Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

Area #1: Wafer-based c-Si solar cells

**Title**
Toward easy industrialized, high-efficient c-Si solar cells with poly-Si passivating contacts

**Daily Supervisor(s)**
Ir. Can Han (C.Han-1@tudelft.nl), Dr. Guangtao Yang (g.yang@tudelft.nl)

Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Supervisor**

**Short description**
Nowadays PERx cell technologies are becoming one of the main industrialized technologies in the PV market. But there are still factors that limit the cell performances. Compared to the Al BSF cell, the contact recombination losses in PERx cells dramatically decrease. However, it can still be minimized by using the carrier selective passivating contact concepts: for example, the silicon hetero-junction technology, the TOPCon (poly-Si passivating contact) technology, et al.

Looking at the industry PERx process technologies, the poly-Si technology becomes one of the most promising one that can be easily deployed into the cell process flow. Therefore, we propose this poly-Si/poly-Si FBC project to study the feasibility and potential of this technology.

Within the PVMD group we have developed excellent poly-Si passivating contact layers, which have already been demonstrated to be perfect contact layers for high-efficiency solar cells. The main challenges are (1) demonstrate high FF, and (2) high Voc, or low contact losses in the solar cells. During the project, TCO layers (ITO, ZnO:Al. et al.) will be developed for contacting different polarized poly-Si materials (n-type or p-type doped), including exploration on various deposition conditions and post-treatments. Different interfacial layers (a-Si:H, SiC:H, et al.) between poly-Si and TCO layers will be tested to minimize the barrier at the interfaces, mainly including continuously decreasing corresponding contact resistivity values, as well as the fundamental analysis on the optimization process. Besides, optical properties of TCOs will also be considered to minimize the reflective and parasitical absorptive losses.

All the materials development and solar cell fabrication will be done in the cleanroom.

**Available from**
March 2020

**Type**
Experimental

**Internal/External**
Internal
### Title
>25% IBC solar cells with ion-implanted poly-Si passivating contacts

### Daily Supervisor(s)
Dr. Guangtao Yang (g.yang@tudelft.nl)

### Supervisor
Dr. Olindo Isabella (o.isabella@tudelft.nl)

### Short description
c-Si solar cells based on the poly-Si Tunnel Oxide Passivating Contact (TOPCon) is becoming one of the most promising solar cell structures that enable both high efficiency and low cost. The record efficiency for the front-rear contacted cell with TOPCon structure is 25.1%. By moving both metal contacts to the back side, the so called interdigitated back-contact (IBC) approach, the solar cell efficiency can be improved significantly due to the absence of optical shading from the front metal-contact. The objective of this project is to improve the IBC solar cell efficiency based on the standard TOP-IBC solar cell process flow developed at PVMD group, which was demonstrated with 23% efficiency solar cells. The main challenge is to (1) minimized the difference between the SunsVoc and Voc of the cell for improving the cell Voc; (2) increase the cell FF by decreasing the series resistance of the solar cell, which can be achieved by (a) minimizing the metal resistance by Cu-plating, (b) increase the mobility of poly-Si materials by hydrogenation; (3) further improve the passivation of the front side of the cell. (4) solar cell characterization for the losses analysis. This thesis project will cover the materials study, solar cell devices fabrication and characterization. During the project, MEMS processes like photo-lithography, thin-film materials deposition and characterizations will be used frequently. All the materials development and solar cell fabrication will be done in the cleanroom.

### Available from
Nov. 2020

### Type
Experimental

### Internal/External
Internal

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### Title
High energy yield Bifacial-IBC solar cells enabled by poly-Si carrier selective passivating contacts

### Daily Supervisor(s)
Dr. Guangtao Yang (g.yang@tudelft.nl)

### Supervisor
Dr. Olindo Isabella (o.isabella@tudelft.nl)

### Short description
c-Si solar cells based on the poly-Si Tunnel Oxide Passivating Contact (TOPCon) is becoming one of the most promising solar cell structures that enable both high efficiency and low cost. The record efficiency for the front-rear contacted cell with TOPCon structure is 25.1%. By moving both metal contacts to the back side, the so called interdigitated back-contact (IBC) approach, the solar cell efficiency can be improved significantly due to the absence of optical shading from the front metal-contact. The objective of this project is to improve the IBC solar cell efficiency based on the standard TOP-IBC solar cell process flow developed at PVMD group, which was demonstrated with 23% efficiency solar cells. The main challenge is to (1) minimized the difference between the SunsVoc and Voc of the cell for improving the cell Voc; (2) increase the cell FF by decreasing the series resistance of the solar cell, which can be achieved by (a) minimizing the metal resistance by Cu-plating, (b) increase the mobility of poly-Si materials by hydrogenation; (3) further improve the passivation of the front side of the cell. (4) solar cell characterization for the losses analysis. This thesis project will cover the materials study, solar cell devices fabrication and characterization. During the project, MEMS processes like photo-lithography, thin-film materials deposition and characterizations will be used frequently. All the materials development and solar cell fabrication will be done in the cleanroom.

### Available from
Nov. 2020

### Type
Experimental

### Internal/External
Internal
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

**Updated list – 5th of June 2020**

<table>
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<th>Title</th>
<th>Theoretical evaluation and experimental demonstration of poly-Si/SHJ hybrid tunnel-IBC c-Si solar cells</th>
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<tr>
<td>Daily Supervisor(s)</td>
<td>Dr. Guangtao Yang (<a href="mailto:g.yang@tudelft.nl">g.yang@tudelft.nl</a>) Ir. Yifeng Zhao (<a href="mailto:Y.Zhao-4@tudelft.nl">Y.Zhao-4@tudelft.nl</a>)</td>
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<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
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<td>Short description</td>
<td>IBC solar cell architecture, combined with carrier-selective passivating contacts (CSPCs), yields the highest conversion efficiency in c-Si technology. Examples are IBC cells with silicon heterojunction (SHJ) or poly-Si alloy (POLO-junction and TOPCon) CSPCs. Despite high efficiencies, both IBC technologies are expensive, due to the complex process flows for patterning the rear CPSCs fingers, the transparent conductive oxide (TCO) in case of SHJ, and the metal fingers. For a simple and cost-effective process in case of poly-Si IBC cells, localized ion-implantation is used to induce different doping polarities for CSPCs, which is now used in the PV industry. In case of SHJ IBC cells, an effective tunnel-IBC concept for patterning the SHJ contacts has been recently introduced, which minimizes the patterning and alignment steps and uses screen printed Ag fingers as mask for ZnO:Al (AZO) wet patterning. In this project, we propose an alternative hybrid tunnel-IBC architecture, that combines heavily-doped poly-Si and SHJ CSPCs. That is, we pattern the rear n+ (p+) poly-Si fingers and coat the whole area with SHJ (i) a-Si:H/(p) nc-SiOx:H (or i/n) contacts. TCAD simulation based theoretical evaluation will be conducted and experimental solar cells will be demonstrated with simple process flows. The research questions will be the influence of the IBC cell performances from (1) the influence of SHJ material properties; (2) the gap size between the metal fingers; (3) the doped amorphous or nano-crystalline layer in the gap area. During the project, MEMS processes like photo-lithography, thin-film materials deposition and characterizations will be used frequently. All the materials development and solar cell fabrication will be done in the cleanroom.</td>
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<table>
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<th>Title</th>
<th>Novel doping free carrier selective contacts on tunnelling oxides for c-Si solar cells</th>
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<tr>
<td>Daily Supervisor(s)</td>
<td>Dr. Guangtao Yang (<a href="mailto:g.yang@tudelft.nl">g.yang@tudelft.nl</a>), Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
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<td>Supervisor</td>
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<tr>
<td>Short description</td>
<td>Recently, the novel carrier selective contacts (CSC) based on metal oxides, for example, MoO3, V2O5, TiO2, ZnO, In2O3; and metal fluoride, for example, MgF2, LiF are used to passivating and contacting the c-Si for high efficient solar cells. The advantage of these CSCs is their high transparency compared to the a-Si:H based passivating contacts. Such CSCs are normally structured in two ways: (1) metal-oxide/a-Si:H (passivation layer)/c-Si bulk, and (2) metal-oxide/SiO2 (~1.5 nm, passivation layer)/c-Si bulk. For both approaches, the mechanism of carrier selectivity is the same: the work function mismatch induced high level band bending at the interfaces. With approach (1) the passivation is obtained due to the a-Si:H inter layer, however, a-Si:H layer is still absorptive, which induces high optical absorption losses and hinders the advantages of such CSCs. In approach (2), due to the non-absorptive SiO2, there will be no parasitic absorption in the CSCs, which will enhance the light absorption in the bulk to the maximum point. On the other hand, this approach is much more industry friendly, as compared to the a-Si:H layer, the SiO2 is much easier to prepare and process. The preparation of such CSC layers are normally prepared via Physical Vapour Deposition (PVD), e.g. thermal evaporation; or Atomic Layer Deposition (ALD). Both techniques will be used in this project. The main challenge/focus of this project are: (i) further optimization of hole selective (mainly</td>
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</table>
V2O5 on SiOx) and electron selective (TiO2 on SiOx) materials for passivating the c-Si surface, which offers high passivation properties and carrier selectivity; (ii) the application of such CSCs in front/back contacted (FBC) solar cells. The scientific questions will be (1) the material properties and their influences on the carrier selectivity, and (2) the cell structure (for example, the contact area, et al.) on the cell performance.

All the materials development and solar cell fabrication will be done in the EKL and Kavli cleanroom.

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**Title**

Copper-plated metallization on bifacial poly-Si solar cells

**Daily Supervisor(s)**

Can Han (C.Han-1@tudelft.nl)

**Supervisor**

Dr. Olindo Isabella (o.isabella@tudelft.nl)

The most common industrial process for producing solar cells features screen-printed contacts. However, this process suffers from low aspect ratio, high metal finger resistivity and contact resistance, excessive shading and high price of silver. Copper-plating has proven to be an effective approach to tackle the above mentioned issues, in which PVMD group has cumulative experiences in past years. Nevertheless, bifacial applications has not been investigated yet, among which bifacial poly-Si solar cell represents promising potential in both academic and industrial aspects due to its improved energy yield (i.e. both sides light exposure).

The aim of this project is to study how to further improve the metallization performance at device level within PVMD group, bifacial poly-Si solar cell application will be firstly applied. The first part is investigation regarding obtaining lower finger resistivity with higher aspect ratio compared to screen-printed Ag and current electroplated Cu within PVMD group. While the second part of the project will be focused on the bifacial poly-Si solar cell application using the previously optimized results. Challenges include poor finger adhesion, adjustment of contact resistivity, unwanted rear metal in bifacial attempt. Possible solutions needs to be investigated, including seed layer variation based on our previously explored evaporated Ti and Ag (passivation quality of cell precursors is to be taken into consideration), various pre-deposition plating/post-deposition annealing treatments, protection approaches on rear side such as applying bias voltage or photoresist layer, etc.

All the materials development and solar cell fabrication will be done in the cleanroom and MEMS lab.

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</table>
Copper-plated metallization on interdigitated back-contact (IBC) poly-Si solar cells

Can Han (C.Han-1@tudelft.nl), Dr. Guangtao Yang (G.Yang@tudelft.nl)
Dr. Olindo Isabella (o.isabella@tudelft.nl)

Photovoltaic industry is driven by high power conversion efficiency with low cost. Crystalline silicon solar cells featuring carrier-selective passivating contacts have demonstrated viable novel cell concepts with efficiencies well above 25%, approaching the theoretical limit of 29.4%. Interdigitated back-contact (IBC) architecture avoids metal grid shadowing on the illuminated side thus enabling a higher efficiency potential. Standard fire-through Ag/Al pastes have been used in IBC cell, but the firing of the paste can lead to large contact area between the metal and the silicon, resulting in limited open-circuit voltages due to the high contact recombination losses at the contacts. Another option is PVD aluminium metallization (such as sputtering), however, thick PVD metal could lead to increased bowing and also breakage of wafers. Cu-plating has been successfully industrialized by SunPower for large-area IBC cells. Nevertheless, it faces issues mainly regarding seed layer choice/optimization, especially for IBC poly-Si solar cells in which the passivation quality is quite sensitive to electrode fabrication procedures. Little research has been focused on it.

A Cu-plating process requires a suitable seed layer stack that satisfies the following requirements: (i) good ohmic contact to both p'- and n'-doped silicon regions, (ii) high rear-surface reflection, (iii) a barrier for Cu diffusion into the Si, (iv) a suitable layer on top to enable subsequent plating, and (v) little or eliminable damage to the underlying passivation layer and silicon substrate. The aim of this project is to explore the required seed layer (stacks) and optimize our IBC poly-Si solar cells.

All the materials development and solar cell fabrication will be done in the cleanroom and MEMS lab.

Optimizations of high-efficiency silicon heterojunction solar cell for tandem solar cells

Ir. Yifeng Zhao, Dr. Luana Mazzarella (Y.Zhao-4@tudelft.nl, L.Mazzarella@tudelft.nl)
Dr. Olindo Isabella (o.isabella@tudelft.nl)

Silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies which achieves the record efficiency of 26.7% for single-junction c-Si. However, the spectral mismatch between the absorption characteristics of c-Si and the solar spectrum limits the conversion efficiency of the single-junction c-Si cell. To better utilize the solar spectrum, a high bandgap perovskite cell is stacked on top of the c-Si cell and demonstrates a record efficiency of 29.15%. Therefore, to eventually deliver highly efficient perovskite/c-Si tandem solar cells, the optimization of the bottom c-Si cell for the tandem application is critical.

Currently, within PVMD group we have developed contact stacks based on hydrogenated nanocrystalline silicon oxide (nc-SiO₂:H) for front/back-contacted (FBC) SHJ solar cells which enable ISFH-CalTec certified efficiency of 22.5% and fill factor (FF) well-above 80%. For tandem application, we need to further optimize those contacts.

The research questions of this project are:
1) investigate the growth mechanism of doped nc-SiO\textsubscript{2}:H and nc-Si:H on substrates with different morphologies (planar and textured);
2) optimize the optoelectrical properties of the doped layers;
3) optimize the passivation quality;
4) cooperate with JSPIII project partners for tandem solar cell fabrication and measurements.

During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, raman spectroscopy, reflection and transmission, J-V, EQE, SunsVOC, lifetime).

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**Title**

\texttt{>24\% interdigitated-back-contacted silicon heterojunction solar cell featuring novel nanocrystalline silicon oxide passivating contact stacks}

**Daily Supervisor(s)**

Ir. Yifeng Zhao, Dr. Guangtao Yang (Y.Zhao-4@tudelft.nl, G.Yang@tudelft.nl)

**Supervisor**

Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Short description**

Currently, silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies thanks to the outstanding passivation quality from the a-Si:H that enables excellent $V_{oc}$ of the cell. Together with interdigitated-back-contacted (IBC) architecture, it enables the highest efficient, 26.7\%, single junction c-Si solar cell. However, the use of traditional doped a-Si as carrier-selective-contacts (CSCs) at the illumination side induces high parasitic absorption, eventually the loss of $J_{sc}$. In this project, the novel mixed phase material, hydrogenated nanocrystalline silicon oxide (nc-SiO\textsubscript{2}:H), which features high transparency and high conductivity simultaneously is implemented. Due to the complexity of patterning IBC cells, we have optimized front-and/back contacted (FBC) cells as proof of concepts for IBC cells. Within PVMD group, we have developed contact stacks based on nc-SiO\textsubscript{2}:H for FBC-SHJ solar cells which enable ISFH-CalTec certified efficiency of 22.5\% and fill factor (FF) well-above 80\%, and it keeps showing potentials for further improvements.

The research questions of this project are:

1) process optimizations of the IBC-SHJ solar cells;
2) optimize the doped layers from optimized FBC-SHJ cells for efficient charge-carrier selective transport;
3) compare the difference between doped a-Si and doped nc-SiO\textsubscript{2}:H for cell performance;
4) cooperate with JSPIII project partners for tandem solar cell fabrication and measurements.

During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. Beside, photolithography will be frequently utilized to pattern the doped layers. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, raman spectroscopy, reflection and transmission, J-V, EQE, SunsVOC, lifetime).
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**Title**: Fabrication of high efficiency poly-SiOx passivated c-Si solar cells

**Daily Supervisor(s)**: Manvika Singh ([M.Singh-1@tudelft.nl](mailto:M.Singh-1@tudelft.nl)), Paul Procel ([p.a.procelmoya@tudelft.nl](mailto:p.a.procelmoya@tudelft.nl)), Guangtao Yang, Luana Mazzarella

**Supervisor**: Dr. Olindo Isabella ([o.isabella@tudelft.nl](mailto:o.isabella@tudelft.nl))

**Short description**: Poly-Si as a carrier-selective contact is now a hot research topic due to the fact that this novel carrier-selective passivating contact layer shows low recombination current, which enables high-efficiency solar cells. However, poly-Si is quite absorptive in the form of free carrier absorption. In this project, the poly-Si material will be alloyed with oxygen to form poly-SiOx material, which is more transparent than poly-Si material, therefore a higher short circuit current is expected. Currently, research on poly-SiOx passivating contacts has been limited to double side flat or single side textured wafers with tunnelling oxide made from NAOS solution. The novelty of this project is that the student will be the first one to fabricate solar cells with poly-SiOx passivating contact on single side and double side textured wafers with tunnelling thermal oxide. The aim of this project is to:

1. Optimize the passivation quality of poly-SiOx passivating contacts, especially the p-type doped material on textured and flat surfaces.
2. Study the effect of different tunnelling oxides such as thermal oxide, NAOS and plasma oxide on solar cells’ performance.
3. Optimize screen printing for metallization.
4. Design and prepare high efficiency front back contacted (FBC) solar cells with poly-SiOx passivating contacts on single side and double side textured wafers.

All the materials development and solar cell fabrication will be done in the cleanroom.

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**Title**: Proof-of-concept of transparEnt PassIvated Contacts (EPIC)

**Daily Supervisor(s)**: Paul Procel ([p.a.procelmoya@tudelft.nl](mailto:p.a.procelmoya@tudelft.nl)), Guangtao Yang, Luana Mazzarella

**Supervisor**: Dr. Olindo Isabella ([o.isabella@tudelft.nl](mailto:o.isabella@tudelft.nl))

**Short description**: The application of carrier selective contacts (CSC) on crystalline silicon solar cells has markedly pushed the power conversion efficiency to almost theoretical limits. However, CSC commonly entails the use of highly doped layers at the cost of parasitic absorption. In this project, we will use state-of-art passivation layers combined with industry appealing processes to form the junction. Then, we will use a transparent conductive oxide layer as electrode and selective layers avoiding to deposit any highly doped layer (ITO, IFO or AZO). This will result in a proof-of-concept of highly transparent CSC. To do so, CSC for each polarity will be tested in terms of passivation at different process stages and also contact resistance. Finally, the CSC will be implemented and evaluated in solar cell devices.

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**Title** | High efficient IBC c-Si based solar cells with poly-Si(C\textsubscript{x}) passivating contacts
---|---
**Daily Supervisor(s)** | Dr. Luana Mazzarella ([l.mazzarella@tudelft.nl](mailto:l.mazzarella@tudelft.nl))
**Supervisor** | Dr. Olindo Isabella ([o.isabella@tudelft.nl](mailto:o.isabella@tudelft.nl))
**Short description** | Carrier passivating contacts consists in an ultra-thin silicon oxide layer capped with doped polysilicon layers. This device concept showed very low recombination current with remarkable efficiency of 25.8%.

The aim of this project is to:

1. optimize at material level poly-Si passivating contacts alloyed with carbon (poly-SiCx) via PECVD to improve the doping concentration (gas flows, multilayer approach)
2. investigate and optimize the interplay of annealing temperature, hydrogenation and doping on the passivation quality of PECVD-deposited poly-SiCx layers on textured c-Si substrates
3. Design, optimization and development of flow charts to implement poli-SiCx passivating contacts at solar cell level interdigitated back contact (IBC) solar cells.

During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), Low-pressure chemical vapour deposition (LPCVD), magnetron sputtering, metal evaporation, silver screen printing. Photolithography processes will be frequently used to pattern the doped. The project involves the entire fabrication process from thin-film deposition to solar cells characterization. Advanced characterization setups (spectral ellipsometry, raman spectroscopy, reflection and transmission, J-V, EQE, SunsVOC, lifetime) will be used.

**Available from:** From June 2020
**Type:** Experimental
**Internal/external:** Internal
Area #2: Thin-film solar cells

**Title**  
High deposition rate for nc-Si for flexible, thin film, solar cells

**Daily Supervisor(s)**  
Dr. Gianluca Limodio (g.limodio@tudelft.nl)

**Supervisor**  
Prof. Dr. Arno Smets (a.h.m.smets@tudelft.nl)

**Description**  
In order to ensure high-throughput of flexible, thin-film solar cells in a high-volume production, it is important that nano-crystalline silicon is deposited faster than lab-scale products. For this reason, together with HyEt Solar B.V., our group develops high deposition rate nc-Si. This layer will be embedded in the tandem structure together with top a-Si cell. The novelty of this process is that the substrate is Aluminium kitchen foil, so plasma conditions and parameters are very different than conventional glass substrates. The tasks will be mainly to i) understanding and investigating the limits of high deposition rate for material composition of nc-Si, ii) developing a deposition technique with a rate of ~1 nm/s, iii) embed this layer in a single junction solar cell, iv) embed this layer in a micromorph tandem solar cell and eventually v) industrial testing of this technique.

**Available from**  
June 2020

**Type**  
Experimental

**Internal/External**  
Internal/External

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**Title**  
Optimization and development of sustainable thin-film, flexible PV modules

**Daily Supervisor(s)**  
Dr. Gianluca Limodio (g.limodio@tudelft.nl)

**Supervisor**  
Prof. Dr. Arno Smets (a.h.m.smets@tudelft.nl)

**Description**  
Recently, thin-film, flexible PV modules have been applied in different scenarios (BIPV, desert high-scale utility, all possible applications with minimal balance-of-system cost). These thin-film, silicon-based, flexible PV modules are currently encapsulated in a plastic foil. An important challenge right now is the possibility of recycling/reusing waste materials/PV modules at end-of-life. However, an optimization of these modules is an important step towards full sustainability together with appropriate recycling methods that should be capable of empowering the re-use of such products. Therefore, these modules produced by HyEt solar B.V. will not end up in a landfill at the end of their lives. So, the project will mainly deal with three aspects; i) optimization of front/rear encapsulant foils, ii) recycling of all the PV modules components, iii) development of new materials for sustainable high-scale production.
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

**Updated list – 5th of June 2020**

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<td>Short description</td>
<td>This project deals with the fabrication of micromorph tandem solar cells on flexible substrates. The main objective is to reach ~12% efficiency in solar cell. To achieve this record, it is important to investigate the solar cell structure, deposition properties and understanding how every single layer has an impact on the solar cells parameters. The main research/investigation will be to: i) develop an efficient tunnel recombination junction, ii) minimize the Stable-Wronski effect of top cell through adjustment of the matching conditions, iii) finish the processing at HyEt solar B.V., iv) industrial testing of these deposition techniques.</td>
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<td>Short description</td>
<td>This project deals with the opto-electrical modelling of a perovskite/a-Si tandem solar cell on a flexible substrate. In a close collaboration with HyET Solar, we work to define key parameters to achieve high efficiency in this type of device that will be produced at HyET. You will employ Advanced Semiconductor Analysis (ASA) software to implement the modelling and predict the efficiency for a thin-film, flexible device. Your main tasks will be: i) implement the perovskite modelling together with a-Si in the HyET product, ii) deep investigation of key opto-electrical parameters for a realistic modelling of this device and iii) make a realistic efficiency prediction.</td>
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<td>Available from</td>
<td>June 2020</td>
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<tr>
<td>Type</td>
<td>Modelling</td>
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<td>Internal/External</td>
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<table>
<thead>
<tr>
<th>Title</th>
<th>Development of perovskite absorber layers via thermal evaporation for monolithic tandem application</th>
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</thead>
<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Dr. Luana Mazzarella (<a href="mailto:l.mazzarella@tudelft.nl">l.mazzarella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>Recently metal halide perovskites materials demonstrated record efficiencies over 20%. Semi-transparent perovskite cells are of great interest in the PV community to overcome the theoretical predicted limit for c-Si solar cells. Perovskite top cells can be combined in a tandem configuration with c-Si bottom cells with efficiencies above 29%. The aim of this project is to develop perovskite absorber layers via thermal evaporations for</td>
</tr>
</tbody>
</table>
single junction perovskite solar cells application.
The research activity will focus on:

- Growth of uniform, conformal and large area films onto different substrates
- Optimize and control the structural, optical and electrical properties of perovskite layers
- Investigate and optimize the interplay of deposition parameters and post-deposition annealing treatment on perovskite properties/composition
- Characterize the microstructure, composition and opto-electrical properties of developed material with advanced characterization techniques (XRD, XPS, SEM, UV/Vis/NIR absorption spectrometers etc.).

The activity will be in collaboration with the department of chemical engineering (TNW).

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<th>Available from</th>
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<td>from June 2020</td>
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<table>
<thead>
<tr>
<th>Title</th>
<th>Thermal evaporated transport layers for semi-transparent perovskite solar cells</th>
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<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Dr. Luana Mazzarella (<a href="mailto:l.mazzarella@tudelft.nl">l.mazzarella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
</tr>
</tbody>
</table>
| Short description                          | Recently metal halide perovskites materials demonstrated record efficiencies over 20%. Semi-transparent perovskite cells are of great interest in the PV community to overcome the theoretical predicted limit for c-Si solar cells. Perovskite top cells can be combined in a tandem configuration with c-Si bottom cells with efficiencies above 29%. This project focuses on the development of transport layers for application in all-evaporated perovskite solar cells. In particular, the activity involves:
- development of hole- and electron- selective layers via thermal evaporation optimizing deposition processes and material properties.
- Particular attention will be paid to the optical and electrical properties of the deposited material and their integration on device level.
- Integration of those layers in device with perovskite absorber. |
| Available from                             | from June 2020                                                                 |
| Type                                       | Experimental                                                                 |
| Internal/External                          | Internal                                                                      |

<table>
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<tr>
<th>Title</th>
<th>Development of a novel low bandgap material based on a-GeSn:H</th>
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<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Thierry de Vrijer (<a href="mailto:t.devrijer@tudelft.nl">t.devrijer@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Arno Smets (<a href="mailto:a.h.m.smets@tudelft.nl">a.h.m.smets@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>Be the first to process this new material! An innovative approach in the DISCO project is that the solar spectrum (0.67-1.12 V) below the silicon band gap will be used as well, which will give an additional 0.2-0.4 V to achieve ground breaking STF conversion efficiencies and high control of the product selectivity. A low band gap thin-film PV junction based on a-GeSn:H using plasma enhanced chemical vapour deposition (PECVD) will be developed. A great advantage of such a bottom cell is that it will never be current limiting, in a device with 3-5 junctions, since a sufficient number of photons are present in the infrared spectral part (0.67-1.12 V) to generate an additional 20 mAcm-2. The bottom junction will also not limit the FF of the total PV component due to this abundance of current density available in the bottom cell. This allows the a-GeSn:H material to have a higher defect density in reference to the other junctions. The research objective of this project is to be the first to develop the a-GeSn:H absorber material.</td>
</tr>
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</table>
The project will consist of an investigation of deposition parameters and their influence on the material properties. A range of the most promising absorbers will be used in a pin superstrate solar cell, to investigate the influence of the absorber on the device characteristics.

<table>
<thead>
<tr>
<th>alloy</th>
<th>Band gap (eV)</th>
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<tbody>
<tr>
<td>a-GeSn:H</td>
<td>0.6-1.0</td>
</tr>
<tr>
<td>c-Si</td>
<td>1.1</td>
</tr>
<tr>
<td>nc-Si:H</td>
<td>1.1-1.3</td>
</tr>
<tr>
<td>a-SiGe:H</td>
<td>1.4-1.6</td>
</tr>
<tr>
<td>a-Si:H</td>
<td>1.6-1.8</td>
</tr>
<tr>
<td>a-SiOx:H</td>
<td>&gt;2.0</td>
</tr>
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</table>

The goal of this project is to optimize the performance of a 3J/4J hybrid c-Si/thin film silicon device. The project consists of two research objectives. The first objective focuses on the interfaces in the multijunction device. Interface engineering between separate junctions in a multijunction device is of utmost importance for a high Voc-Fill factor product. The second objective considers the light management of the multijunction device. To that end, state of the art surface texturing procedures, TCO’s and anti-reflective coatings can be considered to maximize the light coupling into the device.
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

**Optimizing the interconnection process for highly efficient and stable, flexible thin-film silicon photovoltaic modules**

**Daily Supervisor(s)**
Dr. Davide Bartesaghi (davide.bartesaghi@hyetsolar.com) / Dr. Gianluca Limodio (g.limodio@tudelft.nl)

**Supervisor**
Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)

**Short description**
One of the key processes in the production of flexible, thin film silicon solar cells at HyET Solar Netherlands is the realization of interconnections. At the interconnection region, two adjacent cells are connected in series. An optimal interconnection is a combination of a 1) highly conductive pathway for the current to flow from the bottom contact of one cell to the top contact of the next cell; 2) highly resistive area preventing short circuits within one cell or between the two adjacent cell. In the current HyET Solar process, interconnections are realized with a combination of laser scribing and insulating ink dispensing. In order to optimize the process, an in-depth study should be carried out to elucidate which parameters have the largest influence on the resulting interconnection. In view of the possible future introduction of different active layers in the product, the aim of this project would not be limited to having a good control over the process parameters; the main goal would be instead achieving an understanding of how the process can be transferred and re-optimized on different materials.

**Available from**
November 2020

| Title | Development of a Photo-electrochemical device from a triple/quadruple junction solar cell |
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

**Updated list – 5th of June 2020**

**Daily Supervisor(s)**  Thierry de Vrijer (t.devrijer@tudelft.nl)

**Supervisor**  Arno Smets (a.h.m.smets@tudelft.nl)

**Short description**

If you want to work on integrated devices that use multijunction solar cells in a new way, then this project will be of interest to you! In the DISCO project we want to tackle the challenge of creating a large enough voltage from solar energy to simultaneously drive the CO2 reduction reaction and oxygen evolution reactions in an integrated solar to fuel device. By growing multiple photovoltaic junctions on top of each other a high voltage device can be processed. There are 2 projects available in this line of research.

In **PROJECT 1**, triple junction (c-Si/nc-Si:H/a-Si:H) solar cells are processed in the EKL lab at TU Delft. These solar cells are used to directly split water, meaning that the solar cells will be submerged in an aqueous environment. This involves making holes through the photovoltaic device, for ion exchange, and the processing of an electrocatalyst on either side of the pv device for the reduction and oxidation reactions of water.

![Image of solar cell](image1.png)

In **PROJECT 2**, quadruple junction pv devices (c-Si/nc-Si:H/a-SiGe:H/a-SiOx:H) are processed in the EKL lab at TU Delft. These solar cells are used to indirectly reduce CO2, meaning that back and front contacts of the pv device are connected to the electrocatalysts, but the pv device is not submerged in an aqueous environment.

![Image of electrocatalyst](image2.png)

**Available from**  July 2020

**Type**  Experimental

**Internal/External**  Internal
Research Area
Area #1: Wafer-based c-Si solar cells
Area #2: Thin-film solar cells

Area #3: Silicon/Air batteries

Title: Effect of texture on performance silicon-air battery
Daily Supervisor(s): Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor: Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)

Short description:
Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards batteries, primarily to Li-ion batteries. In this project, however, we investigate silicon-air batteries. Silicon is abundant and non-toxic, and can be processed relatively easily. Silicon-air batteries potentially have a higher energy density than some other technologies.
In this project we aim to investigate the effect of the texture of silicon anodes on the performance of silicon-air batteries. By varying the texture the dissolution rate can be enhanced, leading to a more efficient discharge.
For this project you will need to:
- Write a literature review on silicon-air batteries;
- Learn to operate relevant processing equipment;
- Carry out discharge experiments to test the batteries;
- Work on a model correlating the texture to battery operation.

Available from: 1 September 2020
Type: Experimental
Internal/External: Internal

Title: Using silicon alloys for silicon-air battery
Daily Supervisor(s): Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor: Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)

Short description:
Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards batteries, primarily to Li-ion batteries to Li-ion batteries. In this project, however, we investigate silicon-air batteries. Silicon is abundant and non-toxic, and can be processed relatively easily. Silicon-air batteries potentially have a higher energy density than some other technologies.
In this project we investigate different silicon alloys for application as the anode in silicon-air batteries. These alloys will be deposited using CVD techniques, varying the composition and the structural properties of the materials. By variation of the
composition and structural properties the battery performance may be influenced and optimized.

- For this project you will need to:
- Write a literature review on silicon-air batteries;
- Learn to operate relevant processing equipment;
- Carry out discharge experiments to test the batteries;
- Work out a model explaining the influence of the composition and structural properties on battery operation.

### Available from 1 September 2020

**Title**  
Using silicon alloys for Li-ion based batteries

**Daily Supervisor(s)**  
Dr. René van Swaaij \(\text{R.A.C.M.M.vanSwaaij@tudelft.nl}\)

**Supervisor**  
Dr. René van Swaaij \(\text{R.A.C.M.M.vanSwaaij@tudelft.nl}\)

**Short description**  
Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards Li-ion batteries. The anode material used in these cells is usually based on carbon, like graphite.

In this project we investigate different silicon alloys for application as the anode in Li-ion batteries. This project is carried out in cooperation with another research group. These alloys will be deposited using CVD techniques, varying the composition and the structural properties of the materials. By variation of the composition and structural properties the battery performance may be influenced and optimized.

For this project you will need to:
- Write a literature review on Li-ion batteries;
- Learn to operate relevant processing equipment;
- Carry out discharge experiments to test the batteries;
- Work out a model explaining the influence of the composition and structural properties on battery operation.

### Available from 1 September 2020

**Type**  
Experimental

**Internal/External**  
Internal
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

**Area #4: Photovoltatronics**

**Title** Light-induced injection in power transistors

**Daily Supervisor(s)** Dr. Guangtao Yang (g.yang@tudelft.nl), Dr. Patrizio Manganiello (p.manganiello@tudelft.nl)

**Supervisor** Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Short description** Performance of PV modules are strongly affected by the presence of non-uniform conditions. For instance, even when only 3-4 cells are shaded, the output power of a conventional PV module is drastically reduced. The main reason behind this performance reduction is that all cells are connected in series with power optimization performed, in the best case, at module level. Ideally, power processing should be performed per cell, so that every cell in a string can work at its maximum power point (MPP) independently of the operating conditions of the rest of the string. However, cell-level power processing can be extremely challenging, since converters made of expensive components and thick packaging, must be inserted in parallel to every cell. These thick additional components change the topography of the PV module surface, which can hinder PV module reliability and lifetime. To reduce component thickness, one can remove packaging and use bare switching devices. Among the many challenges of this approach, this thesis focuses on the effect of light-induced carrier injection on the controllability of semiconductor switches. Your goal will be to study the performance of the device under different wavelengths both experimentally and through simulations, in order to identify what type of optical filter is needed to ensure transistor's controllability.

**Available from** March 2020

**Type** Experimental, Simulation

**Internal/External** Internal

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**Title** Characterization and modelling of PV cells impedance

**Daily Supervisor(s)** Dr. Patrizio Manganiello (p.manganiello@tudelft.nl)

**Supervisor** Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Short description** Processing the power generated from a PV module is mandatory to ensure optimal operation of
the module and maximize its energy production. Novel technologies based on wide bandgap semiconductors, such as GaN and SiC, promise a strong reduction of the converter size in terms of both active (switches) and passive (inductor, capacitor) components, thanks to their higher switching frequency. On the other hand, with the rise of switching frequency, the parasitic elements of PV cells, such as their capacitance and inductance, become more and more important, and can in theory (partly) replace the input filter of e.g. boost-type power optimizers. Your goal will be to evaluate the impedance of various types of solar cell under different illumination levels, and to model this distributed impedance for different metallization shapes and cell technologies.

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<td>Type</td>
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### PV cell impedance requirements for inductor-less power optimizers

**Daily Supervisor(s)**
Dr. Patrizio Manganiello ([p.manganiello@tudelft.nl](mailto:p.manganiello@tudelft.nl))
Dr. Olindo Isabella ([o.isabella@tudelft.nl](mailto:o.isabella@tudelft.nl))

**Short description**

The increasing switching frequency of power converters, that is expected due to deployment of wide bandgap semiconductor devices, is paving the way toward converters’ full integration. However, the size of passive components, mainly magnetics, is still too big to allow chip integration. Or, on the other hand, inductors that are small enough (and good enough) to be integrated are extremely expensive. Ideally, it would be useful to “integrate” inductors and capacitors in the PV generator by proper selection of cell technology and design of cell metallization, so that an inductor-less power converter could be used. To design such PV cells and modules, it is necessary to know what are their expected resistance, inductance and capacitance. In other words, what is their expected impedance. Your goal will be to set the requirements for the design of solar cells’ output impedance so that inductor-less power processing can be implemented at cell level or for small groups of cells. Starting with a boost converter as a study case, you will define through modelling the cell’s impedance that is needed to remove the input filter of the boost converter without losing any functionalities, for different levels of current and power, as well as for different switching frequencies.

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</table>

### Measuring thermal distribution over PV modules through integrated sensors

**Daily Supervisor(s)**
Dr. Patrizio Manganiello ([p.manganiello@tudelft.nl](mailto:p.manganiello@tudelft.nl))
Dr. Olindo Isabella ([o.isabella@tudelft.nl](mailto:o.isabella@tudelft.nl))

**Short description**

PV modules performance and lifetime are very sensitive to the cell’s operating temperature. One problem among all, long lasting exposure to high temperature, e.g. due to hot spots, can irreversibly damage a solar cell. Nowadays, thermal sensing (if any) is done by attaching few thermocouples to the back side of PV modules, or by shooting thermal pictures with drones. In the first case, the spatial resolution of the sensing is too limited (e.g. 2-3 sensors for a 60-cell module), whereas in the second case the temporal resolution is too little (drone flights are done e.g. once a week or when unexpectedly low performance are detected at system level). Ideally, thermal sensors should be embedded in the PV module laminate, as an integral part of the generator. Your goal will be to build-up a demonstrator of PV module with integrated thermal sensors and validate its performance through indoor and outdoor measurements. This will happen in different steps: (1) selection of proper sensor devices, with measurable temperature
dependency and a form factor allowing their lamination within PV modules; (2) characterization of the selected devices; (3) design of the control circuit and fabrication of the control board; (4) fabrication of the PV demonstrator, where sensors are embedded within the PV module laminate; (5) validation.

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Area #5: X-Integrated PV systems (XIPV)

As mankind population grows, providing with energy, water and food is among the ten top challenges for next 50 years. The share of electricity in the total energy mix will increase in future and this trend is particularly valid for cities and urban areas. Today electricity networks are mostly mono-directional with power flux being transported and distributed from a central power station (gas, coal, nuclear) to the end users. However, a significant transition in energy mix from the fossil fuels to renewable energy sources is recently ongoing. Such transition has a strong impact on electricity networks that must be re-designed to allow a high penetration of electricity generated from renewable sources, such as solar and wind energy. In these novel networks, often called Smart Grids, power flux flows in two directions, from and to the consumer, since the consumer can generate electricity and use it on site or feed it to the grid. This new electricity infrastructure will be implemented in present and future urban areas making them smart too. The main pillars of the future electricity infrastructure in cities will be (i) grid-connected environment / urban integrated photovoltaics (XIPV), (ii) energy storage, (iii) intelligent power control and (iv) market management. The ESE department possesses such expertise and the PVMD group focusses especially on XIPV. The notion of XIPV systems includes not only classical low environmental-impact built-added PV (BAPV) and modern building integrated PV (BIPV) systems but also those PV systems that are incorporated both aesthetically and functionally in the place of installation. These can be flexibly-expandable modular systems, designed to exhibit both very high yearly energy autarky (self-consumption) and/or very yearly energy yield. The PVMD group is active in the R&D of a comprehensive energy yield modelling (i.e. from DC side to AC side) of customized PV systems as indicated in the flow chart below.

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1 Prof. R. E. Smalley (Rice University), the 27th Illinois Junior Science & Humanities Symposium (2005).
2 Prof. E. J. Moniz (MIT) Lecture at Delft University of Technology (2010).
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

Title: Photovoltaic applications in LiFi
Daily Supervisor(s): Yilong Zhou (Y.Zhou-15@tudelft.nl)
Supervisor: Hesan Ziar (h.ziar@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description: light-fidelity (LiFi), also called visible light communication (VLC), has recently gained huge interest. In such a communication system, an optical sensor translates the received luminous modulation flux into an electrical signal which is further decoded. To consider LiFi as an
alternative solution for wireless communication, the receiver must be operational in both indoor and outdoor conditions. PV cells could appear as a solution to this issue. However, since LiFi is a very new technology, there are several questions that still need solid answers before incorporating PV cells into LiFi communications systems. This MSc project is based on theoretical research and investigation and at the end of the thesis the following questions are expected to be answered:

- Using PV cell as the receiver in LiFi system, what PV technology serves the best?
- What is the optimum thickness and size for PV LiFi receiver?
- What is the communication efficiency and SNR (signal to noise ratio) response for PV LiFi receiver?
- What is the maximum achievable data rate (with respect to distance and light level) for this application?
- In general, what are the advantage and disadvantages of integrating PV in LiFi?

The project is further broken down into following sections:
1- Deep research on PV cells and LiFi communication technology;
2- Theoretical study of PV integrated LiFi communication system;
3- Designing experiments to test the claims raised in the research (conducting the experiments depends on the project progress and their feasibility);
4- Reporting.

Background in communication engineering or physics would accelerate the project progress.

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<tr>
<td>Type</td>
<td>Theoretical/Modeling</td>
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<td>Internal/External</td>
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| Title | Application of cloud resolving models in photovoltaic yield prediction |
| Daily Supervisor(s) | Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl) |
| Supervisor | Hesan Ziar (h.ziar@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl) |
| Short description | Clouds passing over PV plants causes the energy production to drop. Knowing cloud coverage with high resolution will give valuable information about photovoltaic power production. Using meteorological data from Royal Netherlands Meteorological Institute (KNMI), it is possible to run cloud-resolving models and obtain cloud coverage for any arbitrary location in the Netherlands. This technique can be well integrated into PV yield forecasting approaches. The benefit of such a combination is that instantaneous power production for PV plant (over a region) can be predicted beforehand and necessary dispatching action can be done. If the result of this research be satisfying, then in the near future, when the share of PV power production in electrical grid increases, this approach could be helpful for proper electrical power dispatching and battery charging/discharging algorithms. |
| Available from | September 2020 |
| Type | Modeling/Experiment |
The project is further broken down into following sections:

1- Literature study about PV and Wireless power transfer techniques;
2- Simulating the wireless power transfer techniques for typical PV cells and modules;
3- Calculating the theoretical and practical power transfer efficiency for PV cell/module application and comparison with direct-contact power transfer approach;
4- Detailed guideline for prototyping;
5- Reporting;

Background in electrical/electronic engineering and basic knowledge of semi-conductor physics along with experience with MATLAB/Simulink, would accelerate the project progress.

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1- Literature study about PV and Wireless power transfer techniques;
2- Simulating the wireless power transfer techniques for typical PV cells and modules;
3- Calculating the theoretical and practical power transfer efficiency for PV cell/module application and comparison with direct-contact power transfer approach;
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5- Reporting;

Background in electrical/electronic engineering and basic knowledge of semi-conductor physics along with experience with MATLAB/Simulink, would accelerate the project progress.

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4- Detailed guideline for prototyping;
5- Reporting;

Background in electrical/electronic engineering and basic knowledge of semi-conductor physics along with experience with MATLAB/Simulink, would accelerate the project progress.
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

1. Literature study about PV, electrolyser and power electronic converters control;
2. Selection of suitable converter for electrolyser application;
3. Development of PV, converter and electrolyser models;
4. Development of novel control strategy of converter;

Background in electrical/electronic engineering and basic knowledge of power electronics converter along with experience with MATLAB/Simulink, would accelerate the project progress.

Title: MPPT algorithm efficiency map of the World
Daily Supervisor(s): Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl)
Supervisor: Hesan Ziar (h.ziar@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description: Maximum power point trackers (MPPT) extracts the maximum available power from the PV modules or arrays. Most commercial MPPTs are working based on the well-known Perturb and Observe (P&O) technique. Efficiency of P&O algorithm is sensitive to power fluctuations (ΔP). Such power fluctuation depends on the technology of the PV modules and the local weather condition, mainly irradiance. As the irradiance fluctuations (both in terms of spectrum and intensity) changes over the globe, the average efficiency algorithm of MPPTs are then location dependent. Since each component of a PV system influences the yearly energy yield, we aim to include this effect in our PV system modelling and yield calculations. Therefore, you will be working on analyzing the irradiance data of on Earth, calculating the MPPT efficiency, and mapping it for various PV technology around the World.

Available from: April 2020
Type: Modelling/Simulation
Internal/External: Internal

Title: PV potential of the fleet of urban vehicles
Daily Supervisor(s): Hesan Ziar (h.ziar@tudelft.nl)
Supervisor: Hesan Ziar (h.ziar@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description: Vehicle surfaces have the potential to absorb solar energy and convert it into electricity. Using PV panels on the surfaces of the vehicles reduces the charging time (initial report by TNO for simple study case suggests a 45% reduction in charging times). However, geometrical complexity in urban area and moving path of a car over a year makes it difficult to accurately map the potential of these moving surfaces. Recently, in the PVMD group, we have mapped the PV potential of highways in the Netherlands, considering the effect of traffic. Using the
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

Experience, knowledge, and even the scripts from this project, you will be working on simulating the true solar energy potential of moving vehicles. Besides, the effects of curvature on the roof, front and back hoods on the PV potential of the vehicles are also expected to be included in the project.

Communication with the Transport & Planning Department of Civil Engineering Faculty is expected during the course of this project. Experience with ArcGIS and MALAB scripting will accelerate the project progress.

**Available from**: September 2020  
**Type**: Simulation/Modelling  
**Internal/External**: Internal

<table>
<thead>
<tr>
<th>Title</th>
<th>Dutch PV portal 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>), Hesan Ziar (<a href="mailto:h.ziar@tudelft.nl">h.ziar@tudelft.nl</a>), Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>The Dutch PV Portal (PVP) is a website hosted on the TU Delft server (<a href="https://pvportal-3.ewi.tudelft.nl/">https://pvportal-3.ewi.tudelft.nl/</a>). The website provides visitors with information on solar energy in the Netherlands. The underlying aim of the PVP is to integrate scientifically valid PV system modelling into an interactive online environment. The third version of the PVP (the PVP 3.0) includes options to design a PV system, retrieve real-time and historic weather data for modelling purposes, and to view an estimate of the national solar energy production in real-time. The objective of this thesis is to create a new version of the PVP which includes additional features and a more accurate energy production model, using PV system modelling research performed within the PVMD group. The thesis will cover the following main topics: (i) the use of LiDAR data to estimate horizon shading on a PV system (lookup table of shading factors); (ii) adding bifacial PV modules to the website design model; (iii) incorporating study cases and real PV systems being monitored by PVMD/TUD within the Dutch PV portal; (iv) developing digital twins of the monitored PV systems, comparing measured and modelled data, and setting up an alarm notification system accordingly. Knowledge in PHP, HTML, and MySQL will accelerate the project.</td>
</tr>
</tbody>
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| Available from | September 2020  
| Type           | Modelling/Coding  
| Internal/External | Internal |
Area #6: Photovoltaic Multiscale Modelling
For MSc students interested in this area, we recommend the course Photovoltaic Modeling (EE4680), starting in Q5.

<table>
<thead>
<tr>
<th>Title</th>
<th>Optimization of the Silicon Bottom Cell in Perovskite/Silicon Tandems for Maximum Annual Energy Yield under Real-World conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Manvika Singh (<a href="mailto:M.Singh-I@tudelft.nl">M.Singh-I@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>), Rudi Santbergen (<a href="mailto:R.Santbergen@tudelft.nl">R.Santbergen@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>Within the PVMD group we are developing the PVMD toolbox software for accurately predicting the energy yield of PV systems. A very promising new type of PV cell technology is the perovskite / silicon tandem. The student will improve the existing models in the PVMD toolbox to make them suitable to be used for perovskite/c-Si tandem applications. Unique to this project is that the bottom cell will be a new type of c-Si solar cell with high thermal budget carrier-selective passivating contacts poly-Si, poly-SiO_x and poly-SiC_x carrier-selective passivating contacts. Usually the design of a new solar cell is optimized for maximum efficiency under standard test conditions. However, in the real world, the cell temperature, the irradiance level and the spectral distribution vary and are often far from this standard. Therefore a better approach would be to optimize the solar cell design for maximum real-world energy yield. To achieve this, energy yield calculations for this type of perovskite/silicon tandem solar cells will be performed and data will be analysed for different locations in the world using PV device, module and system models.</td>
</tr>
<tr>
<td>Available from</td>
<td>August 2020</td>
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<tr>
<td>Type</td>
<td>Modelling</td>
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<tr>
<td>Internal/External</td>
<td>Internal</td>
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<tr>
<td>Title</td>
<td>Electrical simulations of perovskite/silicon tandem solar cells</td>
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<td>---------------------------------------------------------------</td>
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<tr>
<td>Daily Supervisor(s)</td>
<td>Manvika Singh (<a href="mailto:M.Singh-1@tudelft.nl">M.Singh-1@tudelft.nl</a>), Paul Procel (<a href="mailto:P.A.ProcelMoya@tudelft.nl">P.A.ProcelMoya@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>), Rudi Santbergen (<a href="mailto:R.Santbergen@tudelft.nl">R.Santbergen@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>In order to achieve conversion efficiencies of solar cells above 30% a better utilization of the solar spectrum is required. This can be done by a tandem solar cell approach in which a crystalline silicon (c-Si) solar cell is used as the bottom cell and perovskite solar cell as the top cell. However, it is still a challenge to combine a perovskite solar cell with a c-Si bottom cell into a high-efficiency 2T-hybrid tandem cell due to inherent complexity. Most of them are related to: i) understanding of optical-electrical coupling/interconnect between the component cells depending on the band-gap of an perovskite absorber, ii) design of a tandem device that maximizes power conversion efficiency, and iii) module integration of tandem solar cells depending on their architecture. This project will tackle the above mentioned issues by modelling perovskite/c-Si tandem solar cells in the commercial software package TCAD Sentaurus. Unique to this project is that the bottom cell will be a new type of c-Si solar cell with high thermal budget carrier-selective passivating contacts such as poly-Si, poly-SiOx and poly-SiC,. The main goal is to optimize the tunnel recombination junction layer and minimize recombination losses in perovskite/c-Si tandem solar cells.</td>
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<tr>
<td>Available from</td>
<td>October 2020</td>
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<tr>
<td>Type</td>
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<table>
<thead>
<tr>
<th>Title</th>
<th>Simulation of bifacial PV systems with RADIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Andres Calcabrini (<a href="mailto:A.Calcabrini-1@tudelft.nl">A.Calcabrini-1@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Rudi Santbergen (<a href="mailto:R.Santbergen@tudelft.nl">R.Santbergen@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>PV simulation tools are essential to evaluate the technical and economic feasibility of PV projects. These tools combine several models to calculate the electrical yield of a photovoltaic system. The first model is an optical model, which is used to calculate the amount of solar radiation incident on the surface of the solar cells. The calculated irradiance is used in turn to determine the module’s temperature and its electrical power output. Hence, an accurate irradiance model is the key to reduce the errors in the simulated electrical output. In this project, you will work on an irradiance model based on RADIANCE, a ray tracing software suite used in state-of-the-art PV simulation software. This approach will be especially useful to calculate the yield of bifacial PV modules, a technology that is expected to take over 30% of the PV world market share by 2030. You are expected to develop a deep understanding of RADIANCE algorithms to be able to integrate RADIANCE in the PVMD toolbox and validate your simulation results. Since RADIANCE is coded in C and the PVMD toolbox in MATLAB, advanced coding skills are a requirement.</td>
</tr>
<tr>
<td>Available from</td>
<td>May 2020</td>
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<tr>
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</tbody>
</table>
### Title: Density functional theory (DFT) calculations of photovoltaic materials

**Daily Supervisor(s):** Paul Procel Moya ([P.A.ProcelMoya@tudelft.nl](mailto:P.A.ProcelMoya@tudelft.nl))  
**Supervisor:** Rudi Santbergen ([R.Santbergen@tudelft.nl](mailto:R.Santbergen@tudelft.nl))  
**Short description:** Within the PVMD group we use device simulation software to analyse new solar cell designs. Input for these simulations are the opto-electrical properties, such as refractive index or density of states, of each solar cell material. These material properties are usually derived from measurements, but could also be derived from first principles using density functional theory (DFT). In this project you will be using commercially available DFT software, running on a powerful server, to calculate the material properties of novel photovoltaic materials. You will be validating your results against material properties measured in our lab. Finally you will be using the opto-electrical material properties, obtained from DFT, as input for device simulations to identify promising new solar cell designs.  
**Available from:** June 2020  
**Type:** Modelling  
**Internal/External:** Internal

### Title: Self-consistent opto-electrical model for transparent conductive oxides (TCOs)

**Daily Supervisor(s):** Paul Procel Moya ([P.A.ProcelMoya@tudelft.nl](mailto:P.A.ProcelMoya@tudelft.nl)), Can Han ([C.Han-1@tudelft.nl](mailto:C.Han-1@tudelft.nl))  
**Supervisor:** Rudi Santbergen ([r.santbergen@tudelft.nl](mailto:r.santbergen@tudelft.nl))  
**Short description:** Transparent conductive oxides (TCOs) are used as the transparent contact material in most solar cells. By tuning the deposition conditions, the opto-electrical material properties can be optimized. Ideally TCO materials are both highly transparent and highly conductive. However, a higher charge carrier concentration (higher conductivity) also leads to stronger free-carrier absorption (lower transparency). This means a trade-off has to be found between optical and electrical losses. The opto-electrical models developed in the PVMD group allow for fast solar cell optimization, but do require accurate and self-consistent opto-electrical material properties as input. The goal of this project is to develop a model that generates self-consistent opto-electrical properties of TCO materials. You will be mostly modelling, but also measure the material properties of TCO layers fabricated in our lab, comparing model and measurement results, and using your model to find the optimum TCO for different cell types and climate conditions.  
**Available from:** June 2020  
**Type:** Modelling  
**Internal/External:** Internal

### Title: PV lifetime yield modelling

**Daily Supervisor(s):** Malte Vogt ([M.R.Vogt@tudelft.nl](mailto:M.R.Vogt@tudelft.nl))  
**Supervisor:** Rudi Santbergen ([R.Santbergen@tudelft.nl](mailto:R.Santbergen@tudelft.nl))  
**Short description:** PV modules degrade in power output during their operational lifetime due to many different effects such as backsheet cracking, finger corrosion, snail trails, potential induced degradation (PID) or light and temperature elevated induced degradation (LeTID). PV module manufacturers and insurance agencies typically guarantee >80% performance for 20-30 years. In the meantime new more efficient PV modules will be developed and PV module prices will decrease. Thus the question is: At which point will it be economically advantageous to repower the PV modules and/or the system?  
In this project you will implement degradation effects into the PVMD toolbox and evaluate their impact on yield and levelized cost of energy (LCOE) in different climatic conditions. Afterwards you will use the extended toolbox to compare different technologies.
<table>
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<th>Title</th>
<th>Available from</th>
<th>Type</th>
<th>Internal/External</th>
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<tr>
<td>Control strategies for reconfigurable PV modules</td>
<td>July 2020</td>
<td>Modelling</td>
<td>Internal</td>
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<tr>
<td>Energy rating for bifacial PV modules</td>
<td>April 2020</td>
<td>Modelling</td>
<td>Internal</td>
</tr>
<tr>
<td>Opto-geometric modelling of complex urban landscapes</td>
<td>October 2020</td>
<td>Modelling</td>
<td>Internal</td>
</tr>
</tbody>
</table>

**Control strategies for reconfigurable PV modules**

Supervisor:
- Malte Vogt (M.R.Vogt@tudelft.nl)
- Rudi Santbergen (R.Santbergen@tudelft.nl)
- Patrizio Manganiello (P.Manganiello@tudelft.nl)

Description:
In the urban environment chimneys and other objects can cast shadows on PV modules. A shadow cast on even a single cell can dissipate the power output of the entire module. Reconfigurable PV modules use switches to continuously adapt the cell interconnection scheme to the actual shading pattern. For the reconfigurable module to be economically feasible, the gain in energy yield should outweigh the cost of the additional switches and shading sensors. We previously managed to minimize the number of switches. Your goal will be to position the sensors in the module such that a limited number of them is required, and to develop a control strategy that is universally robust with limited sensor input. The analysis will be performed by using and extending the annual energy yield simulation framework developed in our group.

You will be mostly using and developing computer models but for experimental validation you will also need to obtain measurement data from our outdoor PV monitoring station.

**Energy rating for bifacial PV modules**

Supervisor:
- Malte Vogt (M.R.Vogt@tudelft.nl)
- Rudi Santbergen (R.Santbergen@tudelft.nl)
- Hesan Ziar (h.ziar@tudelft.nl)

Description:
Energy ratings are used to realistically evaluate a PV modules performance in different climates and compare different modules. Currently, energy ratings are established for monofacial PV modules, but not for bifacial modules. However, bifacial modules are expected to grow in market share to over 30% within the next ten years. Thus developing a reliable energy rating for PV bifacial modules is of great interest.

In this project you will implement a view factor model to calculate the rear irradiance of PV modules and develop an extension of PV module energy ratings to bifacial modules. Afterwards you will apply the extended energy rating to different PV modules and evaluate different technologies.

**Opto-geometric modelling of complex urban landscapes**

Supervisor:
- Rudi Santbergen (R.Santbergen@tudelft.nl)
- Pirouz Nourian (P.Nourian@tudelft.nl)

Description:
We are developing models for accurately predicting the energy yield of PV systems in complex urban landscapes. As input we use the geometry and the optical properties of all surface elements of each surrounding building that could cast a shadow or reflect light onto the PV modules. The challenge is that this geometric information comes from various sources (CAD, LIDAR) and is used as input for various models (ray-tracing, Matlab) each with their own data requirements. In
addition, the optical properties of every surface element have to be stored. For a PV surface we need to store its absorption depth profile along one or multiple absorber layers, both as a function of the angular and spectral distribution of the incident light. Your task will be to create geometric data models that store optical properties as attributes of surface patches, develop methods to export to, and import from that format. Finally you will embed your methods in our modelling framework and use this to predict the energy yield of PV systems in complex urban landscapes.

**Title**  
Future Hydrogen Town: Designing a PV-Hydrogen-Battery-Fuel cell system for a dutch town

**Daily Supervisor(s)**  
Thierry de Vrijer

**Supervisor**  
Arno Smets

**Short description**  
A clean renewable future requires a long term energy carrier such as hydrogen. But there are many questions as to how hydrogen should be integrated into our lives. What is the most economically feasible system design? To what extent should storage and generation be decentralized? Should our cars be electrical or hydrogen based? and how about our heating? And if this system is very expensive now, when will it be economically feasible? In this project you will set out to answer questions like this, expanding on a TRNSYS model developed by previous students.

**Available from**  
April 2020

**Type**  
Modelling

**Internal/External**  
Internal

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**Title**  
Future Hydrogen Town: Designing a PV-Hydrogen-Battery-Fuel cell system for a dutch town

**Available from**  
August 2020

**Type**  
Modelling/Experimental

**Internal/External**  
Internal
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

Area #7: Projects with external partners

<table>
<thead>
<tr>
<th>Title</th>
<th>Site optimization of floating PV systems by means of high albedo reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Supervisor(s)</td>
<td>Ir. Maarten Romijn (<a href="mailto:m.romijn@hydropv.eu">m.romijn@hydropv.eu</a>), Hesan Ziar (<a href="mailto:h.ziar@tudelft.nl">h.ziar@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Dr. Olindo Isabella (<a href="mailto:o.isabella@tudelft.nl">o.isabella@tudelft.nl</a>)</td>
</tr>
<tr>
<td>Short description</td>
<td>PV is spearing rapidly but as a consequence of low efficiency, PV panels require a lot of space. This means that in many cases PV installation should compete with other industries such as agriculture and building industry. However, if the available in-shore and off-shore water areas are used for PV installation, this issue can be avoided. Putting PV modules on water areas brings challenges though. Hydro PV (<a href="https://www.hydropv.eu/">https://www.hydropv.eu/</a>) is a company working on novel ideas to use floating PV solutions and placed them on the water surface behind the dams. Among their activities, they are looking for approaches to increase the yield of floating PV systems using reflectors. To do so, optimum material with optimum arrangement should be selected and placed. This project aims to: (1) study wavelength selective reflective surfaces of UV resistant polymers for the visible part of sunlight spectrum, (2) investigate reflectivity of UV resistant polymer surfaces to sunlight, (3) run ray-tracing simulations of sunlight from the reflective surfaces to the PV modules for different sites/latitudes, (4) simulate the resulting temperature of the back surface of the module above the water, and (5) compare the findings with reference land-based PV systems.</td>
</tr>
</tbody>
</table>

Requirement: Besides knowledge on PV system simulation and design, as the candidate may
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 5th of June 2020

visit or partially work at Hydro PV test center in Ouarzazate, Morocco, she/he should have good communication skills (in English and/or French).

<table>
<thead>
<tr>
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<th>April 2020</th>
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<tbody>
<tr>
<td>Type</td>
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<td>Internal/External</td>
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</tbody>
</table>

**Title**

Blind monitoring of PV systems

**Daily Supervisor(s)**

Yitzi Snow (yitzi@solarmonkey.nl)

Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Supervisor**

Dr. Olindo Isabella (o.isabella@tudelft.nl)

**Short description**

This research project is part of ongoing R&D at Solar Monkey, a company involved in the accurate prediction of PV system yields based on geographic and meteorological data. Solar Monkey currently monitors thousands of rooftop PV installations, collecting yield data from the inverter. This generation is compared to the yield which would be expected based on a detailed model of the system. The system design includes information such as the inclination, orientation, and type of each solar panel. In the future, it would be interesting to also monitor systems where this information is totally unknown; the only information available would be weather data and historical generation for that system. The goal is to develop an algorithm which can predict the expected yield for a PV system, without any previous knowledge of the system design. Because we are monitoring systems where the layout is unknown, this is referred to as blind monitoring.

**Requirement:** Apart from a background knowledge in PV system design and modelling, data analysis and computations will be written in Python programming language, so experience with Python is strongly preferred.

<table>
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<th>June 2020</th>
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<tbody>
<tr>
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