if it had a massive 280 kWh battery. Unfortunately, the total cost of the vehicle would likely increase by a factor of 2-3. To achieve a range of 1,000 miles, not only the battery needs to be optimized but the whole vehicle. It is notable that many EVs have a significantly lower power consumption than the Nissan Leaf and therefore would not need batteries as excessively large.

What about Tesla's plans to create a 1,000-mile battery?

Fraunhofer ISE calculated that a solar roof of 1.6 m² would only cost about € 130 to produce and would increase the range of the vehicle by 13-23%. This would make VIPV attractive and as of today the more economical option than scaling up batteries.

It is hard to predict the exact developments in e-mobility. However, to achieve large-scale adoption of renewable energies in all sectors, it is exceedingly likely that lithium batteries will become available with increased power density and at a reduced cost, simultaneously. As Elon Musk has pointed out repeatedly: Improved power density leads to a reduction in cost because the mass of used materials per kWh is reduced.

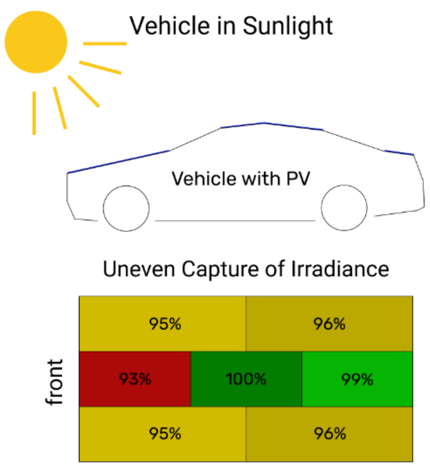
We can imagine that the cost of batteries will drop by a factor of 5-10 in the next 10 years. This would be comparable to the price drop of solar modules over the last 10 years. In this scenario, EVs would receive dramatically longer-range batteries at the same or lower cost compared to today. If the standard battery capacity is, for example, around 100 kWh, the usability improvement resulting from adding PV will be minimal because the number of required charging moments will already be low.

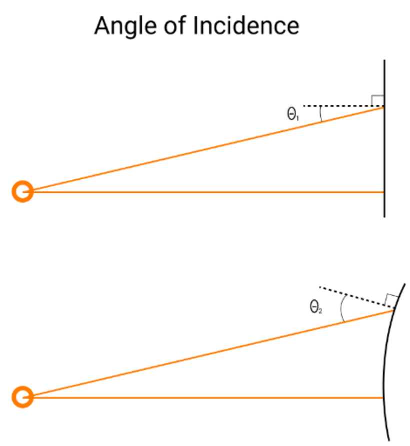
Source:
https://bit.ly/3e5ph9B

What are the challenges involved in making VIPV reliable?

Maximum power yield: To harvest the maximum amount of solar electricity from VIPV, the PV coverage of the vehicle and the efficiency of cells must be maximized. To do this, challenges in the manufacturing processes must be overcome to bring cells into bent and double bent shapes. Further, vehicles will almost never receive a homogenous amount of sunlight. Therefore, diverse conditions of partial and dynamic shading of the cells must be optimized for.

STC testing: The sun is so far away from Earth that for the intents of characterizing sunlight, the sun is at an infinite distance. Photons arriving on Earth are parallel to each other. For STC flash testing in a lab or fab environment, we use light sources that are very close to the sample. A xenon flasher uses a punctual light source, which further aggravates the problem of nonparallel light. WAVELABS simulates sunlight using LEDs. LEDs are arranged in an X-Y matrix on a flat plane. The light beam is focused on a plane which is a specified distance away from the light source. If the underlying cell is not flat, the light will hit it at an angle that is not perpendicular to the cell. This leads to distortions in homogeneity and intensity.





What are the challenges involved in making VIPV reliable?

Therefore, some of the light is lost and cannot be converted to electrical energy. It is possible to adjust for this loss with a simple calculation. However, true results of cell efficiency cannot be obtained in this way. It is possible that car manufacturers will struggle with this in the future when consumers demand a higher and higher power yield for their VIPV.

PV modules in conventional solar parks degrade by a rate of about 0.6%/year. Over the life span of a vehicle, and given added vibrations and variations in sunlight exposure, this number could be negatively affected. Either way, it is important for the industry to understand this behavior as greatly as possible.

Safety and reliability: Among the major challenges for vehicle designers and constructors are topics like electrical safety, crash safety (especially with regard to pedestrian collisions) and impact resistance.

The main challenge here for solar engineers and scientists will be to guarantee the longevity of VIPV operation, accounting for vibrations across a span of at least 10 years of wide-ranging driving conditions.

For proper reliability testing, we need to establish a baseline of optimal production for a new, undamaged, non-degraded system. To establish this baseline, it is necessary for us to understand how much sunlight irradiance can even be realistically harvested. To do this, we need to collect real-world data of vehicles moving, standing and parking from all over the planet.

What are the challenges involved in making VIPV reliable?

Performance prediction: Data collection of real-world sunlight irradiance that is received by a vehicle year-round is a challenge. Data sets do not currently exist or are not widely available. The data profile of how much sunlight vehicles receive dependent on driving, standing or parking is mostly unknown.

We imagine that, in due time, a standard test cycle will need to be created to support the automotive industry. This would be comparable to the International Test Cycles for Emissions and Fuel Economy for (legacy) combustion engines. These new VIPV standards would probably include a standard profile of sunlight received over time. This will help in ascertaining the actual range a driver can expect to achieve during standard operation.

What are some possible solutions that WAVELABS can support?

WAVELABS LED sun simulators and our world-leading solar metrology know-how can help address several of these problem areas:

- STC testing
- Optimization of power yield
- Performance prediction
- Reliability testing

We have concepts and technology that we are not publishing here because we want to retain the option of applying for patents at a later point in time. If you need solutions, we are happy to help!

LED's get solar on the road!

WAVELABS believes in a 100% sustainable energy future. Transportation is a big piece of the puzzle to get our global society "on the road" towards this goal.

That is why, we are looking for partners that have challenging problems in the VIPV space because WAVELABS technology and know-how can help solve at least some of these challenges.

LED's get in touch!

If you would like to start a dialog and describe your specific challenge to us, please do not hesitate to contact us at any time!

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