

› **HERE COMES THE SUN**

UNSW SPREE Symposium | Bonna Newman

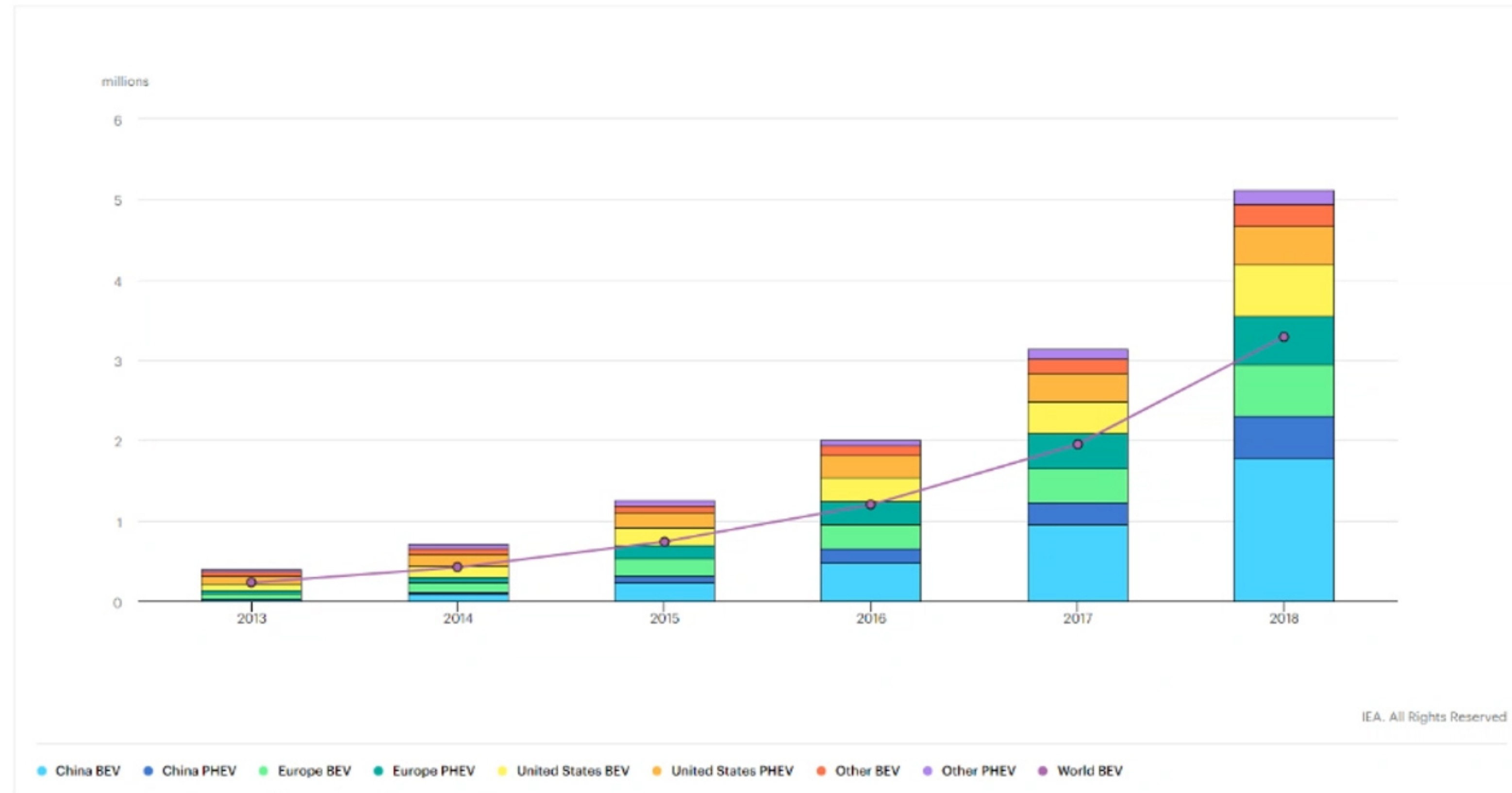
TNO innovation
for life

Photo Courtesy of

Lightyear



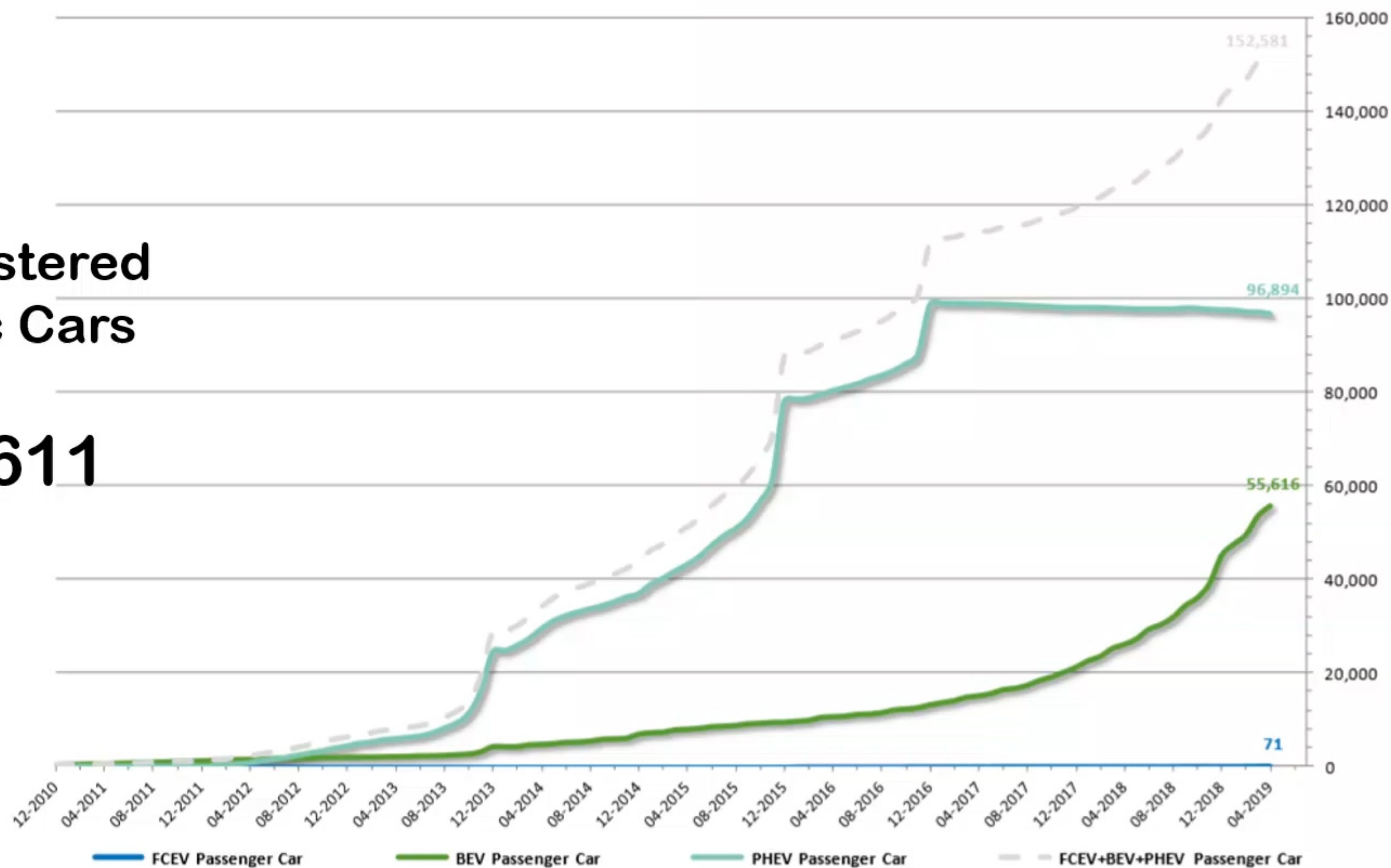
GLOBAL ADOPTION OF EVS



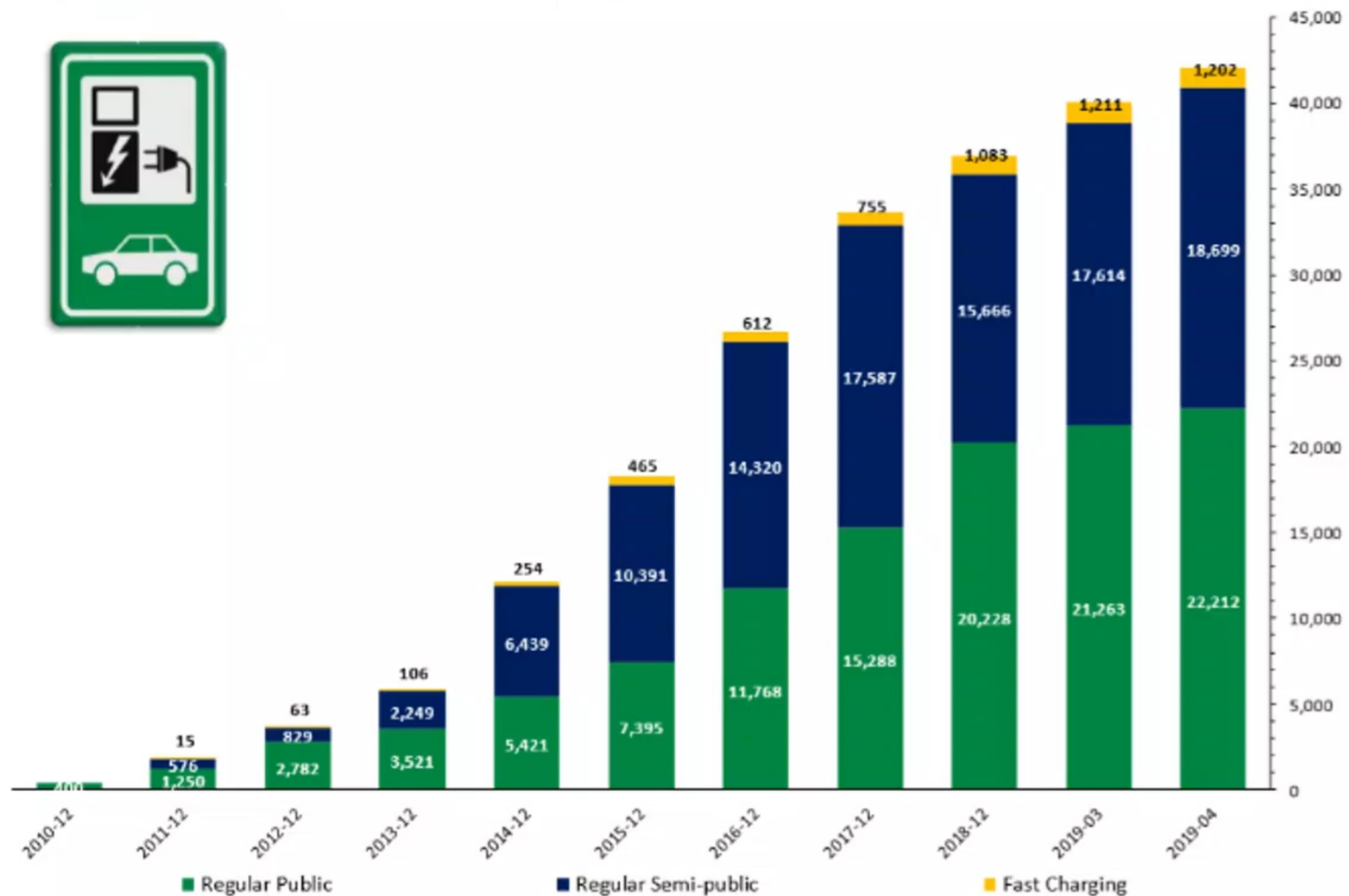
Development in the number of electric vehicles registered in The Netherlands (fleet)²

NL Registered Electric Cars

173,611



Development in the number of charging points¹²





2019 WORLD SOLAR CHALLENGE RESULTS

1st Place: Cruiser Class



4th Place: Challenger Class



12th Place: Challenger Class



17th Place: Challenger Class



TNO UNITS



TNO ENERGY TRANSITION – SOLAR INNOVATION THROUGHOUT THE PV VALUE CHAIN

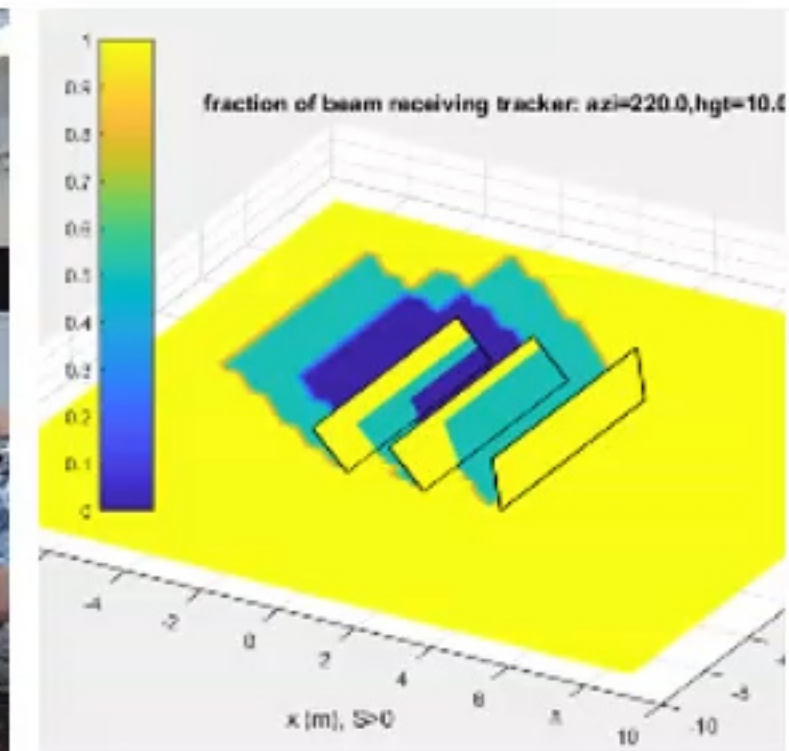
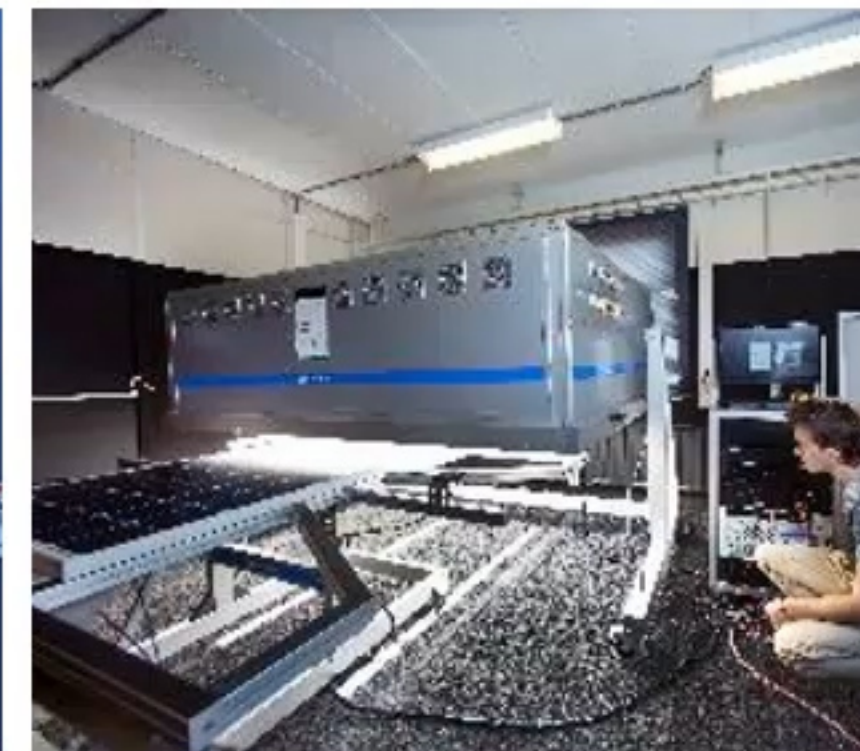
Raw materials

Cell

Module

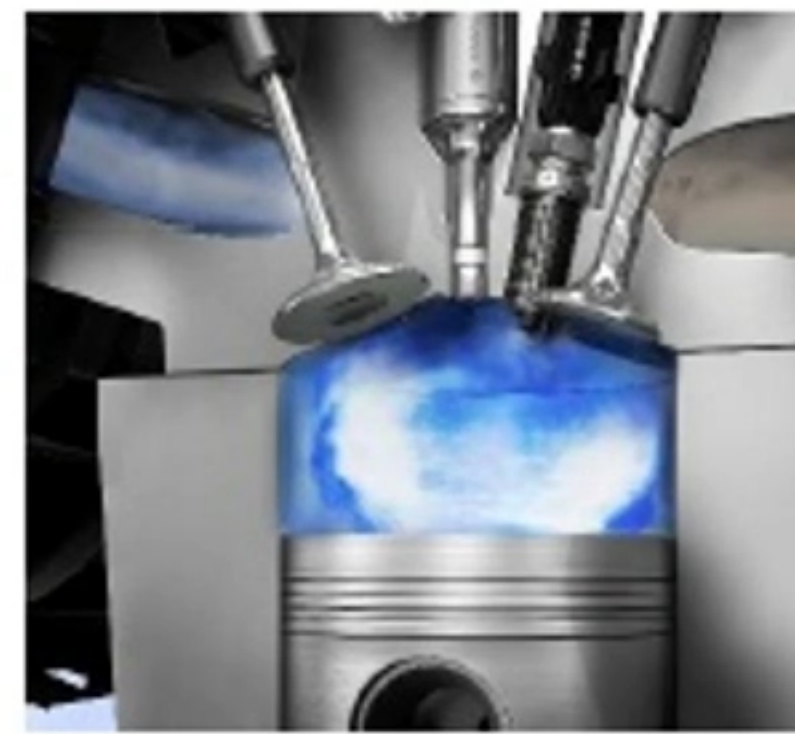
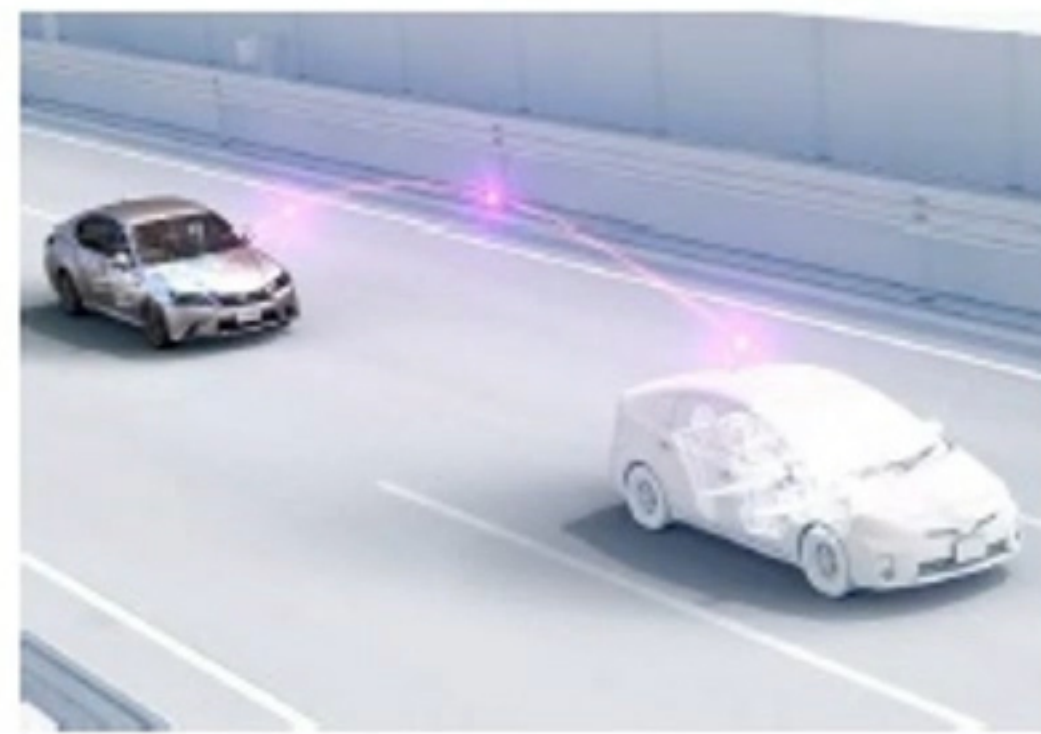
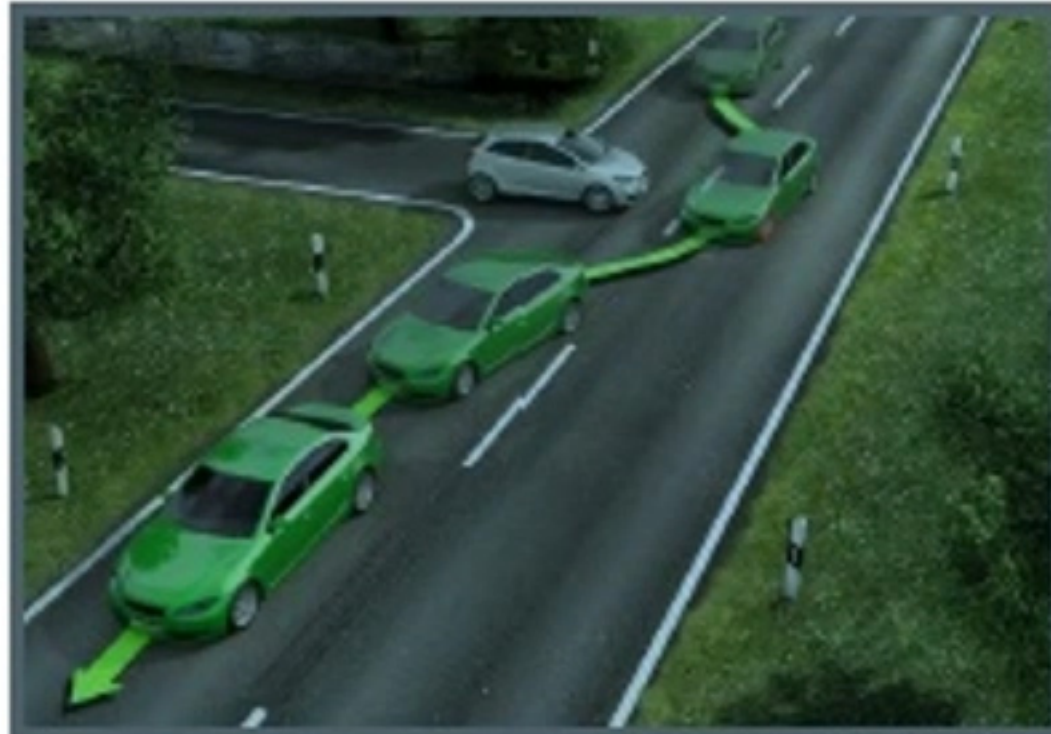
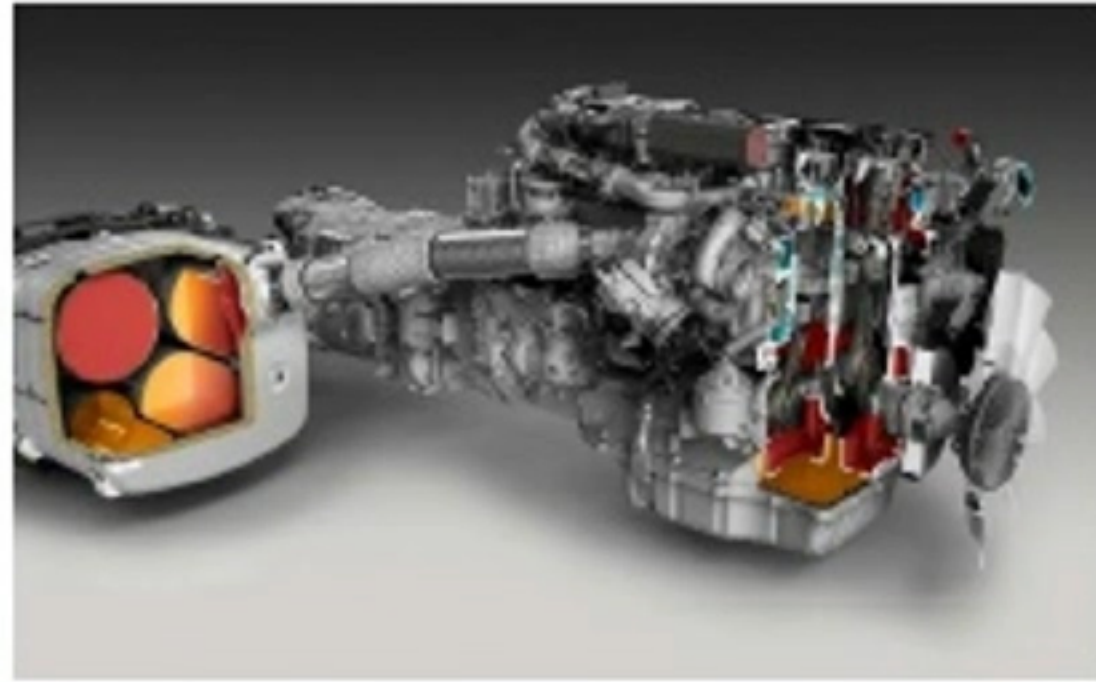
System

Application



› TNO AUTOMOTIVE RESEARCH

Develop, apply and demonstrate new innovative technologies and methodologies that improve **safety, efficiency & sustainability** of vehicles



CURRENT SOLAR EV COMPANIES



Lightyear 

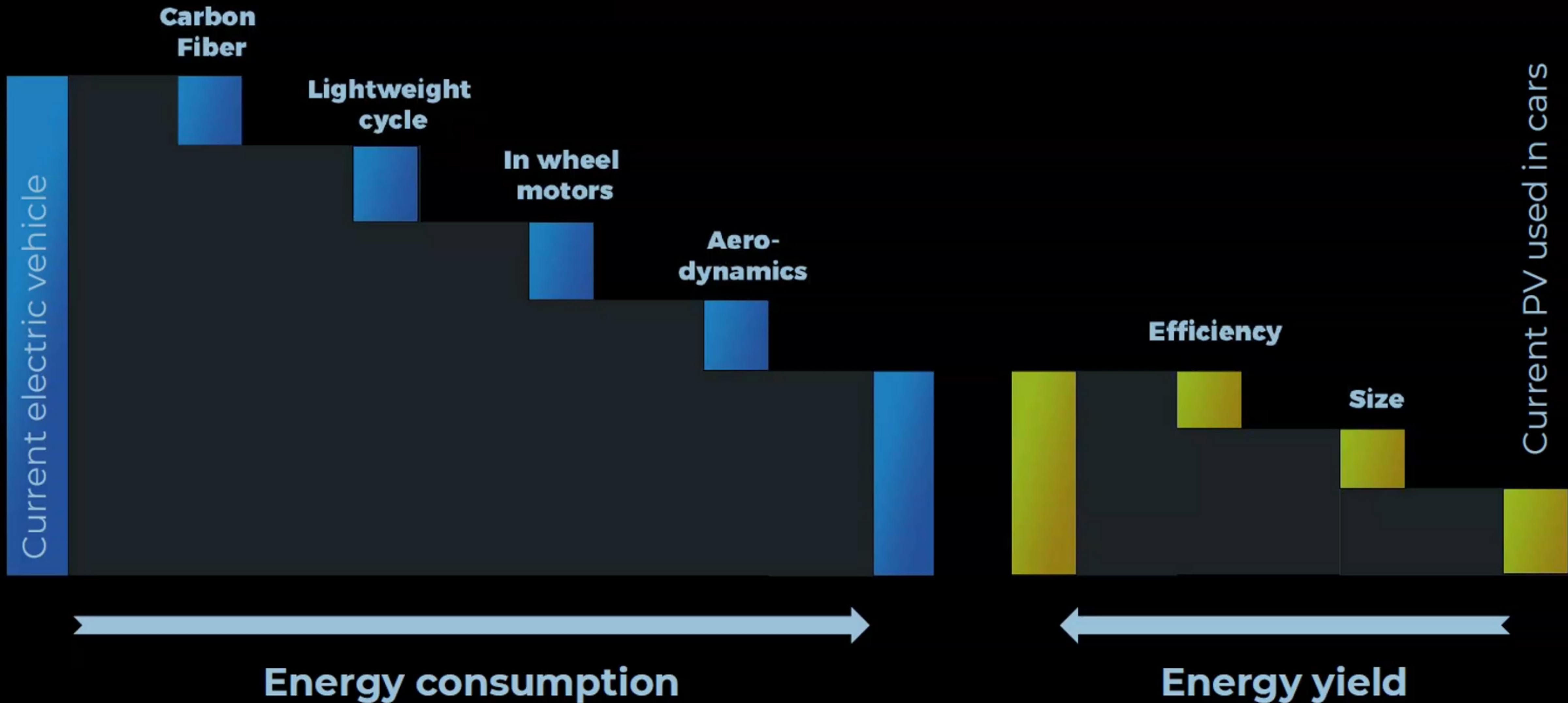


SONO  MOTORS

So why hasn't it been done before?



L I G H T Y E A R

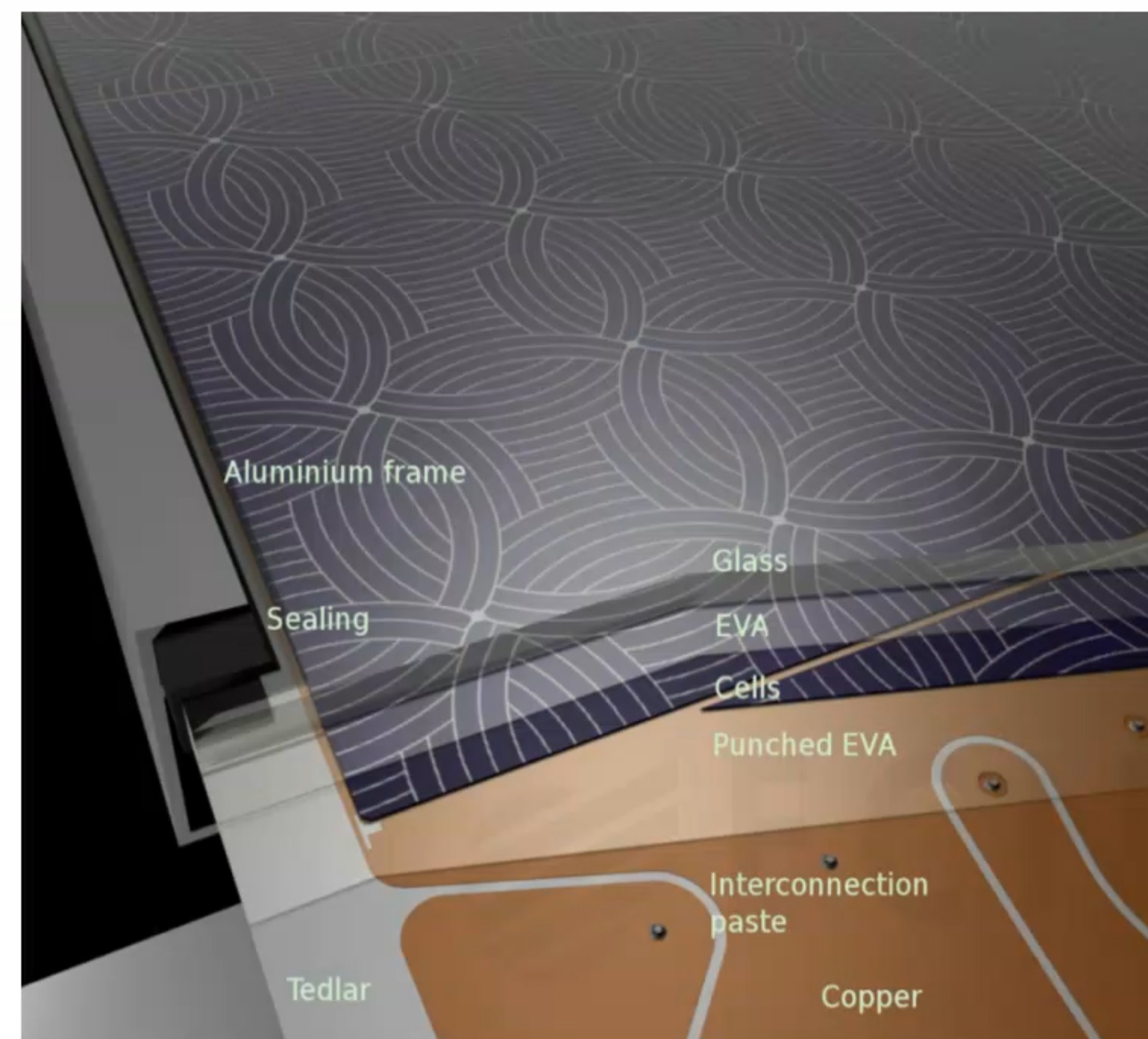


TECHNICAL CHALLENGES FOR PV ON CARS

- › Maximum performance (Max. sun-facing area ~5 m²)
 - › High efficiency
 - › Curved surface
 - › Good shade and dynamic performance
- › Lightweight for vehicle efficiency
- › Aerodynamics and Aesthetics
- › Materials, coatings, and layout
- › Reliability (15 years)
 - › High wind and speed damage
 - › Vibrations
- › Safety

CONDUCTIVE BACK CONTACT FOIL

- › Conductive back-sheet foil
 - › Copper as conductive layer → less Ag on cell
 - › Patterning by chemical etching or milling
- › Contact cell to foil through conductive adhesive
 - › Printed on foil
- › Isolation cell from foil by encapsulant
 - › Holes only at contacts



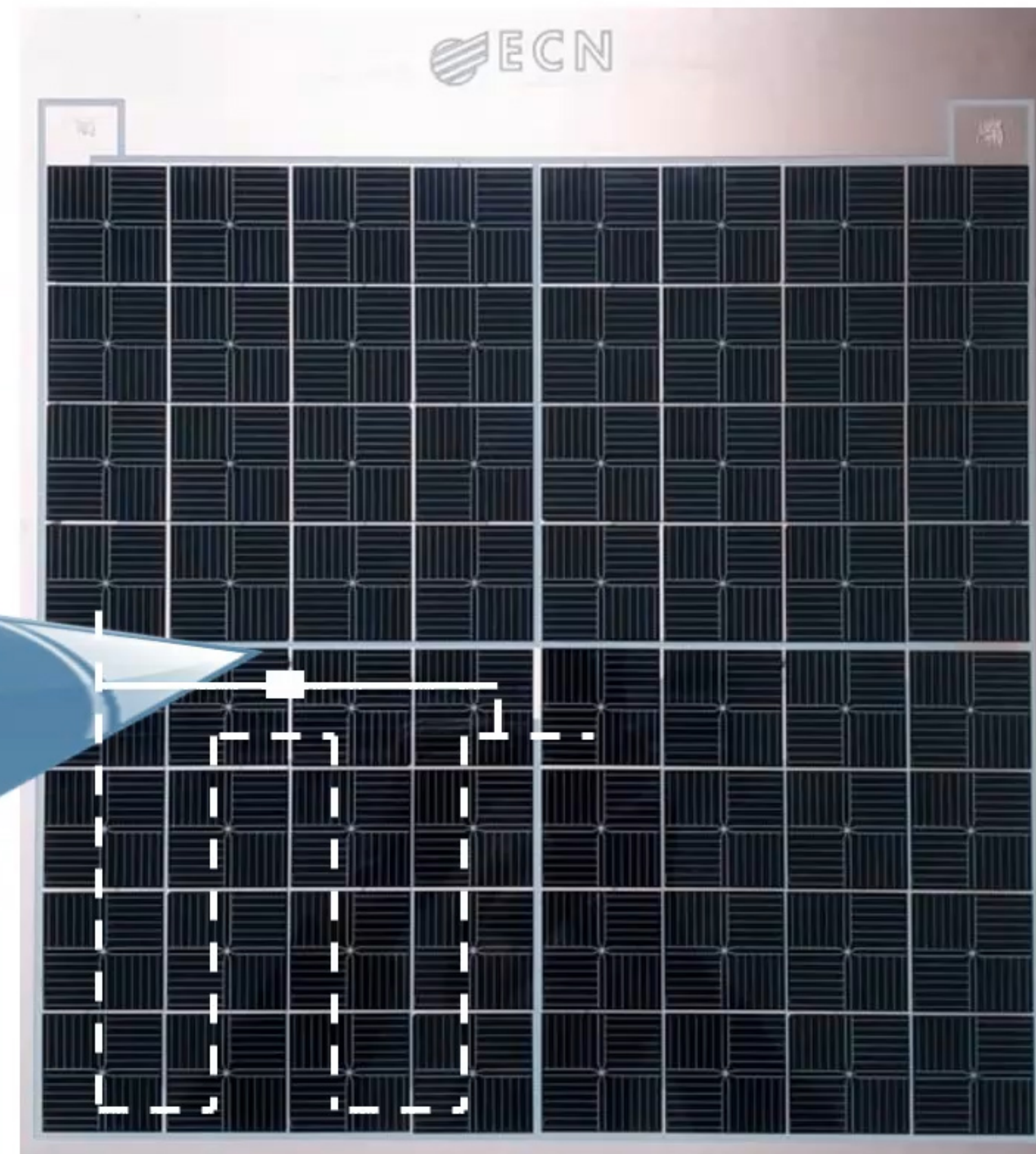
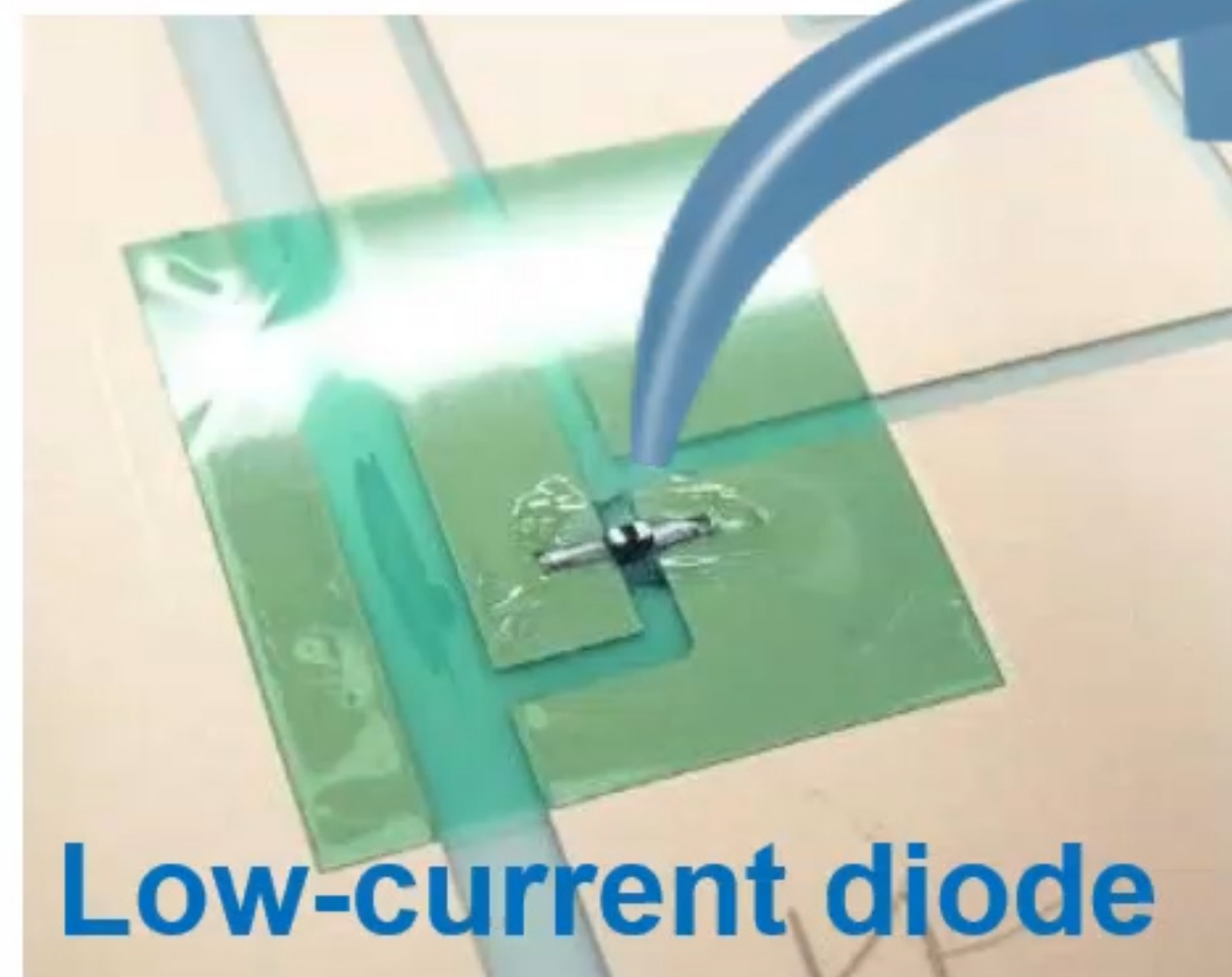
CONDUCTIVE BACK CONTACT FOIL

- › High throughput, highly-automated back contact module technology
- › Adaptable for all back contact technologies
 - › IBC & MWT
 - › Diffused, TopCON, and HJT cells
- › Low temperature conductive adhesive process
- › Easily adapted on-the-fly for flexible designs
- › Excellent CtM due to plenty of interconnection material

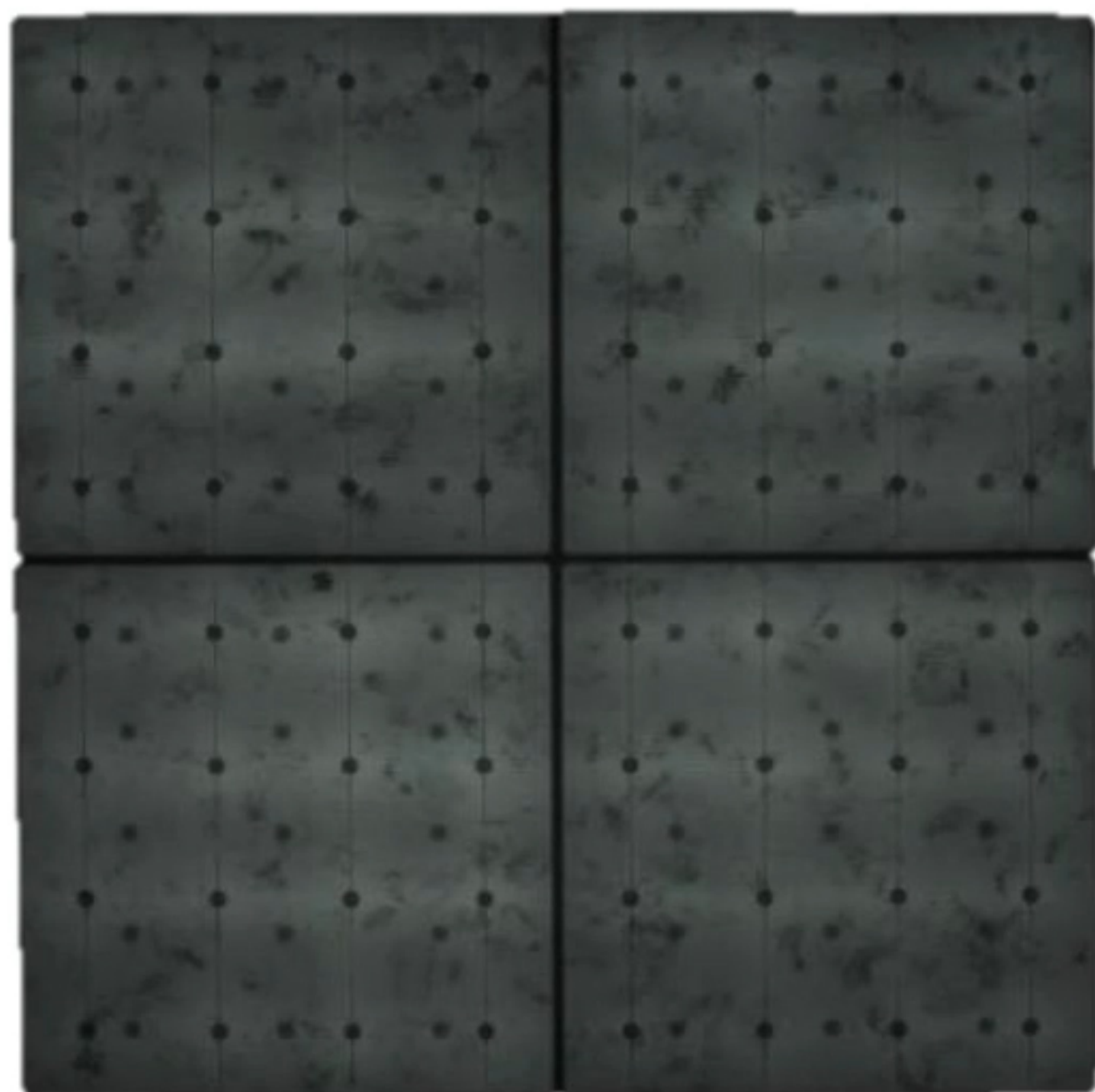


TNO SOLUTIONS: TESSERA™

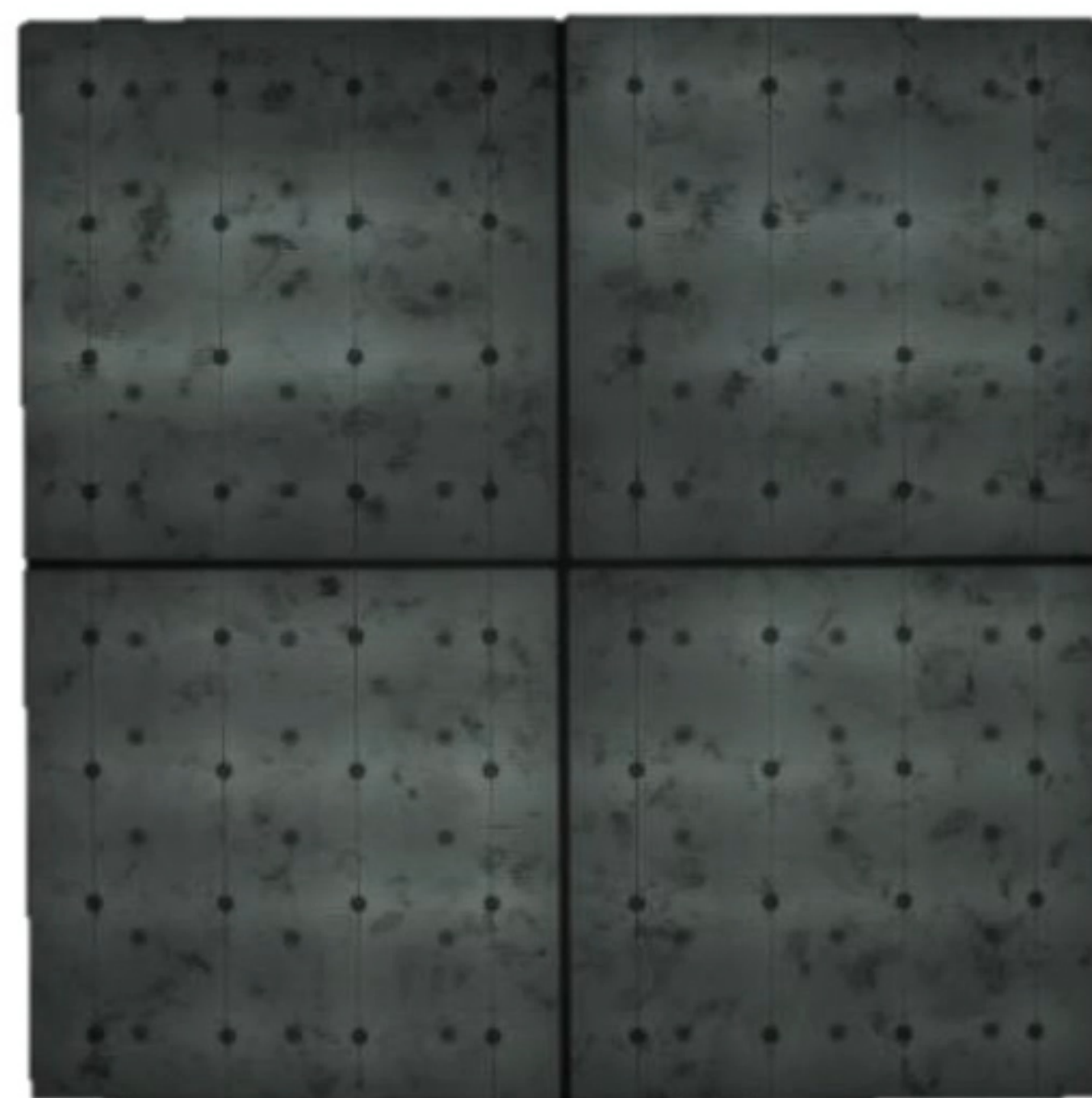
- › Solution for shade linearity
- › Small cells made from larger commercial cells
- › Developed for back contact cell technology
- › Conductive foil used to create specific circuitry
 - › Tunable voltage and current
 - › Integration of other components in foil



FLEXIBILITY AND AERODYNAMICS



Flat

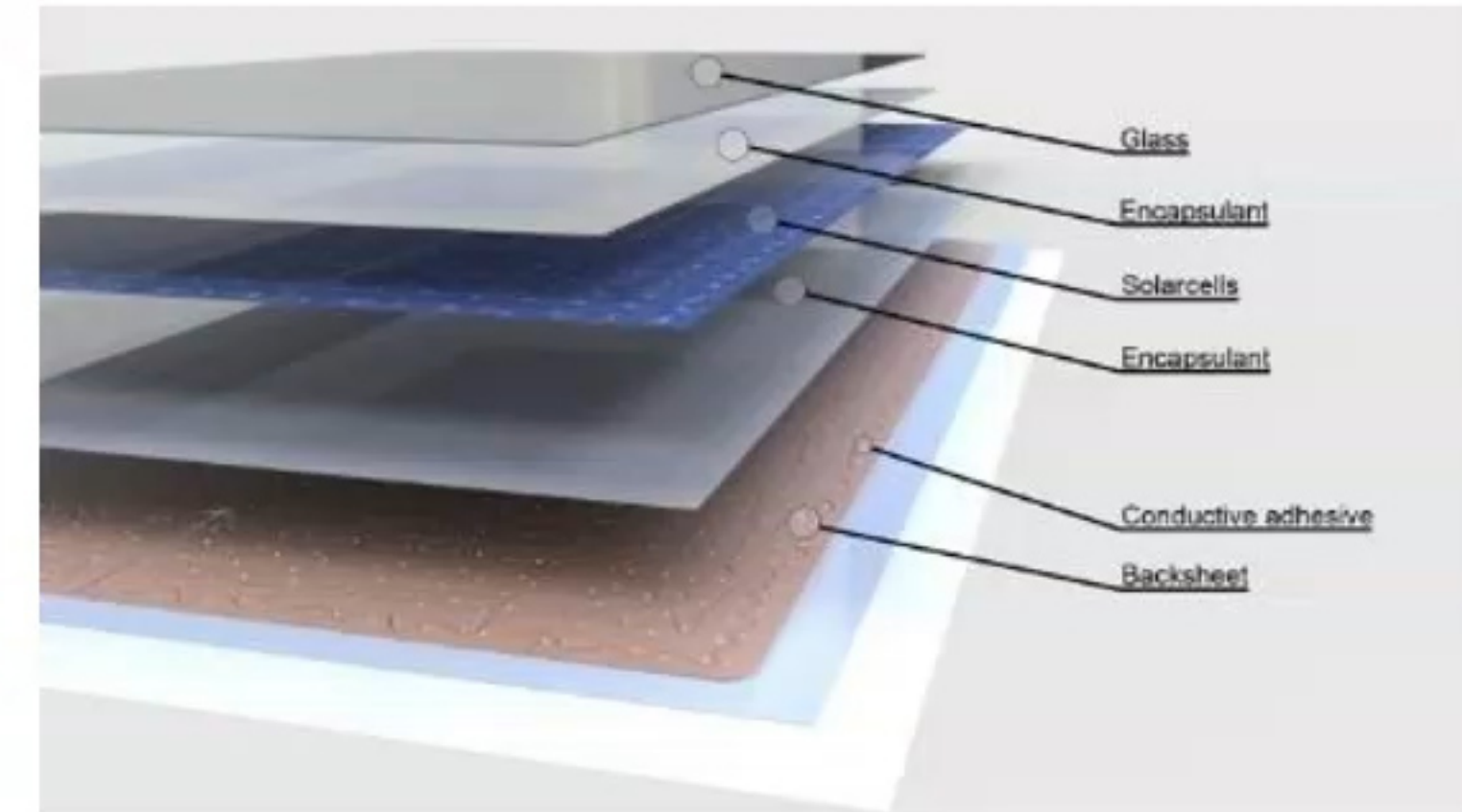
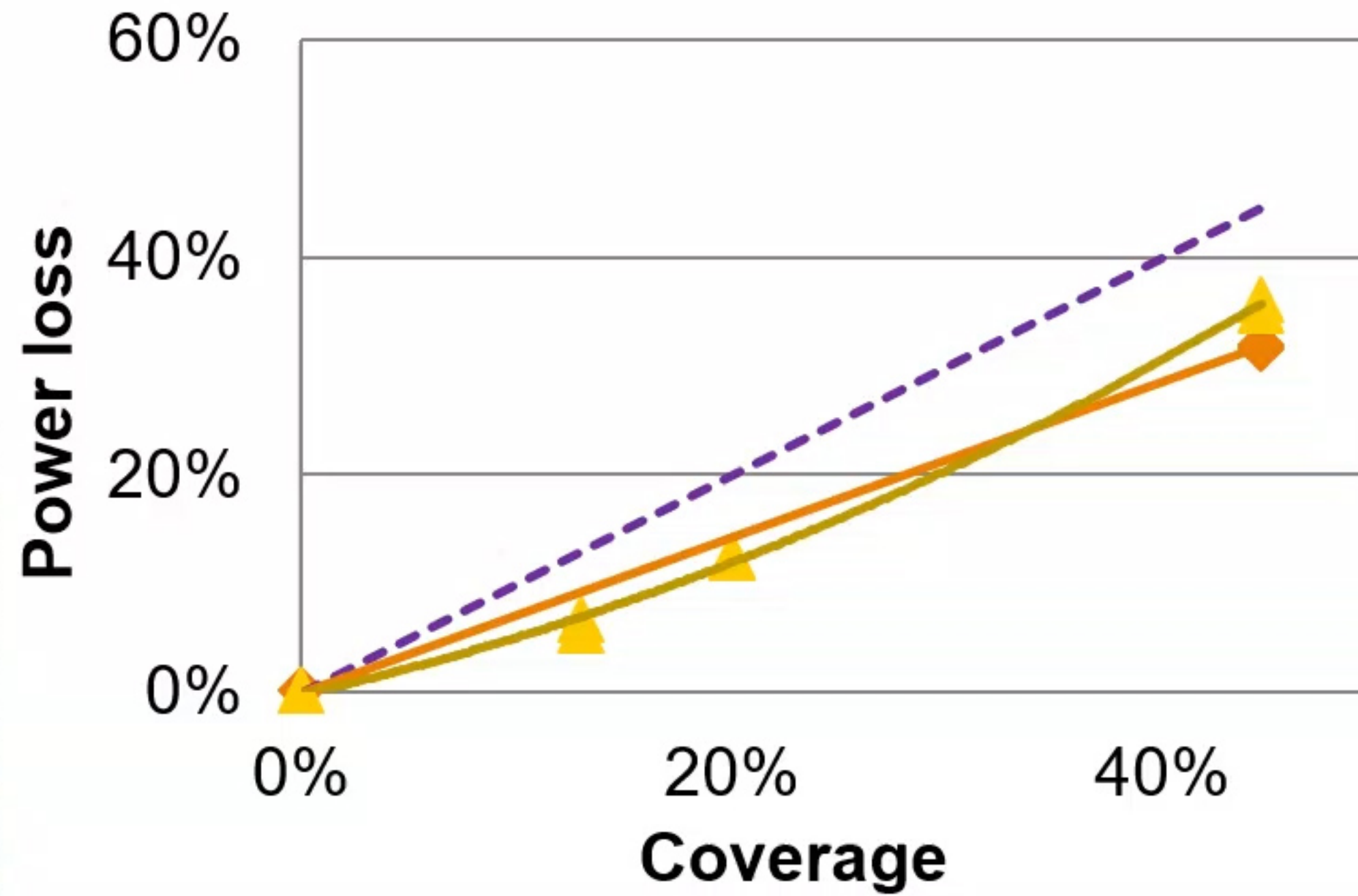
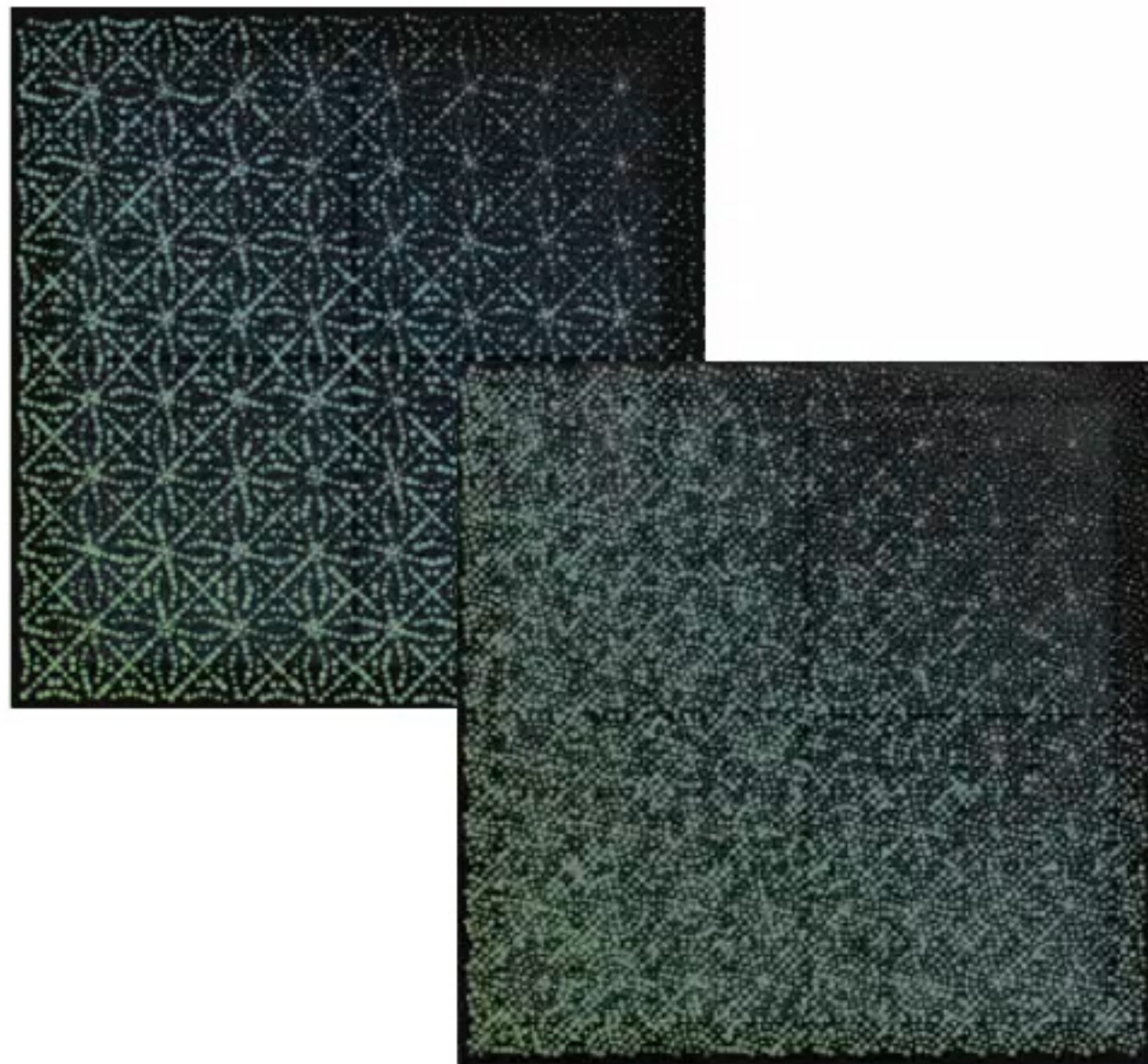


$$R_{\text{curv.}} = 12.5 \text{ cm}$$

$$\Delta_{\text{eff}} = -0.9\%$$



AESTHETICS




1ST GENERATION PROTOTYPE

- › Full-size car roof (more than 90% active area)
- › > 19% active area efficiency under STC, indoor laboratory irradiation*
- › > 86% cell-to-module performance

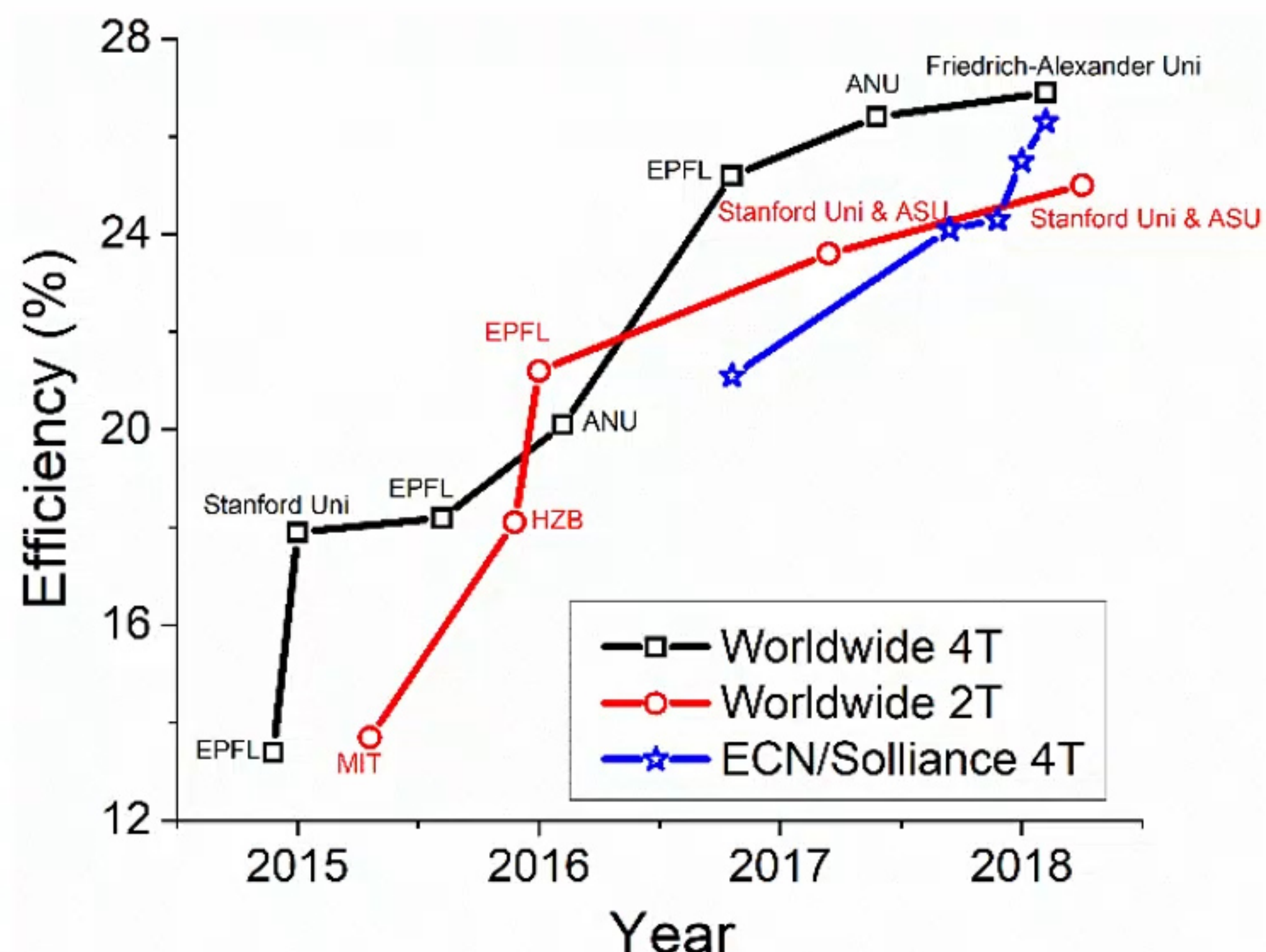


LIGHTYEAR P-ZERO

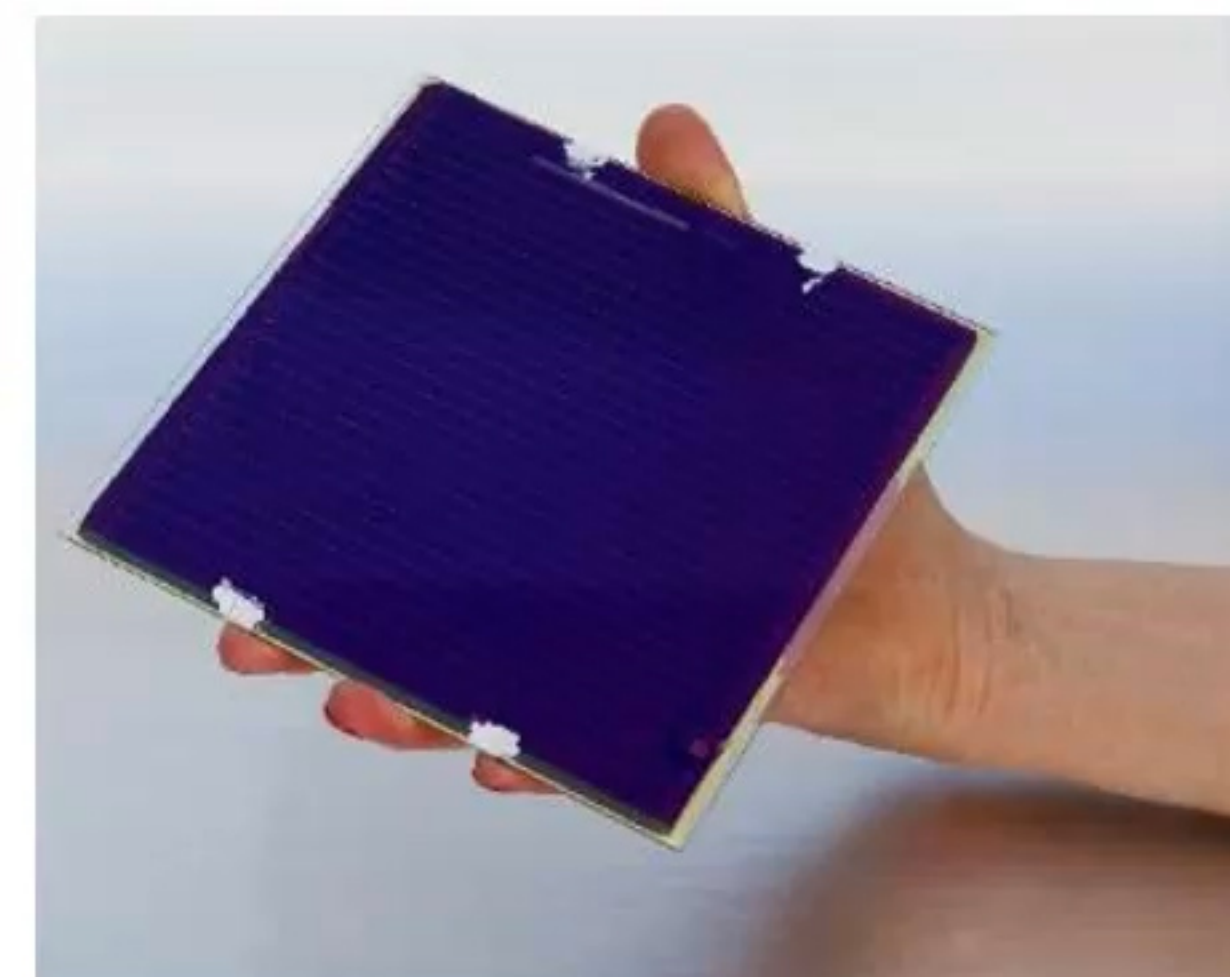


Lightyear 

HIGH EFFICIENCY - PEROVSKITE/C-SI TANDEM TECHNOLOGY



Progress of 4T perovskite/cSi cell efficiency from combined ECN/Solliance efforts (blue)



6x6 inch² perovskite module made at Solliance¹

¹<https://solliance.eu/nl/solliance-sets-14-5-cell-performance-record-on-large-perovskite-modules/>, April 9th, 2018

SAFETY & RELIABILITY TESTING

- › Compliance testing for automotive and solar combined
 - › Crash/Functional safety testing
 - › Electrical safety (< 60V)
 - › Pedestrian impact testing
 - › Vibration and shock testing
 - › Extended accelerated temperature and environmental testing
 - › IEC 61217 & 61730

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I Legislative acts

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REGULATIONS

- | | | |
|---|---|---|
| * | Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC ⁽¹⁾ | 1 |
|---|---|---|

⁽¹⁾ Text with EEA relevance.

EN

Acts whose titles are printed in light type are those relating to day-to-day management of agricultural matters, and are generally valid for a limited period.

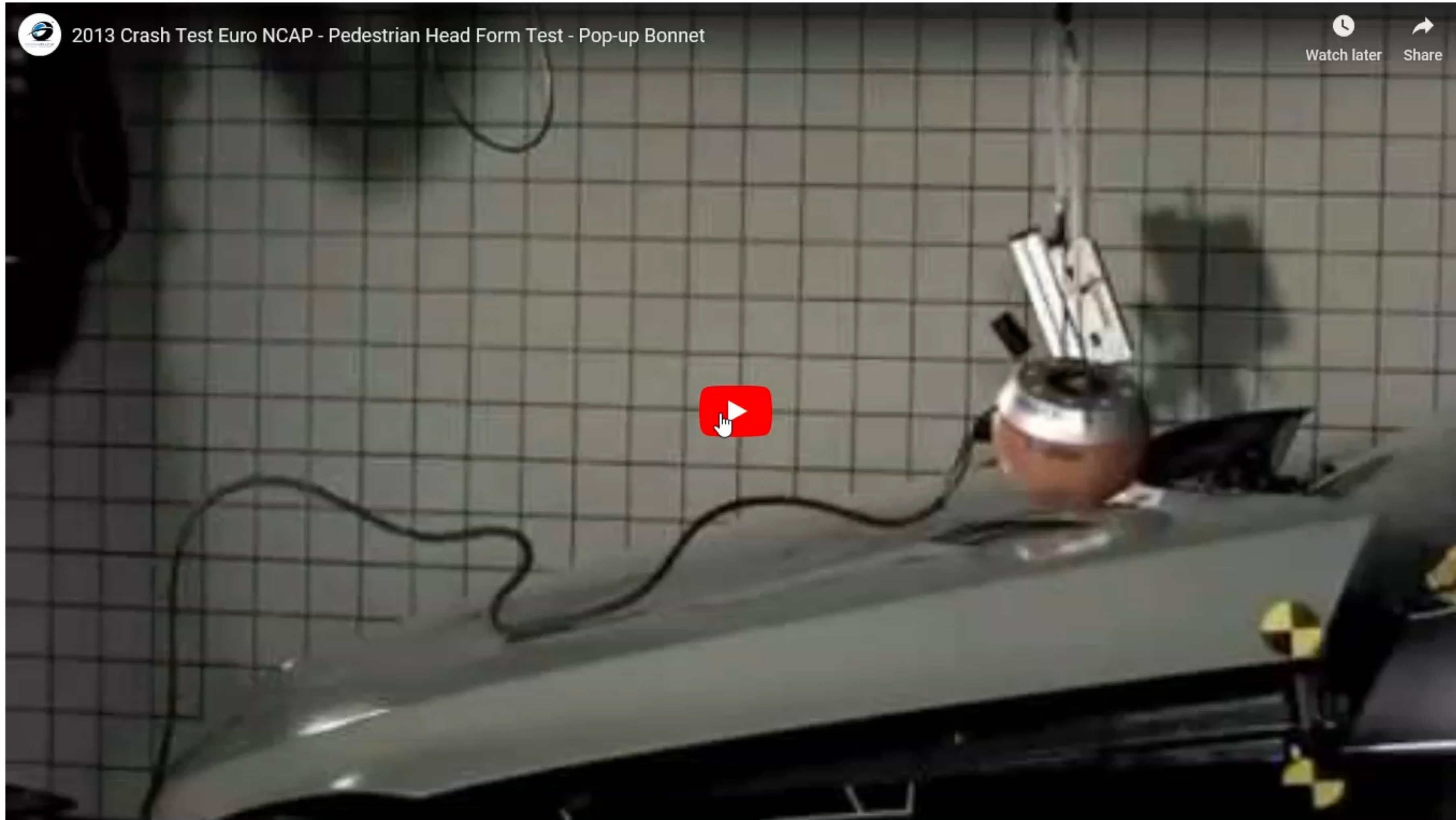
The titles of all other Acts are printed in bold type and preceded by an asterisk.

REQUIREMENTS FOR NORMAL AUTOMOTIVE HOODS

- › Mechanical stiffness
 - › High global stiffness (bending, torsion)
 - › Dynamic stiffness (vibrations)
- › Controllable deformation in frontal collisions
- › Energy absorption at head impact
- › Low weight



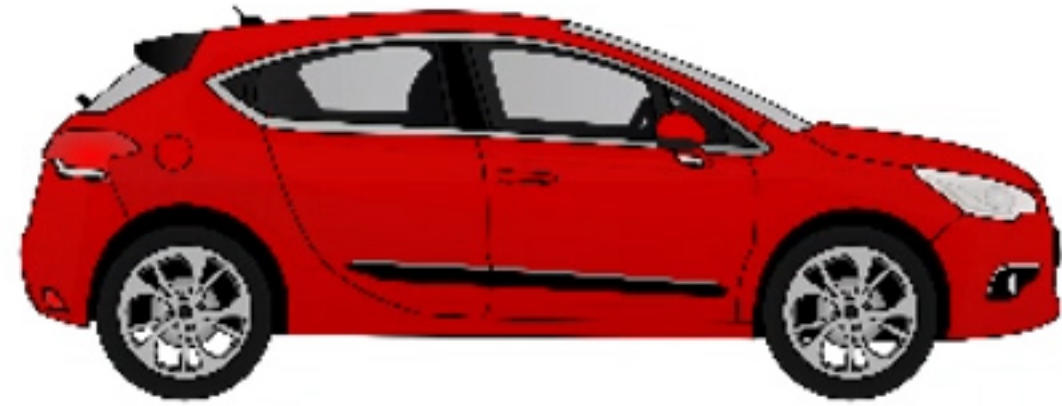
PEDESTRIAN SAFETY



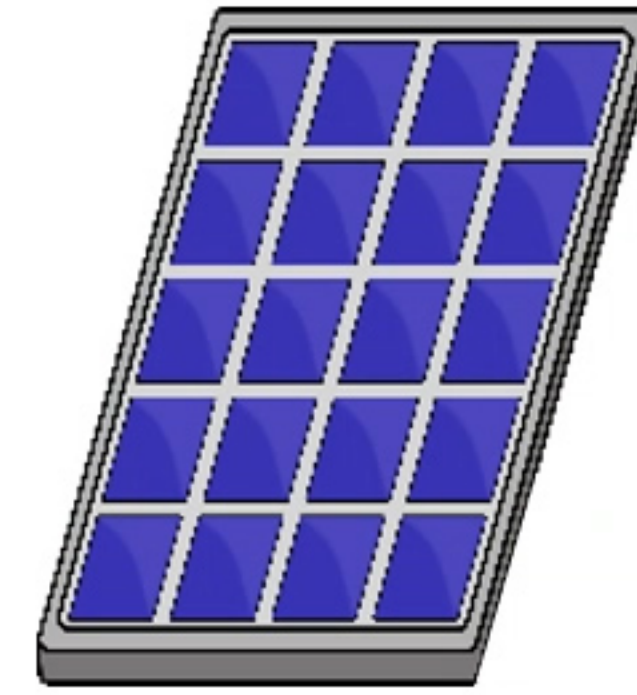
IEA PVPS TASK 17 – LEADING ACTIVITY 1.2

- › Identifying benefits of VIPV:
 - › CO₂ reduction
 - › Range extension – reduce anxiety
 - › Economic benefit – saved fuel / grid charging
- › Quantifying the benefits with an Energy Flow Model
 - › Modelling in Europe
 - › Expansion to global cases (including Australia, with the help of UNSW)

SOLAR VEHICLE ENERGY FLOW MODEL



Car Energy Demand Model

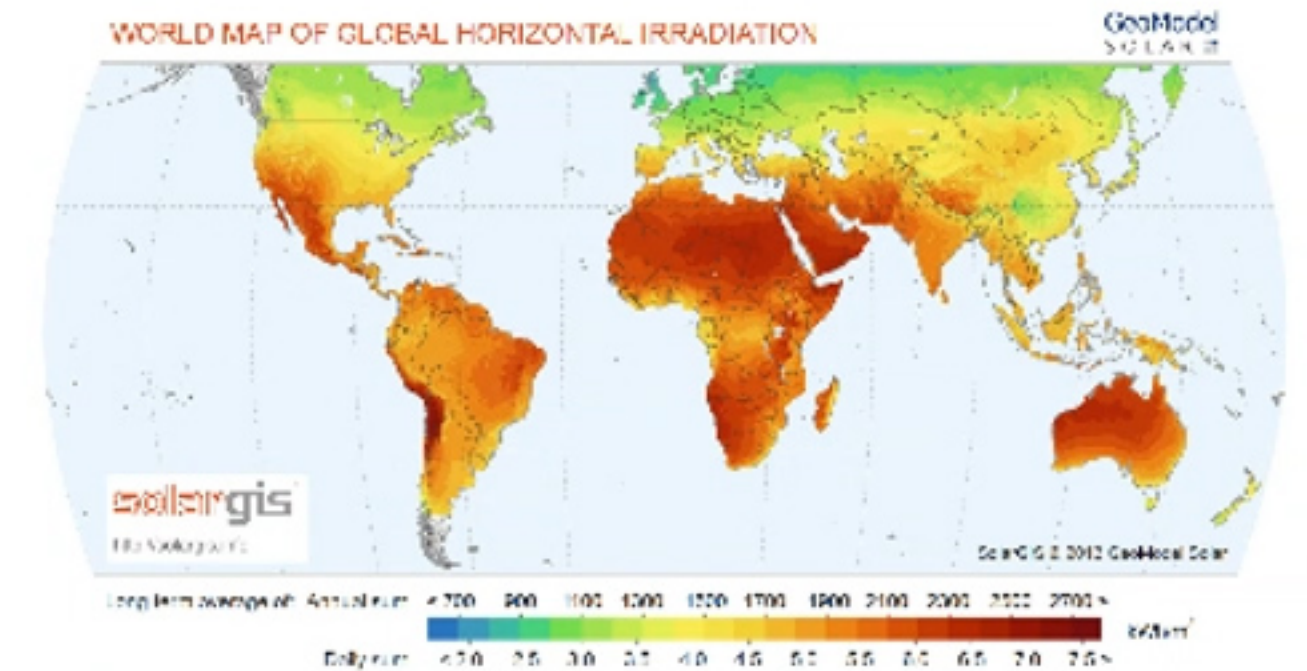


Solar Yield Model



Battery & Charging Model

- Number of Charging Moments (CMs)
- CO₂eq Savings
- Economic Savings



Location and Irradiance

INITIAL CASE STUDIES – DETAILS AND ASSUMPTIONS

PV Energy Yield Model – BIGEYE:

- ~750Wp, Horizontal, No shading,
- Locations: Netherlands, Sweden, Spain

Energy required by car:

- km driven - based on driving profile
- Car efficiency specifications [kWh/100km] - based on road type – city, highway, combined
- Comfort control – use of heater or AC ($f(T_{amb})$)

Battery performance:

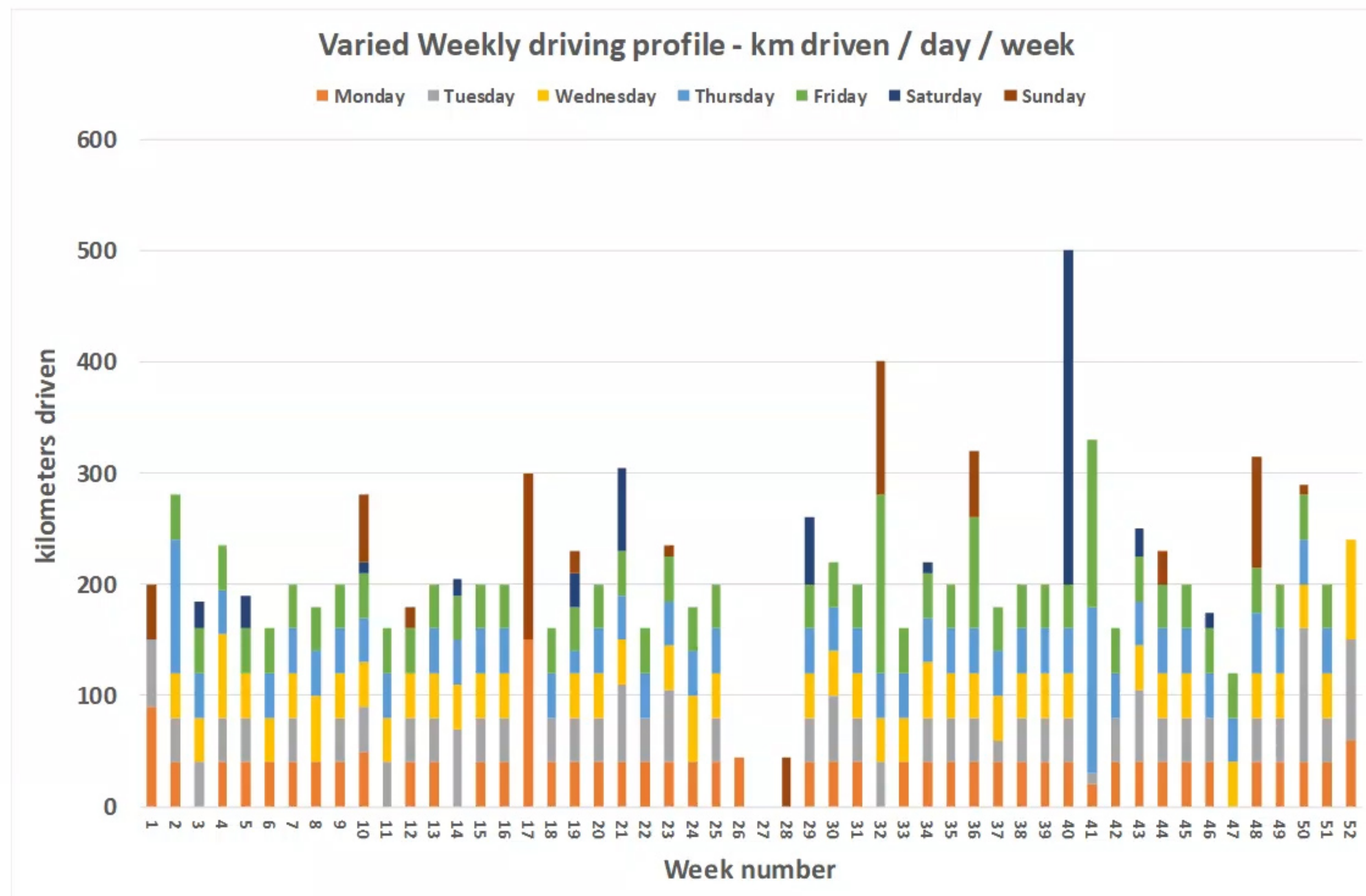
- Capacity
- Losses in charge controller – in and out of the battery

Grid charging rate:

- fixed slow rate

VARIABLE DRIVING PROFILE - ~11,000 KM / YEAR

- › Daily commute
- › 20km to and from work + variability
- › 5 days / week
- › 46 weeks / year + 6 weeks holiday
- › Variable road types
- › 11,085 km/year



BENEFITS SUMMARY (EUROPE)

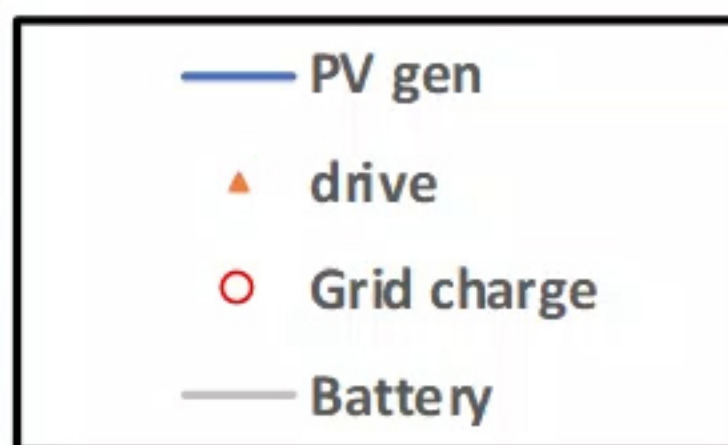
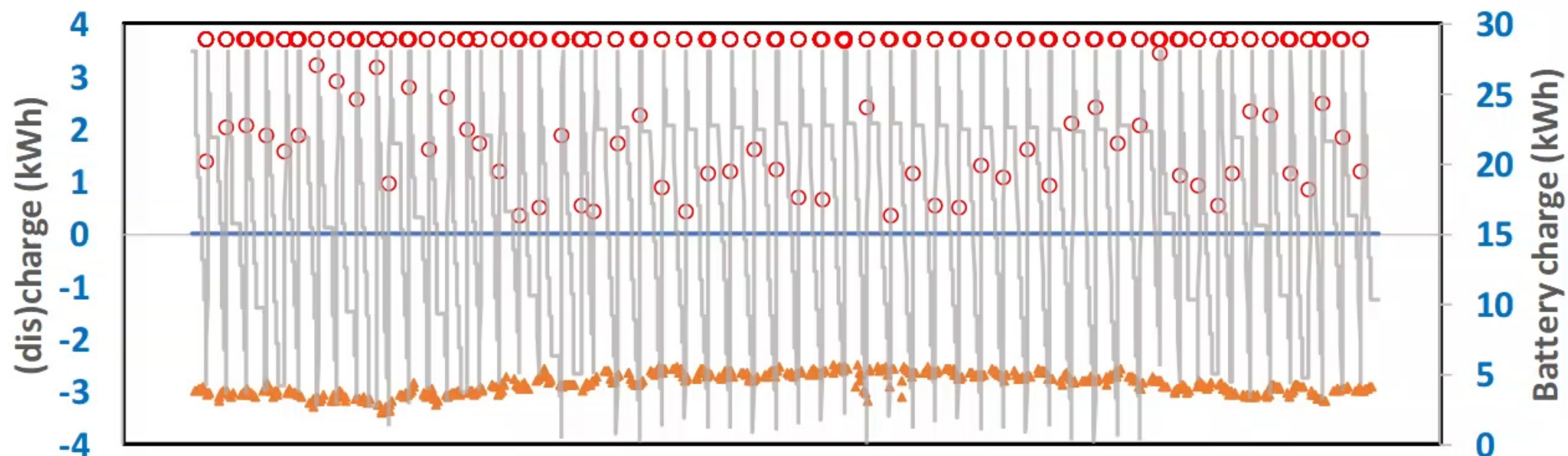
Location	Energy demand [kWh / year]	Potential PV Generation (% of energy dem.)	Reduced Grid Dependence (CMs)	Savings (/year)	CO2 (/year)
Maastricht	1486	53%	56%	€ 234	273 kg
Madrid	1518	80%	32%	€ 354	410 kg
Stockholm	1537	48%	62%	€ 218	254 kg

Simple driving profile – 10k km/year commuting
 Conservative charging strategy
 Grid charging cost - € 0.30 / kWh
 CO₂ emission factor, grid consumption - 0.5 kg-CO₂/kWh

EFFECT OF SOLAR CHARGING (NL)

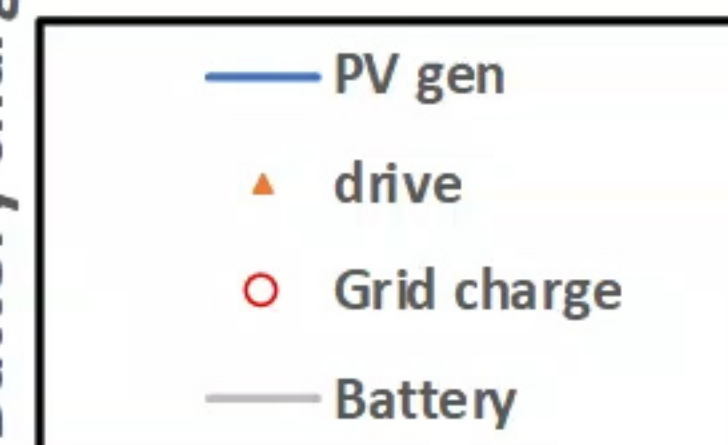
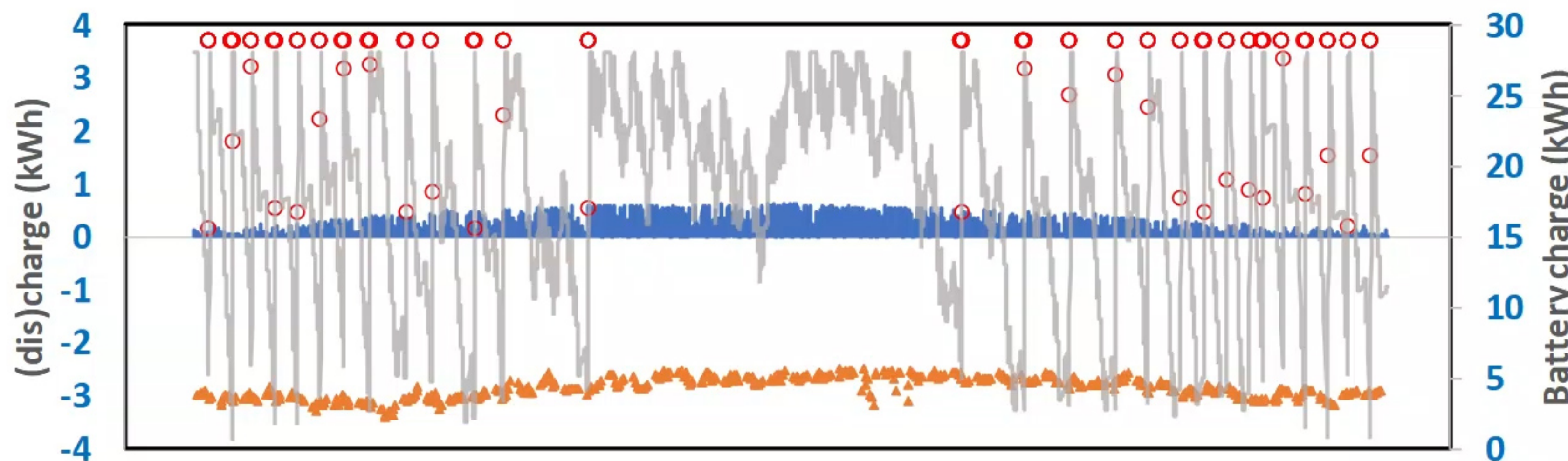
No PV:

59 grid charge/yr

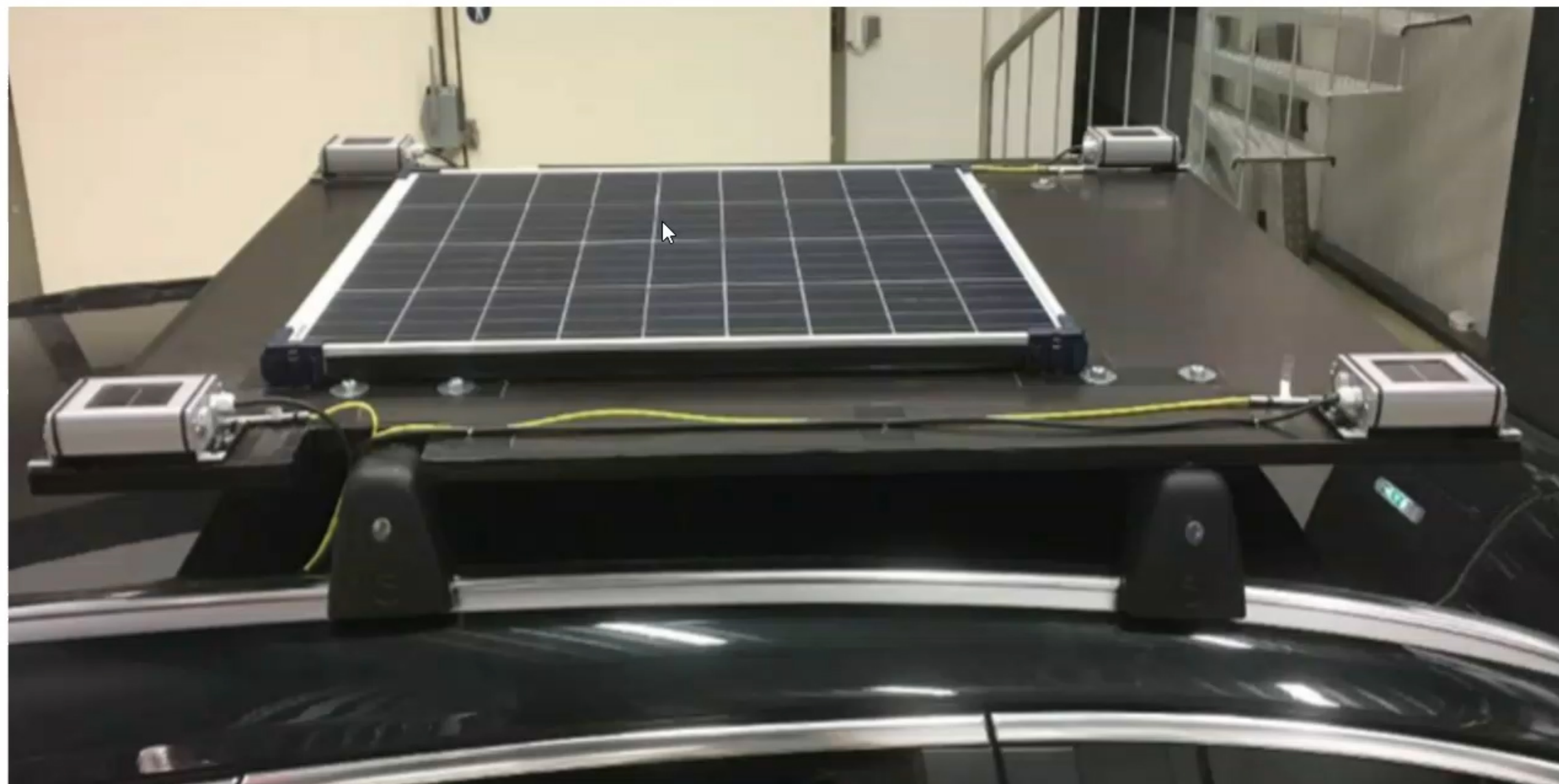


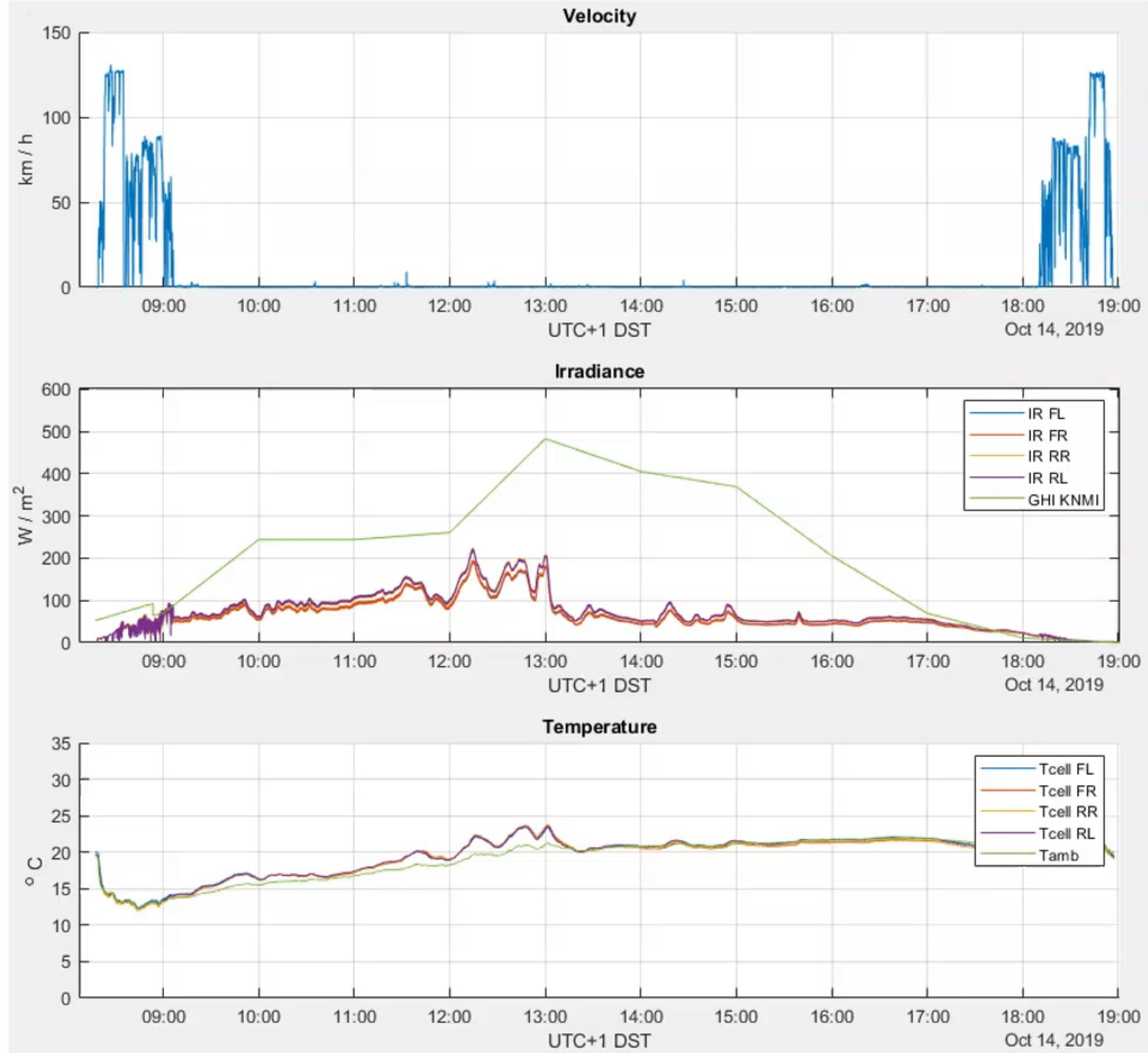
PV:

33 grid charge/yr

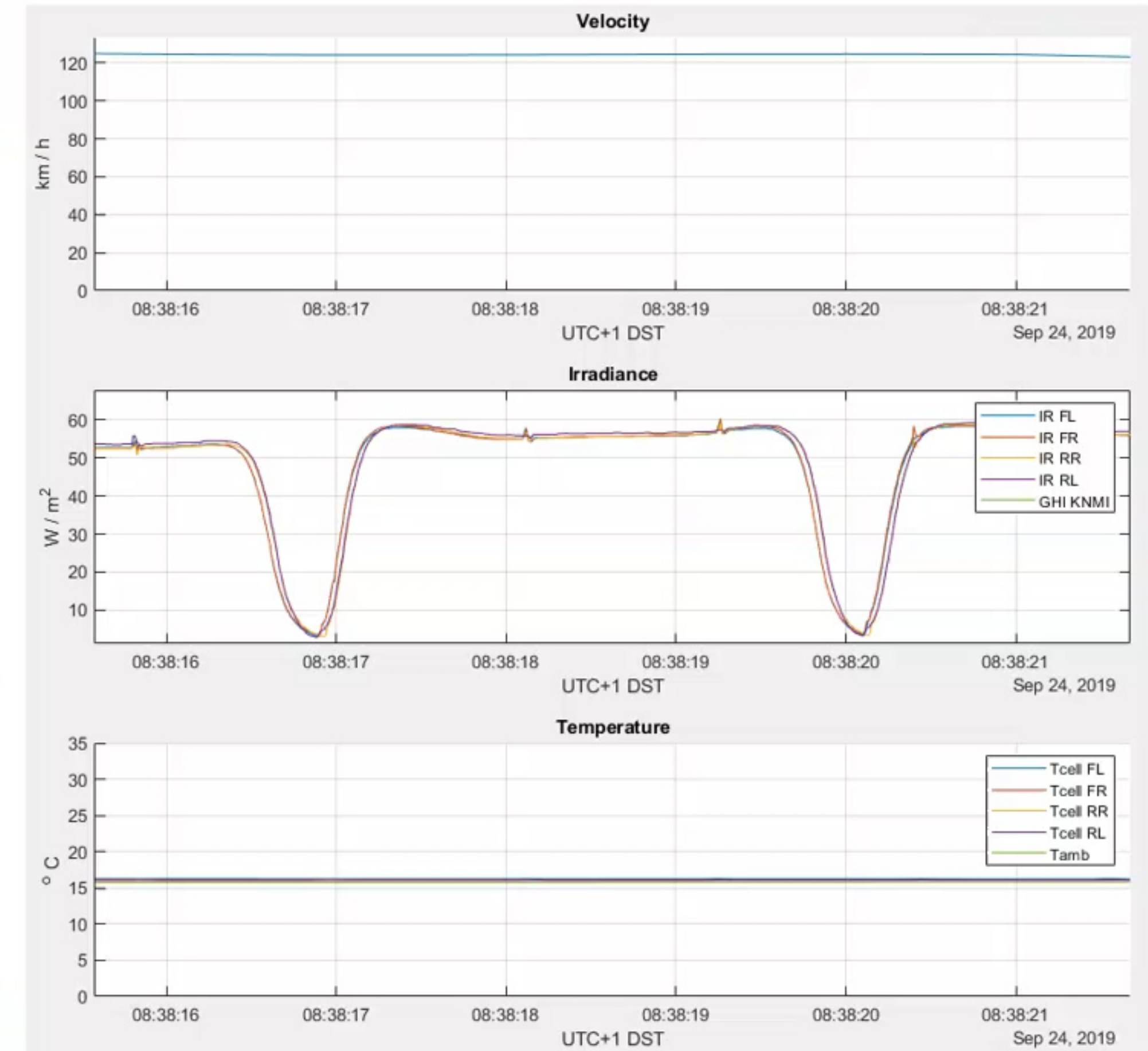
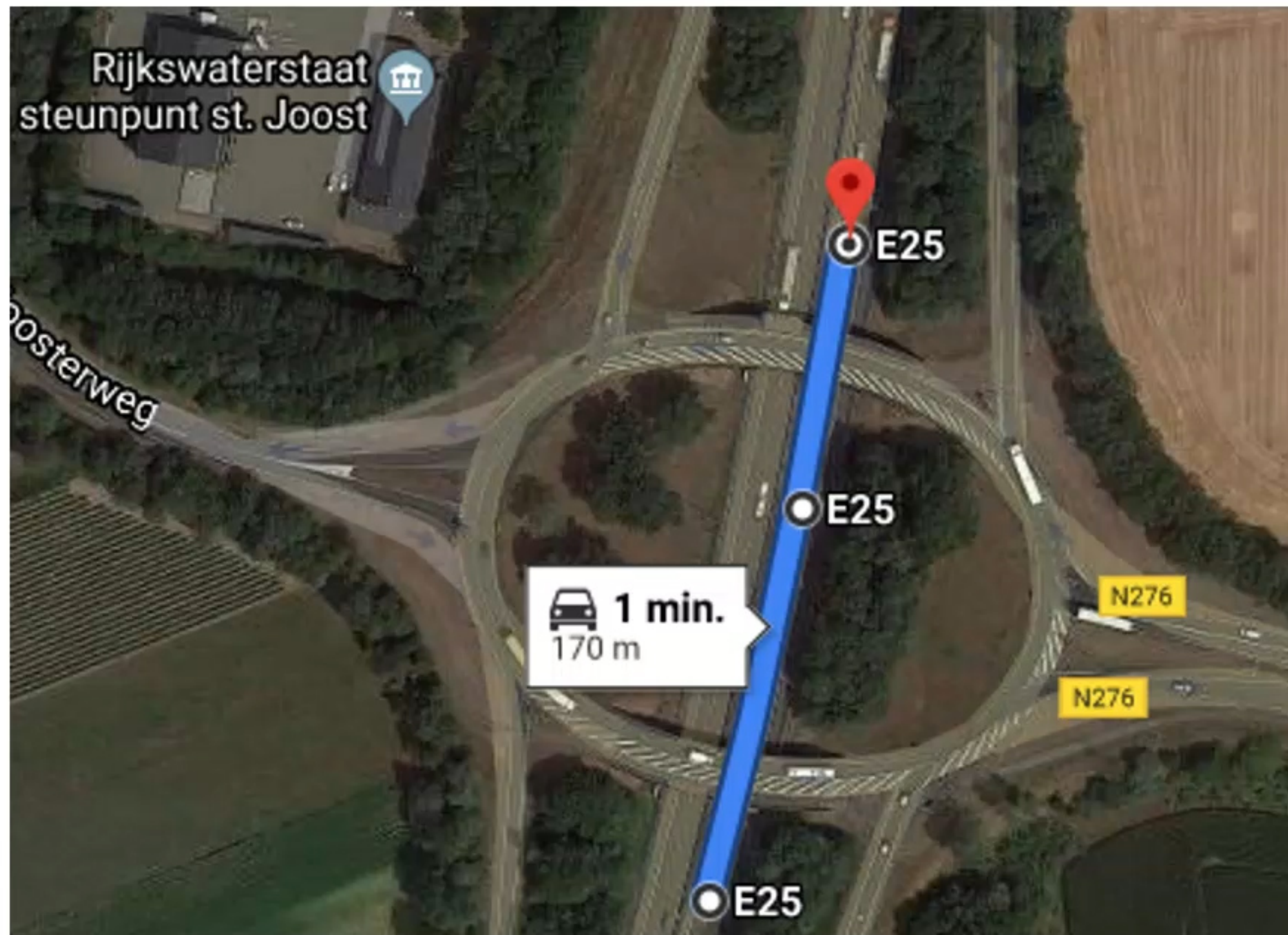


VEHICLE IRRADIANCE TEST SETUP





SOLAR POTENTIAL & DYNAMIC ENVIRONMENTS



CONCLUSIONS

- Solar EVs are a reality with current PV technologies
- Safety and reliability are significant challenges for VIPV
- Significant data collection is needed to forecast performance and understand the potential

Benefits include:

- Independence from the grid
- Freedom from infrastructure investments
- Truly sustainable transport



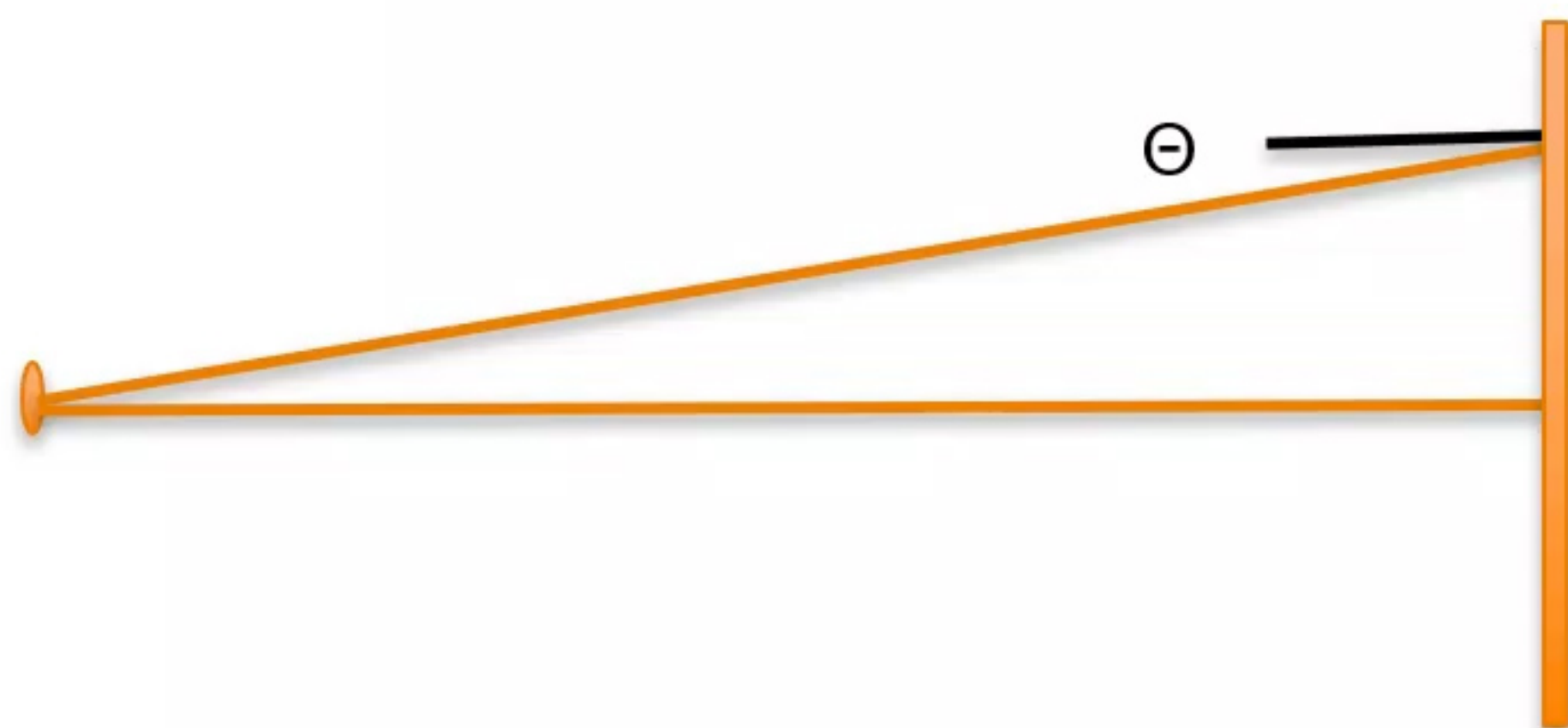
› THANK YOU FOR YOUR ATTENTION

Take a look:
TNO.NL/TNO-INSIGHTS

TNO innovation
for life

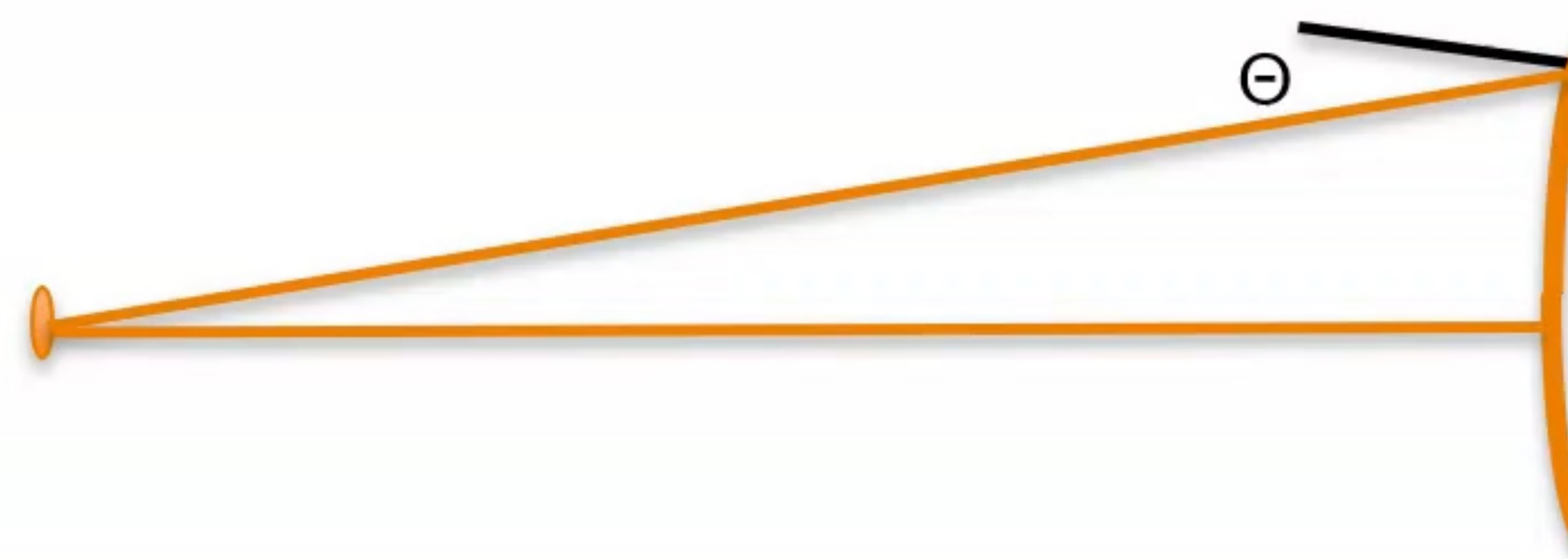
EFFECT OF 3D SHAPE

- › Flat module



- › PASAN corrects irradiance for distance and Θ to have uniform irradiance distribution

- › Effect of 3D shape



- › 3D shape has longer distance and higher angle Θ compared with flat module

IMPACT OF BATTERY SIZE

- › Sensitivity to battery size
- › Charging moments are reduced with increased battery capacity

