PV Innovation from Japan

Market, R&D and business strategy for PV people

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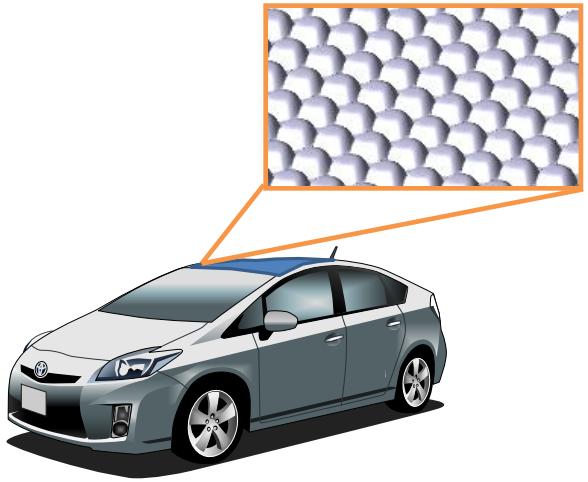
Current Technology



Future Technology

What happens to the car-roof PV?

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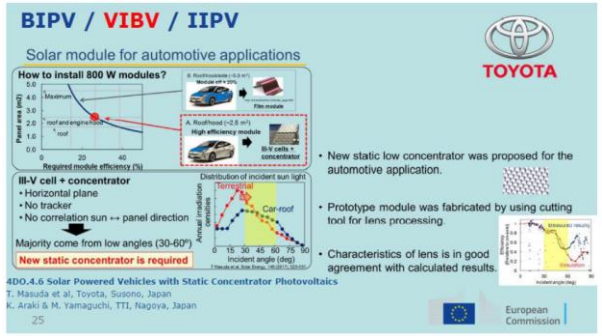
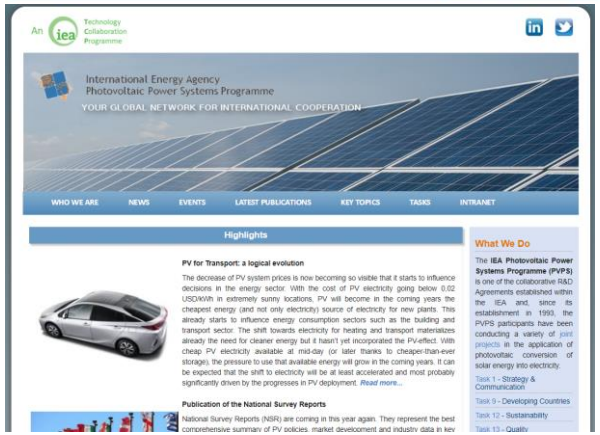


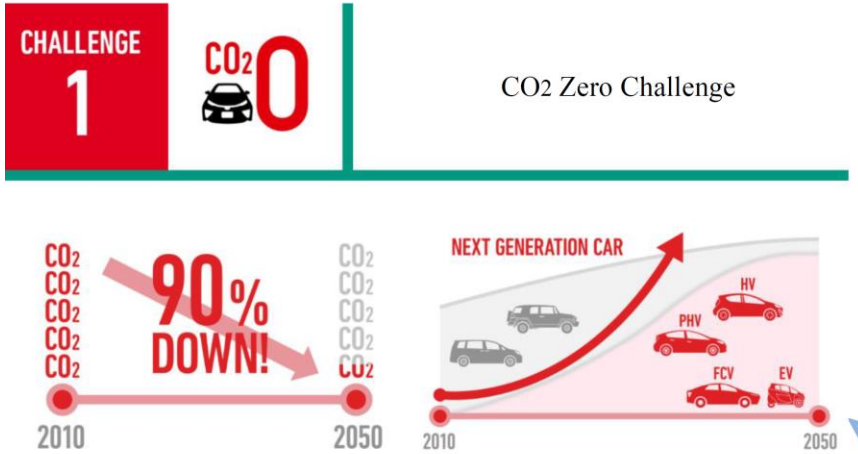
Toyota Motor presented in the EUPVSEC (Sep. 2017)
High-efficiency PV on the car-roof → Solar-driven car



IEA started a new task of “PV for transport” in Dec. 2017

Several new car manufactures announced EV with a big solar panel (up to now).

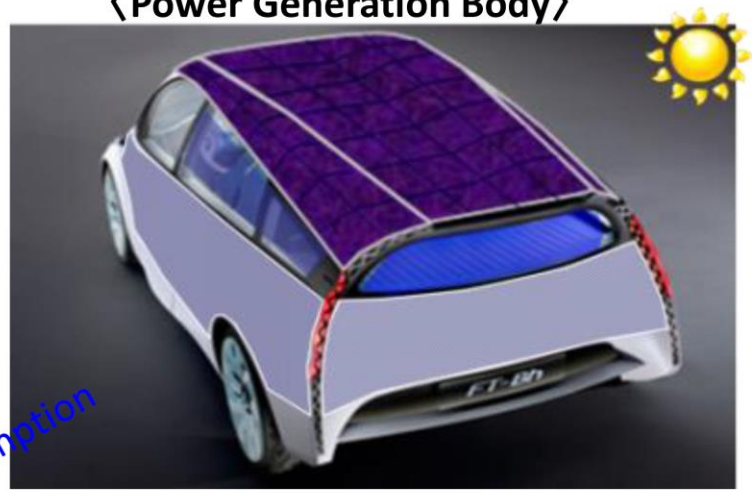
Future Vehicle Powered by Solar

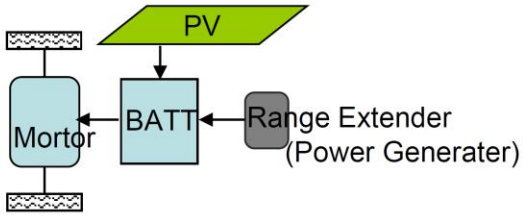


PHV!

5 x PV
Half Electric Consumption

〈Power Generation Body〉





30 km/day ave.
by Solar Energy

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A. Satou, presented at the 44th IEEE PVSC, Washington DC., June 25-30 2017.

Do not distribute images.

Sono Motors

https://sonomotors.com/sion.html/
(Accessed on Sep. 28, 2018)

LG Electronics

Lightyear

https://i.ytimg.com/vi/jXfmqGFKTO8/maxresdefault.jpg
(Accessed on Sep. 28, 2018)

Hanergy

http://www.hanergy.com/en/content/details_38_3609.html
(Accessed on Oct. 06, 2018)

MiaSolé

https://ivoiregion.net/photo/solutions-miasole.html

70 % of passenger's cars run by solar energy – Calculation base

Type	Masuda et al. [9]	NEDO [10]
Base solar resource	Global horizontal irradiance in Nagoya, Japan, N35.2°, E136.9°, averaged in 1961–2012	Global horizontal irradiance in Tokyo, Japan, N35.7°, E139.7°, given by METPV11 standard solar irradiance database [17]
Projected area for the PV panel	Roof + Engine hood: 2.6 m^2 Roof: 1.8 m^2	3.23 m^2 = 1 kW
Required PV module efficiency	–	31%
Temperature loss coefficient	0.91	0.91
MPPT loss coefficient	0.95	0.95
DC/DC conversion loss coefficient	0.90	0.9
DC Charging/discharging loss coefficient	0.95	0.95
Total loss coefficient by PV system	–	0.739
Loss by the Electronic Control System (ECS)	0.36 kWh/day	0.12 kWh/day
Driving range from electricity	17 km/kWh	12.5 km/kWh
Gasoline mileage for HV	–	47.6 km/L
Car-battery size	–	40 kWh (EV) 1.3 kWh (HV) 10 kWh (PHV)
The ratio of the number of solar-dependent passenger cars	68%	70%

Potential market of the car-roof PV

Supply side

Simply applying the current car sales

A: Potential share of the solar-driven passenger's car →70 % (Previous table)

B: Annual sales of the passenger's car in the statistics→70,849,466 (in 2017)

C: Required capacity of PV to achieve 30 km/day drive →1 kW (Previous table)

$$A * B * C = 50 \text{ GW/yr}$$

Demand side

C. Breyer @ EUPVSEC (Sep. 2018)

In 2050, 19.1 TW of PV (accumulated) will be demanded for transportation.

3/4 of the energy consumption in transportation section came from cars.

Supposing the volume production starts in 2020, the annual market size is simply estimated as

$$19.1 \text{ TW} * (3/4) / 30 \text{ yr} = 500 \text{ GW/yr}$$

50 GW/yr (or 500 GW/yr!) market will be created tomorrow?

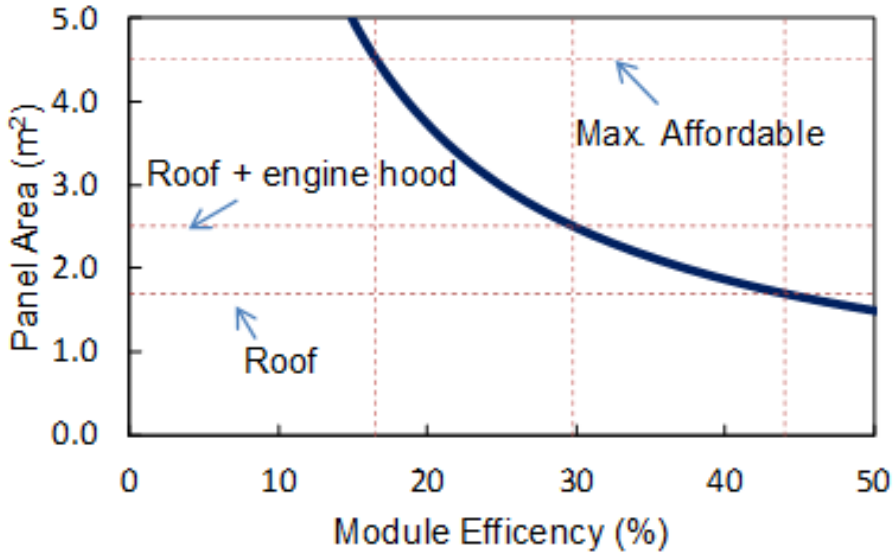
No.

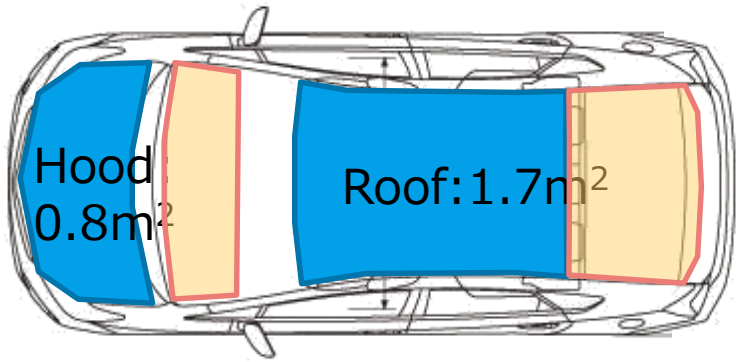
The bright future of the car-roof PV is not the extension of the current technology.

Performance requirement to full-range car-roof PV

Type	Potential	Achieved
Si	28.5%	26.7% (94%)
III-V (GaAs)	29.7%	28.8% (97%)
III-V (3J) [1]	42%	37.9% (90%)
III-V (5J) [1]	43%	38.8% (90%)
III-V on Si	38.0%	35.9% (94%)
CIGSe	26.5%	22.9% (86%)
CdTe	26.5%	22.1% (83%)
Quantum Dot	25.8%	13.4% (52%)
Perovskite	24.9%	22.7% (91%) [2]

1: Non-concentration (1 kW/m^2 irradiation onto the cell);
2: Not a stabilized efficiency.





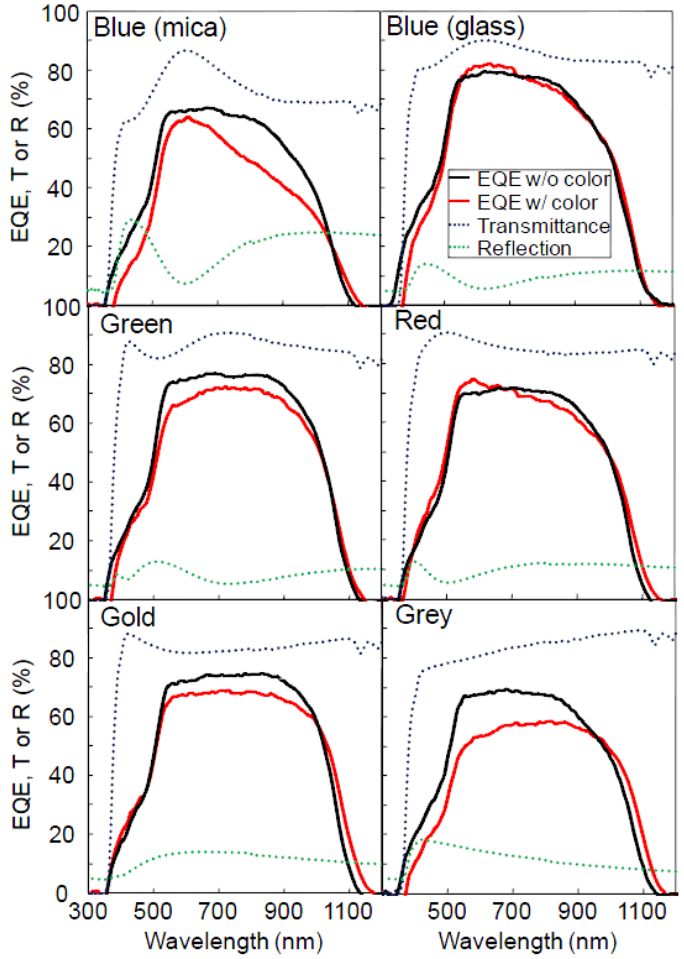
K. Araki, L. Ji, G. Kelly, and M. Yamaguchi: Coatings, 8, (7) 251 (2018).

Courtesy of R. Schilling,
photograph in 1985, Germany

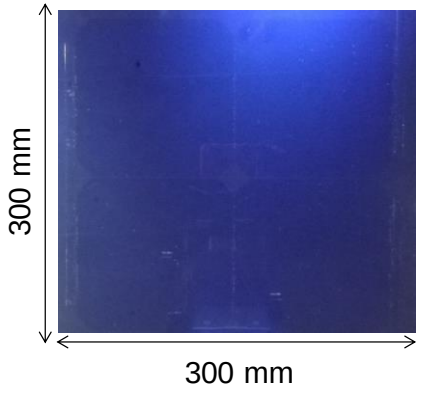
Maybe, this is a range-extender.

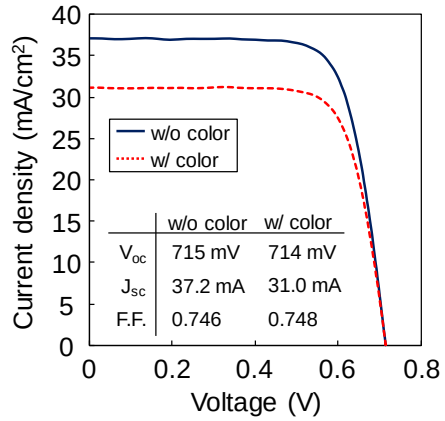
Challenge to visually attractive and high-power-retention

Note: Roughly 40,000 automobile colors are already used today, and about 1,000 colors are added to the list each year



Color	Photo	Illuminated angle	L*	a*	b*
Blue (mica flake)		25°	41.9	-5.1	-36.5
		45°	23.8	-0.7	-19.5
		75°	16.9	1.7	-12.6
Blue (glass flake)		25°	30.3	-6.2	-21.4
		45°	18.6	-1.9	-13.4
		75°	13.4	0.0	-9.0
Green (glass flake)		25°	42.9	-15.7	7.0
		45°	27.0	-9.4	0.9
		75°	18.8	-5.8	-2.4
Red (glass flake)		25°	27.5	17.1	-8.9
		45°	18.2	8.2	-4.3
		75°	14.1	3.8	-2.1
Gold (glass flake)		25°	46.4	-1.5	15.0
		45°	29.4	-1.2	7.5
		75°	20.3	-0.8	3.2
Grey (glass flake)		25°	47.3	-1.8	-6.0
		45°	29.5	-1.3	-4.9
		75°	19.9	-1.0	-4.1





T. Masuda, S. Hirai, M. Inoue, J. Chantana, Y. Kudo, and T. Minemoto: IEEE Journal of Photovoltaics 8 (5), 1326-1330 (2018).

Challenge to the curved surface

Do not distribute images.

For the current PV technology, the packing loss on the 3-D curved surface is much more significant than PV cell efficiency. The coverage of the Solar-Prius roof area was around 60 %.
2-D curve may be easy to cover by flexible thin-film module. But, coverage to 3-D curved surface requires “expandable” module.

Constrain the car design to 2-D curve or flexible/expandable module (R&D challenge)

http://www.carnewschina.com/wp-content/uploads/2016/07/hanergy-china-2-4.jpg

OR

D. Sato, K.H. Lee, K. Araki, T. Masuda, M. Yamaguchi, and N. Yamada1: 7th WCPEC, (2018).

Expandable/Flexible car-roof PV module using wearable device technology

We have two scenarios, to respond to 500 GW/yr (demand side) potential market.

1. Solar car scenario
2. Range extender scenario

Solar car scenario (this is not a car race)

Market size: 50 GW/year (70 % cars running < 30 km/day, run by the sun)

We need to solve three technological breakthroughs.

1. Affordable III-V multi-junction cells (HVPE and substrate recycling)
2. Color control like automobile body color
3. Coverage to 3-D curved surface

This is the scenario of IEA PVPS Task-17.

Range extender scenario

Market size: ??? (Maybe relied on incentive polices)

- The market may grow without technological breakthrough, but it may be taken over by the survivor of the solar car scenario.
- Entry market may be buses and trucks rather than passenger’s cars.
- Crystalline Si module, not very suitable to the curve coverage, may be the main player.
- Revolution may occur in China???

Let’s do R&D together

As resources increase, greenhouse gas 8% reduction will be achieved quickly.

20 years ahead → 10 years ahead → 5 years ahead

Acknowledgement

A part of this research is based on NEDO entrusted research "research and development of ultrahigh efficiency · low cost III-V compound solar cell module". I thank the people concerned.

For this proposal, we received a hot discussions at various conferences. I am thankful to CPV guys and PV masters of high spirit.

Regarding in-vehicle PV and peripheral technologies, I repeatedly discussed with Toyota Motor Corporation, Miyazaki University and Nagaoka University of Technology. Again thank you once again, next time I will delicious delicacies in Nagoya.

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