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Review

List of todo of R&D and International Standardization for Realizing that most of the EVs Run by the Solar Energy

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Abstract: A car-roof photovoltaic has an enormous potential to change our society. With this technology, 70% of the personal car can run by the solar energy collected by the solar panel on its car-roof. Unfortunately, it is not a simple extension of the conventional photovoltaic technology. This paper list what we need to do for realizing the future that majority of the personal cars run by renewable solar energy, after clarification of the difference from the conventional photovoltaic technology. In addition to the technological development, the standardization of this innovative technology will be important, and the list was made highlighting the standardization.

Keywords: photovoltaic; standardization; EV; PHV; car-roof; flexible PV; performance modeling; rating

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1. Introduction

We may see a significant tide in a surprising combination of PV (photovoltaic) and other products. One is BIPV, and another is a car-roof PV. The demand for zero-energy building is increasing. We have had a dream that PV could replace the building wall. However, the dream was a dream. We sometimes forget PV is often ugly with blue-black obstacles to our scene. We once tried colorful or see-through PV, but it was not more than a showcase of new technology. Since PV becomes conventional devices, they have been always-promising products. Recently, the game is changing with a new colorful and artistic PV panel using advanced coating technology. They are not exotic but vivid, comfortable and kawaii. The recent development of EV (Electric vehicle) and PHV (Plug-in hybrid vehicle) related automobile technology open the door to the "solar-engine car." It is expected to replace 70 % of personal-owned cars and contributes to significant cut of the greenhouse gas emission. Considering the annual world sales of the car, it is expected that the market size will be 50 GW/year that is one order larger size of the current market of the PV panels. When this happens or to make it real, the car-roof PV should not be blue-black, but soul colors are often seen in the car body. Coating technologies and their application of PV technologies will be game-changing and a key-technology to our sound sustainability. It may be a dream right now, but it is worth challenging.

In this article, the R&D todo lists for the game-changing car-roof PV technology is discussed.

2. Clarification of the technologies, the difference from conventional PV technologies

Before discussing the todo list for the realization of the car-roof PV technologies, it is important to clarify why new challenges are required, namely why this technology is not in the extension of the current photovoltaic technologies.

2.1. Background of the car-roof PV development

Use of PV (Photovoltaic) to the energy source of the personal and family cars has been considered and by many automobile manufacturers. Ford Motor presented a concept car powered

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by PV in the exhibition in 2014 [1]. It used CPV (Concentrator Photovoltaic) technology to enhance the battery charge during parking. Toyota Motor started to sell a plug-in hybrid vehicle (PHV) with a 180 W solar panel made by Panasonic that expected to contribute as a part of the energy source for the car engine in 2016 [2]. This movement was observed in other car companies in 2016, including Fisker Karma[3], Hanergy[4], Sono Motors[5-6], and Stella Lux[7]. Nissan known as a major supplier of electric vehicle (EV) mentions the necessity of charging-free EV like solar EV to take off customer's pain of charging [8]. Now, PV is becoming recognized as one of the future energy sources to automobiles.

Toyota Motor experimented installing the PV panel on the car body and monitored the energy generation [8]. The measured data implied the possibility that the cars that run less than 30 km/day may rely on the solar energy without the necessity of the charging electricity and gas. This type of the car is about 70 % of the total. As a result, the suppression effect of the greenhouse gas emission may reach 8 % [9].

2.2. The new value in appearance

Another consideration we need is that the PV panel may be looked closely and carefully. Most of the car customers may hate the exotic appearance of the PV module and PV cells. Since the cars relying on the solar energy may prevail to 70 % of the total personal cars, it is hard to expect that customers accept the current PV modules as a car component. Ideally, the color of PV panel will be identical to the color of the car body. At the same time, any additional color hampers the light absorption by the solar cell, and thus hamper the energy conversion performance. The development of the color control technologies of PV modules with minimum suppression of the photovoltaic performance, but the realization of the fine color suitable to the car body, is vitally important. Recently, the color control technologies of photovoltaic modules show significant progress, including adding a print interlayer to the module [10], printing a ceramic layer on the front glass, using a front glass but adds a multilayered coating to generate the color [11], varying the thickness of the antireflection coating of the cell, thereby tuning the color [12], using multilayers on the cell [13], nanoparticles on the cell that give the cell a nice color [14], and inserting a foil with a uniform or graphical print [15-17]. Even the colored graphic can be added using back contact foil [18-20].

Needless to say, the shape of the car-roof is three-dimensionally curved. However, both the PV panel and solar cells are flat and rigid. It is not a good marketing strategy to change the shape of the car body to fit the standard PV panel, like a box consist of the flat plates.

Figure 1. Picture of the car-roof of Solar-Prius, a PHV product of Toyota Motor mounting 180 W of high-efficiency crystalline Si cells. Note that the area with significant curvature is not covered by the solar cells (like inside the yellow circle) [21]

Some commercial cars like Solar-Prius of Toyota Motor and products of Sono Motors place the crystalline Si solar cells on the curved surface. However, it does not entirely cover the curved surface. The area where the radius of curvature is small was not placed the solar cells (Figure 1). In case, they

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force to place the solar cells in the high curvature area; it will often be cracked in either the solar cell or the interconnects.

For coverage of the curved surface, a good candidate may be a flexible and thin-film PV module. It is relatively easy to cover the two-dimensionally curved surface like toroidal surface. However, it is difficult to cover the three-dimensionally curved surface like spherical surface.

Accepting some gaps will be necessary to cover three-dimensionally curved surface by solar cells or thin-film photovoltaic, a possible solution is a static concentrator module [9, 22-26].

2.3. High performance required to be an engine of the cars

The available solar energy is proportional to the area of the car-roof, and it is limited. For securing sufficient energy with a limited area, high efficiency will be required at first to the car-roof PV product (Figure 2). Roughly speaking, 30% of efficiency, 3 m^2 of available area for the PV on the car, and 1 kW performance are required to the car-roof PV.

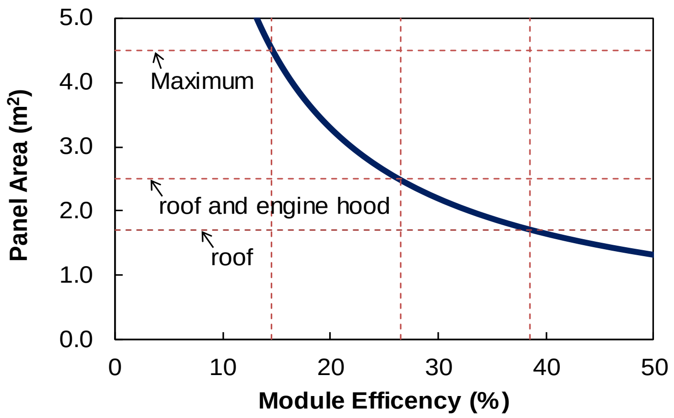

Figure 2. Calculated required power conversion efficiency of the PV system on the car-roof, assuming that EV or PHV runs 17 km per kW electricity. The solar irradiance was modeled in Nagoya, Japan, assuming that the shading objects appears in the range of 5° to 60° of the grazing angle (uniform distribution) [9].

Apparently, it is not an easy requirement of the solar cell in the current technology. 30% is above the theoretical limit of the most-common crystalline Si solar cells. The potential of the possible efficiency (standard testing condition) to various semiconductor materials like Silicon, III-V, CIS, CdTe, Organic, Dye-sensitized and Perovskite differs by the level of available crystal quality, point defects, dislocations, and interface recombination affects the potentials of the solar cell efficiency. Investigation of the efficiency potential of various types of the solar cells were done by interviewing experts of each category of the semiconductor materials used to the solar cells, including, Dr. Yamada, Dr. Katsumata, Prof. Ohshita, Prof. Yamamoto, Dr. Hayashi, Prof. Nakamura, Dr. Takamoto, Dr. Tanaka, Dr. Taguchi, Dr. Yata, Dr. Masuko, Mr. Hashiguchi, Dr. Sugimoto, Mr. Hiroi, Dr. Sai, and Dr. Matsubara about realistic limit of ERE (External radiation efficiency) considering the possibility of improving threading dislocation density and other crystal quality [27]. The result was summarized in Table 1.

It is important to note that most of the type of the solar cell has already reached to 90 % of the potential values by the efforts of scientists and engineers working for in each category. It is also true that only multijunction cells are possible to exceed the 30 % of the wall of efficiency. The problem is III-V multijunction cell is expensive and commonly used to high concentrator photovoltaic application. Development of the low-cost process is required.

Table 1. List of the potential efficiency of various types of the solar cells with contrast to the achieved (best in the laboratory) efficiency. Note that the requirement given by the car manufacturers was more than 30% of efficiency and only III-V multi-junction cells (shaded in yellow) satisfies this requirement [27].

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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 %	22.6 % (85 %)
CdTe	26.5 %	22.1 % (83 %)
Quantum Dot	25.8 %	13.4 % (52 %)
Perovskite	24.9 %	22.1 % (89 %)[2]

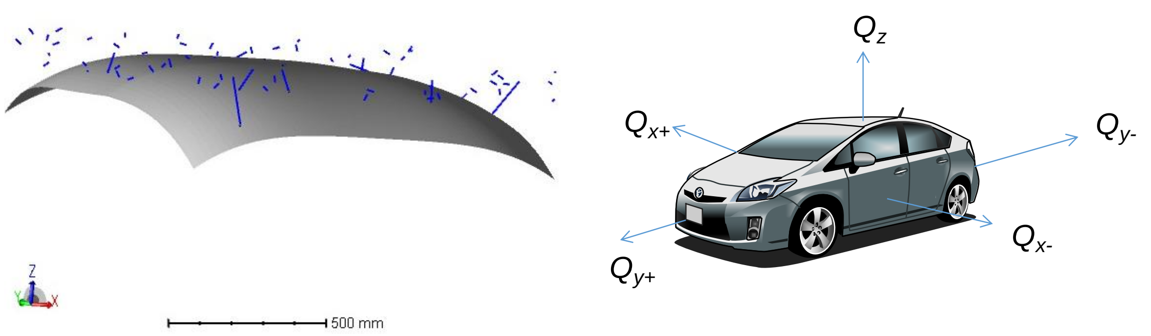
[1] Non-concentration (1 kW/m^2 irradiation onto the cell)

[2]Not a stabilized efficiency

2.4. The difference in performance modeling and characterization

Unlike the PV panels either on the roof of residential houses or ground installation, the PV panel for automobile installation has a 3-D curved surface like "Solar Prius PHV" of Toyota Motor started its sales in 2016. Currently, the typical interest of the car-owners of the car-roof PV is saving the number of times of the gas and electric charges. Therefore, the efficiency of the PV panel and the management of the solar energy onto the car-roof are not critical to the drivers. They will be satisfied if the PV panel fills the battery during parking. However, when the car mounts 1 kW PV car-roof PV panels, and the solar energy exclusively drives the cars, the efficiency rating and energy prediction will be critical.

For the modeling work and standardization of the energy generation of the car-roof PV, it is essential to define the meaningful and scientifically accurate method of the solar irradiance as well as its conversion to electricity on the 3-D curved surface of the car-roof PV. First, it is critical to recognize that the solar irradiation onto the car-roof and the car-body will be different from the one on the standard installations of the PV panels. In principle, the traditional PV panels are installed so that they avoid shadows from other structures. However, the car-roof PV modules are not orientated for utilization of the solar energy, and the driver's convenience often shades the panel. Second, the relative orientation of the PV panels on the car to the sun position is not fixed but frequently changes by driving. Third, the PV panels on the car body and the car roof are often three-dimensionally curved. It often shaded by its own curved surfaces. Therefore, the essential value of the product, namely the scale of performance needs to be reconstructed from the beginning (Figure 3).



(a) (b)

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Figure 3. Three-dimensional properties of the PV module and its irradiance: (**a**) Three-dimensional curved module with the distribution of the ray hit onto the module with randomly given illumination rays onto the surface. Long blue lines correspond that the three-dimensionally curved surface absorbs them. Note that some rays just above the module do not hit the module due to its curvature.; (**b**) Three-dimensional irradiance around the car-body. Qx+, Qx-, Qy+, Qy- and Qz are defined as the solar irradiance on five surfaces around the car. For the measurement, one pyranometer is set horizontal on the car roof (Qz), and four pyranometers are placed vertically at each side of the car (Qx+, Qx-, Qy+, Qy-). Note they are orthogonally placed but they are on the local coordinates.

2.5. The difference in the utilization of the solar energy

For accurate characterization of the solar irradiance, the current irradiance dataset based on the two-dimensional aperture area like sloped surface, horizontal surface, vertical surface, and direct normal irradiance, is not sufficient. Expanding to the three-dimensional sunshine irradiance is necessary (Figure 3) [28].

When the personal car relies on the solar energy, the energy administration will be crucial. It will be needed to combine map data, the image around the car (shading prediction), and irradiation forecast. The issue is the accurate prediction of the irradiation onto the car. The required prediction technologies will be different from the typical weather and solar-resource prediction technologies (Table 2).

Table 2. Comparison of the required solar resource prediction technology form conventional techniques.

	Meteorological	**Terrestrial PV**	**Car-roof PV**
Goal	Horizontal (2-D)	Sloped surface (2-D)	3-D→ local coordinates
Calculation Speed	1-hour order	1-minute order	0.1 seconds order
Climate	Cloudy/Sunny	Mainly sunny	Cloudy/Sunny
Algorithm	Ray-tracing	Parametric (incl. integration)	Look-up table Linear combination
Area	10 – 1000 km order	1 – 10 km order	10 m order

Considering the required efficiency, it is likely that the solar cells used to the car-roof photovoltaic module may be multi-junction cells (Table 1). It is well-known that the multi-junction cells are sensitive to the variation to the solar spectrum. Advanced and precise prediction of the solar spectrum at least considering a variation of the atmospheric parameters will be necessary [29].

2.6. Need for new standardization

The fact that the car-roof PV uses the three-dimensional solar resource by the three-dimensional curved photovoltaic module means that the standard rating and testing method may not lead to the appropriate values. The possible testing method has been discussed among experts including scientists and engineers in testing laboratories. Figure 3 indicates a possible method using a mixture light sources representing the diffused sunlight and the direct sunlight.

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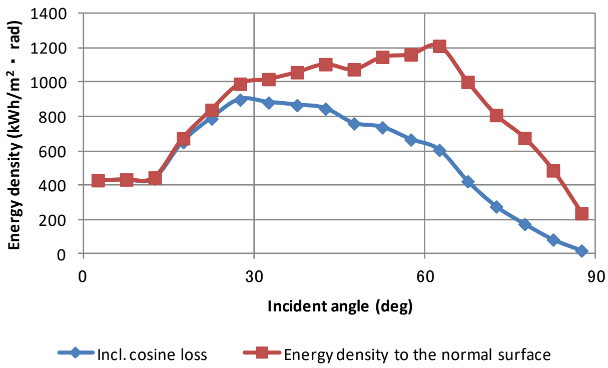
(a)



(b)

Figure 4. Possible testing method of the car-roof PV: (**a**) Configuration of the light sources for measurement of the car-roof PV with combinations of the diffused light plus collimated light; (**b**) Possible angular distribution of the artificial light source for the measurement of the car-roof PV. The intensity of the diffused light and the collimated light may be adjusted the total angular distribution on the reference surface identical to the distribution of (b) [22].

Traditionally, the car manufacturers test components in many aspects of the car-specific conditions. Some of them are not the tests commonly done in the PV panel. We are investigating the car-specific components test and relate to the PV tests. The most closed type of the components are car-electronics and exterior components. Table 3 summarizes the comparison between the car-electronics and the PV. Note there are some differences.

Table 3. Comparison of the testing conditions of the typical electronic components of the car.

Target	Test	JASOD001	JASOD902	Condition	PV
Transient voltage	Durability to transient voltage		X	Various waveform, 96 hours	X
	ESD	X		Using capacitor	
EMC	Electrical field	X		0.1 – 10 V	
	Magnetic field	X		5 – 100 V/m	
Temperature	Low T storage	X		-40 C 70 hours	
	Low T operation	X		-30 C, - 70 hours	
	High T storage	X		120 C 94 hours	X
	High T operation	X		100 C 118 hours	
	Heat cycle	X		-30 – 100 C, 30 cycles	X
	Heat shock		X	-30 – 120 C, 6 cycles	X
Humidity	Water dew	X			X
	Temperature/Humidity cycle	X		60 C - -10 C, 90 RH%	X
	High humidity	X			

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	High humidity operation	X		60 C 90 RH%, 94 hours	X
Vibration	Vibration test		X	JISD1601	X
Impact	Impact test	X		JISC0912	
Water	Water jet, wet insulation	X		JISD0203	X
Saltwater	Salt spray test	X		JISC5208	X
Dust	Dust test	X		JISD0207	X
Oil	Oil resistant test	X		JISK6301	X

2.7. Related technologies out of the car

When most of EVs run by the solar energy, a smart-control of the solar energy will be demanded (Figure 5) [29].

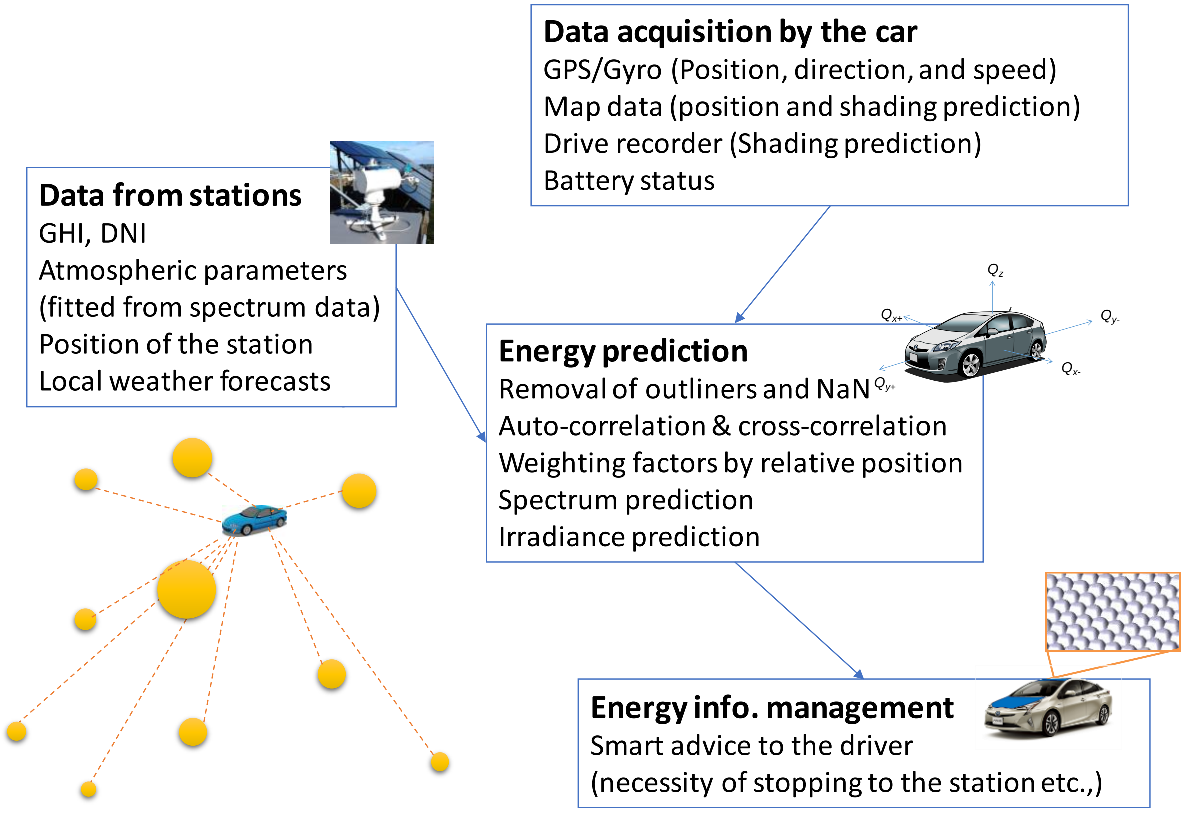

Figure 5. Smart control of the solar energy onto the car-roof [29].

To construct the energy administration system and related services, the core technology is precise modeling of the energy generation of the car-roof, including spectrum prediction. In addition to the hardware, infrastructure and system integration, precise but the high-speed calculation of the energy prediction in a short period that was discussed in the previous section and Table 2 will be critical.

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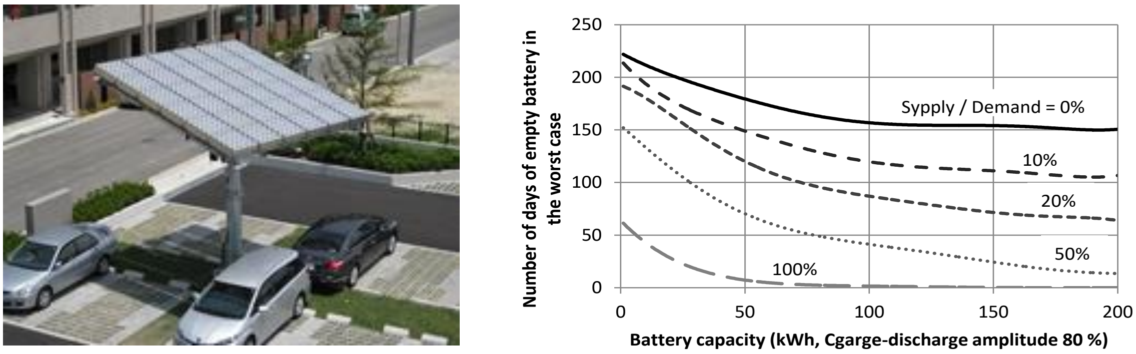
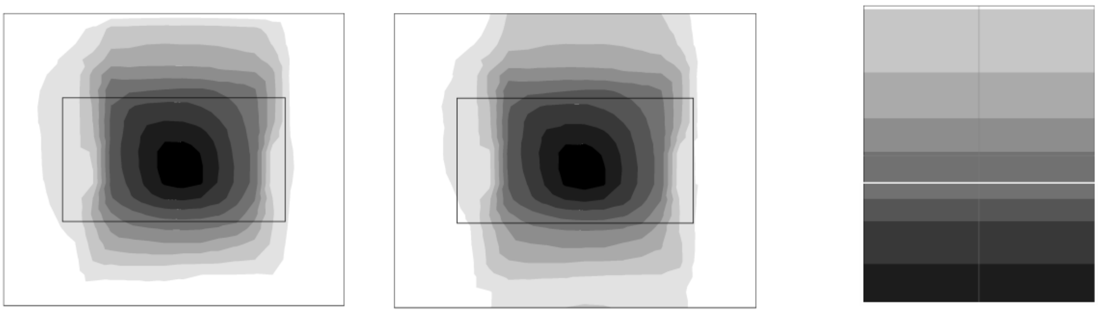


(a) (b)

Figure 6. Image of EV solar station using CPV 8Concentrator photovoltaic) and its performance simulation using a Monte Carlo method. (a) Picture of the test system installed in Mach of 2010, just on the date of the Great East Japan Earthquake. This system was removed by Daido Steel in 2015 [30].; (b) Estimated battery size per a station as a function of the ratio of the acceptance of surplus solar energy from the car. Note that the battery size is expected to be reasonable, in case the ratio of accepting the surplus energy increases by the smooth circulation of the solar energy from the car [31].

Depending on the driving patterns, there may be a possibility that the car-battery becomes full or empty. Then, circulation of the car-generated solar energy will be critical. One possibility is the infrastructure of the solar EV station that supplies electricity from pure solar energy and accepts surplus solar energy from the car (Figure 6). The operation of this system will be effective with the combination of the smart energy administration system (Figure 5). For optimum and economic system design, a Monte Carlo method will be effective [30-31].



(a) (b) (c)

Figure 7. Distribution of shadow on the ground by an array of several types of the photovoltaic panels. The dark area is the zone where annual illumination is low by shadow. White rectangular region corresponds to the panel positioned in horizontal stow position. (a) Illumination under the isolated tracking PV panel; (b) Illumination under the array of the tracking PV panel; (c) Illumination under the flat-plate sloped PV panels [32].

The duration of parking is longer than the driving for most of the personal cars. Collection of solar energy is as important as driving. The value of the shadow by the garage will vary. One possibility is that the garage roof may be tracking photovoltaic to collect the solar energy efficiently and simultaneously partially illuminate the car-roof by the sunlight from the edge of the moving panel (Figure 7). The prediction of the solar illumination under the panel was analyzed for the hybrid photovoltaic system for agriculture, but this approach can be applied to the garage design to the solar-driven EVs [32].

3.Discussion – impact to the entire PV technologies

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With the effort of developing technology to the car-roof irradiation prediction that is necessary to the car-energy management system, the severe challenge to the solar energy prediction of the 3-D and moving coordinates will improve the accuracy of the PV energy prediction, and thus leads to the establishment of the real-time market of the PV surplus energy.

Besides 3-D irradiation issues, the R&D of the car-roof PV technology has many other ripple effects. The massive new market and its impact on the society will have sufficient power to change the technology environment (Figure 8).

For example, the car-roof PV technology has many similarities to the ZEB (zero-emission building technologies). Many technological challenges on the car-roof PV will help to solve problems in the PV integration to the building. The power-conversion technology in the car will be useful to develop DC-side PV energy buffer. The realization of the real-time market backed by the precise energy nowcasting will create a new industry (ballast industry), mainly by the electric furnace industries for smoothing PV impact to the grid.

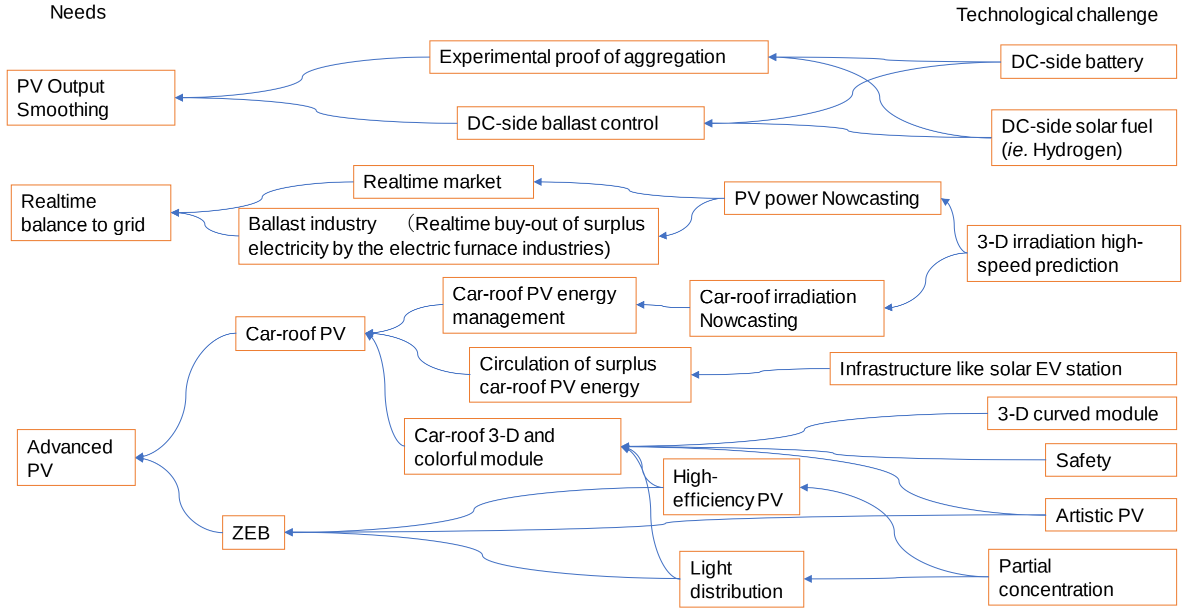

Figure 8. A scenario that the R&D on the car-roof PV impacts to the entire PV technologies.

4. Conclusion - List of todo

The todo list on technology aspect is simple. It is research and development that was clarified in the previous section. On the contrary, for standardization of the technology, we needed to discuss among scientists, engineers in manufactures, engineers in testing laboratories, and experts in related organizations. After recognition and clarification of the difference from the conventional PV technologies, the list of todo was discussed by a group of scientists and engineers (see the acknowledgment section for detailed information of the group).

3.1. Rating tests

The following questions need to be resolved before the performance evaluation.

3.1.1. Definition of the standard irradiation for testing the car-roof photovoltaic products

- Orientation/declination of the artificial collimated light mimicking the direct solar irradiation onto the car-roof.
- Is it sufficient to represent the direct beam of the sunlight by a single angle of the light? Do we need to prepare multiple collimated lights to represent various levels of the sun height?
- The standard value of the ratio of (the diffused sunlight) / (the direct sunlight).

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3.1.2. Definition of the standard irradiation

- Definition of the standard illumination, including spectrum, irradiance, the ratio of the collimated component to the diffused component, size of the light source relative to the photovoltaic module, and angular distribution.
- Size of the diffused source relative to the size of the car-roof PV. The diffused light source contains rays with low angle, and such rays may not be absorbed by the car-roof PV unless the size of the light source is large enough.
- Hight of the diffused source from the car-roof PV. Since the size of the diffused light source is finite, the distance from the light source affects the measurement conditions.
- Spotlights may be used as the collimated light source representing the direct component of the sunlight. The specification of the collimation is needed.
- Since the size of the spotlight is limited, and it is likely smaller than the car-roof panel area. Multiple spotlights may be necessary, but we need to decide the specifications and requirements of the spot-light array.
- It is likely that the car-roof photovoltaic may be the spectral-sensitive multi-junction solar cells. For reasonable spectral representation, a cocktail of multiple lamps will be necessary. The solar simulators using a cocktail lamp are already commercialized, but they need to be upgraded with additional control of diffused / direct ratio, and angular distribution.

3.1.3. Specification of the light source and the testing room

- The detailed procedure needs to be prepared.
- The color of the wall/floor/ceil of the testing room may affect the measurement. Considering that the car-roof PV product may have cosmetics of the controlled color coatings, it is crucial to quantify the influence of the color of the testing room. Note that the car-roof PV is used a relatively higher ratio of the diffused sunlight and that diffused light is affected by the color of the room through wall/floor/ceil reflection.
- Is car-fixture needed (same color)? Fixtures may save the problems of the color issues.

3.1.4. Misc

- The PV for the personal cars is not only loaded on the car-roof. How about the door, and engine hood? When this happens, can we apply the same testing conditions?
- The temperature of the standard testing condition (indoor) is 25 C. Is it an appropriate testing condition to the car-roof PV? Do we need to increase the temperature, for example, to 60C?
- Is the flexible PV tested before mounting or after mounting? The shape of the photovoltaic panel changes after mounting on the car. The panel shape affects the photovoltaic performance.

3.2. Design qualification

The following questions need to be resolved before the qualifying the design.

3.2.1. Environmental tests

- List of the testing item and its conditions. Preferably with pass / fail criteria.
- The necessity of car-specific tests, including weight, dimensions, aerodynamics, robustness to car-wash, etc.,

3.2.2. Requirement to qualification

- Definition of the minimum requirement and its background
- Label, specification sheet, and its required item list
- Retest guideline, namely when the car-roof PV does the minor design change to fit the new or customized car design, what kind of the retest item needs to be required to keep qualification recognition?
- Range of resembles as the criteria for the necessity of retests.
- Who is the testing certification body? Are they controlled by IECEE (IEC System of Conformity Assessment Schemes for Electrotechnical Equipment and Components)?

3.2.2. Misc

- List and definition of terms.
- Specification of the car-interface like cables and connectors.

3.3. Power modeling

The following points are todo list for development of power-generation modeling of the car-roof PV. Note that there are opinions that this issue is out of the standardization.

3.3.1. Modeling work

- **Simplified parameter (Curve correction)**: Full 3-D parameters may not be intuitive and thus difficult to understand to most of the engineers working for photovoltaic accustomed to 2-D parameters. A kind of a correction factor, for example, a curve correction coefficient will be helpful. This parameter should be identical to the curve shape.
- **Modeling by rigorous calculation**: For the development of the solid modeling, parameter measurement and representation to the standard operating conditions, some approximation will be necessary. To validate the approximated approach, rigorous modeling should be once established as a benchmark of the research and development.
- **Interaction to the string orientation**: Both output current and output power of the curved car-roof PV will not be proportional to the absorbed irradiance even though it is connected to the three-dimensional curve. The mismatching loss among string that is not significant in conventional photovoltaic module unless it is partially shaded will be significant to the car-roof PV. Inherently it will make a variation of the cosine loss and self-shaded loss that enhance the mismatching loss among strings. The mismatching loss varies by the orientation of the string relative to the sun orientation.
- **Unit element vs. Shape calculation**: Related to above item, a direct extension from 2-D modeling that has been used to the conventional PV is that the three-dimensionally curved surface is divided into many small unit elements, conduct standard calculation, and then compute from a surface integral. It is important to compare any curve-correction factors by this approach.
- **Curve-shape representation (for example, 90% angle)**: A 3-D CAD file may provide the three-dimensional curve profile of the car-roof. Thanks to the development of the CAD/CAE technologies, it is not very difficult to do geometrical calculation directly from the CAD file. However, this procedure often concedes the apparent problems because the geometrical information often concealed in the Blackbox. An intuitive and practical parameter will be helpful for understanding what is going on in the geometrical and modeling calculation.
- **Outdoor measurement validation**: It should be done by multiple modes of operation, like various levels of latitude, climates shading (like rural or urban area).

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- **Definition of the light-source model**: For the development of the testing procedure discussed in the above section, the development of the light source modeling will be necessary.

3.3.2. Parameter measurement for modeling

- **AOI (Angle of incidence) measurement**: Since the car-roof PV collects the three-dimensional sunlight, especially the rays from a high incident angle, AOI measurement will be crucial. Different from the conventional PV panels, the AOI characteristics is not axially symmetrical. It is not uniform at the position of the panel, because the curvature varies, and the self-shading effect varies by the position of the car-roof panels.
- Standard solar irradiation condition onto the car-roof
- **PV fine color**: It is likely that the advanced coating technology decorates the car-roof PV and show a variety of the colors like car-body paint. Impact of the color variation needs to be intensively studied. The impact factor of the color should be defined in both physical background and detailed measurement procedure.

3.4. Energy prediction

The following points are todo list for development of energy prediction of the car-roof PV. Note that there are opinions that this issue is out of the standardization.

3.4.1. kWh/kW, km/kW issue

The most representative scale of the merit of the car-roof PV to users will be the ability of the running distance of the car with given performance, possibly rated by the nominal power of the photovoltaic module. The running distance is the function of the car energy efficiency, and thus electrical energy per rated power, namely kWh/kW may be alternative scale for the car-roof PV performance. The kWh/kW is primally a function of "effective solar irradiance" and may not identical to the irradiance conventionally used to PV community.

- **Difference between GHI and car-roof PV**: Possibly, the closest scale of the normal solar irradiance may be GHI (Global Horizontal Irradiance). The quickest way is to clarify the difference from GHI both by modeling and measurement.
- **Power modeling vs. climate**: Clarification of the quantitative difference of the power output influenced by climate and other meteorological conditions. Note that the generation in cloudy and rainy days will be equally crucial to the car-roof PV, unlike the conventional PV for utility.
- **3-D solar modeling**: Car-roof PV tries to collect solar energy not only from the normal directions. The module itself is three-dimensionally curved. Modeling the solar irradiation by 3-D may be convenient.

3.4.2. Energy nowcasting

Note that the item differs by the general system design. The most straightforward system may be the anticipation of the most-likely energy generation from the information of the energy generated from the surrounding cars trough inter-cars communication. If the prediction by this method is accurate and robust enough, it is not necessary to collect irradiance information.

- High-speed calculation algorithm
- Link to the drive recorder image (dynamic shading)
- The requirement to the dataset (item etc.)
- Map integration

3.4.3. Standard smart administration

Again, it depends on the system design.

- Standard data format
- Standard procedure (using satellite?)

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