MONDAY HIGHLIGHTS

PVSC 46 | 17TH JUNE 2019 | CHICAGO, IL

PLENARY PRESENTATIONS

Yannick Combet from Thales unveiled the concept for the Stratobus airship. Classed as a High Altitude Pseudo Satellite (HAPS) it measures 140 m in length, operates at an altitude of 20 km and provides communication, navigation and observation services to civil and military clients. The Stratobus will have a payload capacity of up to 450 kg and can cover a zone of 100,000 km^2. Power will be supplied by 300 kWp of photovoltaics with an array voltage of 1200 V and storage in 540-800 kWh batteries. This power is sufficient to operate and propel the airship for up to a year. The project is presently in a feasibility stage, with a demonstration unit scheduled for 2024 and operation from 2027.

WELCOME!

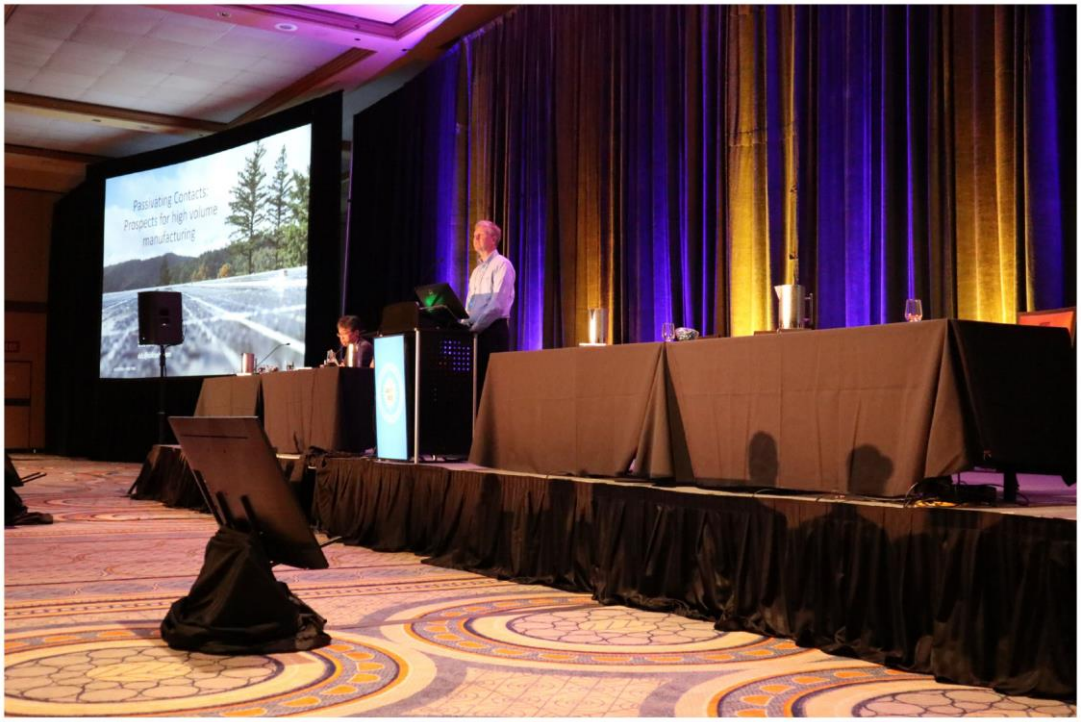
Sarah Kurtz, chair to this year's PVSC, opens the confernece with an introduction and announcements highlighting events of general interest.

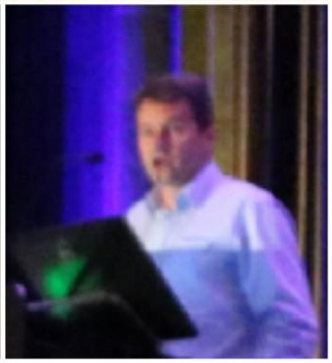
HIGH SCHOOL COMPETITION

Nine teams from around the country presented their solar research project during the Poster session.

TUTORIALS

Sunday tutorials covered topics from fundamentals of PV to utility scale system issues.





Raffi Garabedian, CTO of First Solar summarized the amazing developments of the past decade in PV electricity generation, not just achieving grid parity but actually now being the cheapest source of energy; in some locations being cheaper than the marginal cost of a coal power plant. He emphasised that despite concerns from a decade ago, solar plants are now actually adding to grid stability with the power inverters providing rapid frequency response and reactive power to the grid. Large solar farms are now seen as a grid stabilising influence. He highlighted how the solar industry has been operating at close to zero margin, making it difficult for new, innovative technologies to get a foothold. CdTe represents a throughput of production advantage, which has allowed it to survive against the larger Si industry. He suggested prioritizing government and university research efforts in new technologies that may disrupt the established Si and CdTe technologies.

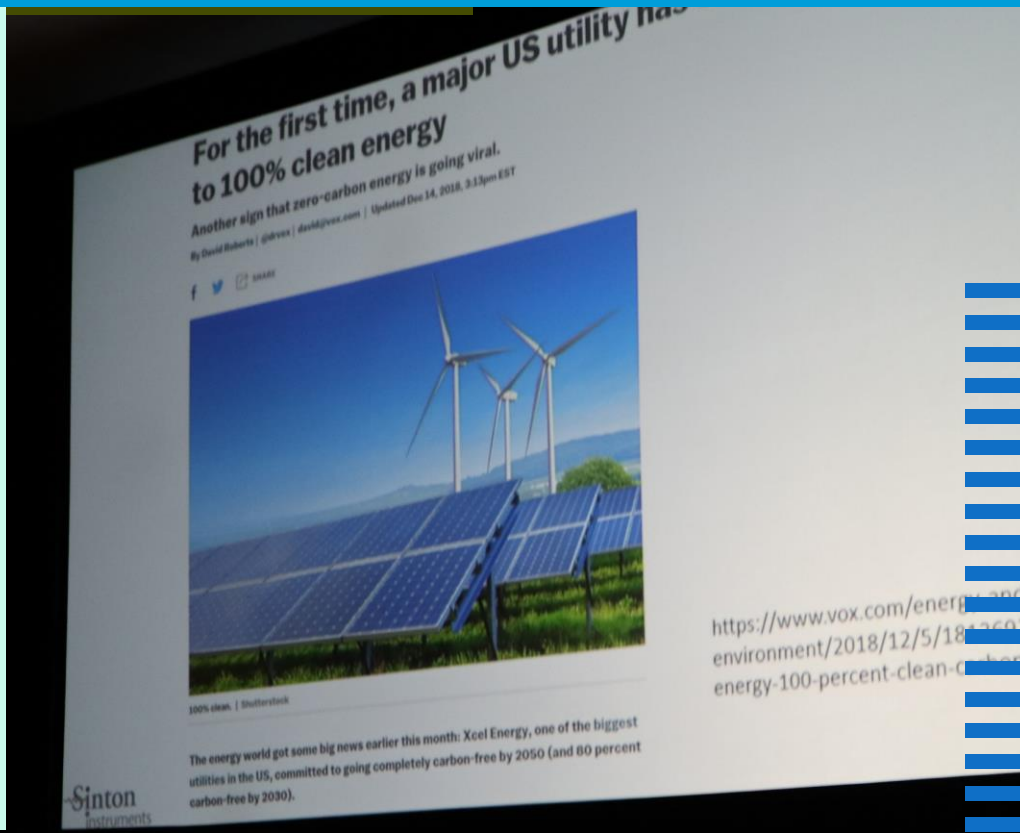
Denis De Ceuster from DDC Solar presented an overview of passivating contacts for silicon solar cells. He started by pointing out that the standard Al-BSF technology is limited to 20% power conversion efficiency, rising to 23.5% with the emerging PERC architecture. To achieve yet higher efficiencies (up to 25%) requires passivated contacts. The technology also has the virtue of enabling bifacial modules and is free from light induced degradation. He reviewed three general architectures: (1.) the silicon heterojunction cell that uses thin amorphous silicon passivation layers benefits from a short process flow with no high temperature processing but is estimated to be 2.5x more expensive than the PERC process. (2.) Thin Tunnel Oxide Passivated Contact (TOPCon) has the virtue of being compatible with the PERC process, and adding only a couple of additional process steps to the production line. The TOPCon layer can be implemented on the rear of the cell with a standard diffusion on the front, or on both sides of the cell. The TOPCon approach has the virtue of being the least expensive of the passivated contact approaches, with an estimated cost of 1.5x the cost of a standard PERC process. (3) Non-silicon heterojunctions, where the doped amorphous silicon layers in (1) are exchanged with carrier-selective materials, for example TiO_2 as an electron contact and MoO_x as a hole contact. The approach generally shares the same disadvantages as the silicon heterojunction approach (1).

PHOTOVOLTAIC SPECIALISTS CONFERENCE
46th IEEE
Chicago, Illinois • June 16-21, 2019

OPENING KEYNOTE

The opening keynote was given by Ron Sinton on "The Path Towards a Major Utility Commitment for 100% Carbon-Free Electricity". Ron explained how one of the largest electricity utility companies in the USA, Xcel, has pledged to become carbon free by 2050. He explained that the process started in Colorado with a local referendum result setting a modest target for renewable electricity generation. The initiative grew in popularity, leading the city of Boulder to pledge becoming 100% renewable by 2030, followed by the City of Denver, Breckenridge, and Pueblo, among others. Recognising the momentum and expectation that these pledges generated, in 2017 Xcel agreed to close two coal power plants with a target of 55% renewable generation by 2026. This has since been followed in 2018 with Xcel announcing to become 80% carbon free by 2030, and 100% by 2050. While the transition is motivated by an appetite from consumers for clean electricity, the transition is enabled by the competitive costs of wind and solar electricity; now cheaper than the marginal cost of coal in many locations. Additionally, Xcel makes the case that investment in solar and wind is advantageous for Xcel's investors, suggesting the beginning of a trend where investor-owned utilities may become primary drivers of solar expansion. Ron concluded by observing that when he started his work in PV 37 years ago, a 0.1% increase in solar cell efficiency could secure a research group a new point on a record efficiency graph. Today it has an impact on a 100B$ growth industry.

"The Path Towards a Major Commitment for 100% Carbon-Free Electricity"



REGULAR SESSIONS:

In Area 1 the "Spectral Selectivity" session Jeronimo Buencuerpo from NREL presented work on enabling ultrathin III-V solar cells using photonic crystals, demonstrating that a 2D photonic crystal on front and rear of 300 nm thin III-V cells enables absorption close to the Lambertian limit. The photonic crystals were fabricated using scalable laser-interference lithography and wet etching.

In Area 2 "Advances Towards High Voc CdTe Photovoltaics" the speakers discussed how the use of group-V elements and Se alloying afford a promising strategy for maximizing the open-circuit voltage. Grover et al reported that *In-situ* doping through doped CdTe powder leads to uniform hole concentration in ~10^{16} cm^{-3} range, which leads to high V_{OC}. Ding et al reported that low V_{OC} in a CdTe/MgCdTe solar cell with a Cu doped ZnTe contact is mainly resulting from low built-in voltage. Amarasinghe et al reported that high group-V doping > 10^{16} cm^{-3} in CdSeTe thin films can be achieved by vapor transport deposition. Munshi et al reported that long lifetime > 150 ns can be obtained in As-doped CdTe, which leads to high V_{OC} greater than 950 mV. Zheng et al reported that a band gap graded CdTe thin film solar cell with Se alloying demonstrated an efficiency of 16%.

In Area 3 "III-V Multijunctions" Ryan France from NREL announced a new 6-junction inverted metamorphic solar cell with a record that raises the world record for solar power conversion to 47.1% at a concentration of 144 suns AM1.5D. This cell architecture also set a new world record for one-sun efficiency of 39.2% under the AM1.5G spectrum. This result necessitated some careful work to remove resistive barriers in the solar cell stack, which were found to arise from Zn diffusion in the 4th junction. A later presentation by Manuel Hinojosa further elucidated the usual behaviour of Zn diffusion at sub cell interfaces and the role that point defects play in affecting dopant diffusion from tunnel junctions. A fully lattice-matched 4-junction device with 2 dilute nitride GaInNAsSb low-bandgap sub-cells was reported by Arto Aho from Tampere University, Finland. The architecture has so far demonstrated 29% efficiency under one sun and 40% under 100 suns.

In Area 4 "Silicon Material: Fundamentals, Defects and their Mitigation" Mariana Bertoni of Arizona State University spoke on Simone Bernardini's behalf presenting the need to modify Auger parameterisation currently used throughout the field to include a temperature dependence. Most interestingly, increased temperatures can allow for higher intrinsically-limited lifetimes in silicon.

In Area 5 "Performance Testing and Standards" T. Song from NREL demonstrated the reliability of the asymptotic Pmax method, as compared to others methods (MPP tracking, SCFC) to measure IV curves of emerging PV devices. An uncertainty of more than 1 percent was estimated to persist. Bruce King from Sandia National Laboratories described how a differential method for measuring the angle of incidence response of utility grade PV modules. Fixed tilt modules were found to benefit most from the presence of an antireflection coating while single axis tracked modules benefitted the least. Paul Ndione from NREL presented a method to directly measure module I-V parameters over a wide range of temperatures using a flat-bed solar simulator and temperature control system. After considering temperature non-uniformity over the module area and measurement repeatability, temperature coefficients for I-V parameters were reported (with their associated uncertainties). S. Reichmuth presented an overview of measurement issues encountered by calibration laboratories when measuring silicon solar cells with thin or discontinuous busbars. Use of coaxial I-V probes at Fraunhofer ISE shows promise over traditional I-V-I "triplet" configurations. Detailed procedures used for measuring "busbarless" cells were also presented.

Monday registration went smoothly thanks to all the staff and organizers of PVSC. Moderators and GSA also help run the Oral sessions.

In Area 8 the "New Module Materials, Designs and their Optimization" session spectrally selective reflectors were shown to reduce module temperature. Many approaches for reducing stress on ribbon connections were presented finding the geometry, spacing, connector aspect ratio to be important.

POSTER AWARD WINNERS

Michelle Vaqueiro-Contreras from UNSW Sydney, winner of the Area 4 poster prize for her work "Direct Observation of the Boron-Oxygen Complex Precursor Responsible for Light Induced Degradation in Silicon Photovoltaic Cells".

In Area 2 – "Interfaces and Contacts Layers in Thin Film PV" Anna Kindvall from Colorado State University won the poster award with the presentation of "Effect of Process Temperature and Copper Doping on the Performance of ZnTe:Cu Back Contacts in CdTe Photovoltaics".

In Area 3 – "III-V Devices, CPV, and Optics" Yukun Sun from Yale University won the poster award for "2.0 – 2.2 eV AlGaInP solar cells grown by molecular beam epitaxy".

In Area 4 – "Materials & Modelling" Michelle Vaqueiro-Contreras from UNSW Sydney won the poster award with her work on the "Direct Observation of the Boron-Oxygen Complex Precursor Responsible for Light Induced Degradation in Silicon Photovoltaic Cells". Using low temperature spectroscopy, a level with an apparent activation energy of 42 meV has been found that was previously impossible to detect using DLTS. This level is suggested to be responsible for the light induced degradation promoting trap assisted Auger recombination

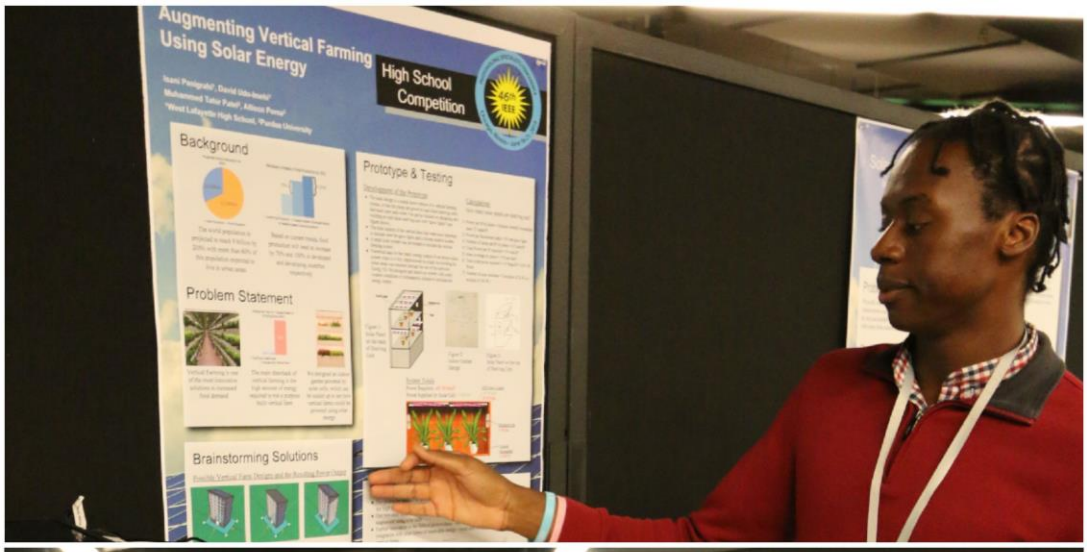
In Area 5 – "Characterization" Michael Owen-Bellini from NREL won the poster award with a presentation on accelerated stress testing of PV modules using a sophisticated weathering chamber to combine various stress conditions and observe the module response using IV data and EL images.

In Area 6 – "Improvements and Scale-up of Organic, Hybrid and Perovskite Solar Cells" M. Bani Salim from Texas A&M University won the poster award with the work "Electronic Properties and Molar Excitation Coefficient for Organic Solar Cells Materials by using TD-DFT Method". New approach for electronic properties determination by Time dependent DFT method aimed at building a database for OPV materials properties.

In Area 8 – Daniel Riley from Sandia National Labs won the poster award with a presentation on "Differences in Snow Shedding in PV Systems with Framed and Frameless Modules".

PVSC HIGH SCHOOL COMPETITION

The PVSC High School Competition was a resounding success! In total, nine teams (32 students) from around the country presented their solar energy research projects, supported by teacher-facilitators from their local schools as well as graduate student/post-doc mentors from Arizona State University, University of New Mexico, and Purdue. These mentors met with their teams virtually and/or face-to-face throughout much of the school year to offer advice, feedback, and encouragement.



Thanks to a generous grant from NSF, 12 high school scholars from Arizona were able to travel to the conference to participate in person with their Chicago-area peers. These high school scholars were fully integrated into the conference experience, attending the opening keynote session and touring the exhibition hall before participating in Monday's poster session alongside the adult presenters. Such cross-age events help create a sense of belonging for young inspiring engineers, communicating that we are all photovoltaics scholars, different in level, not type; as such, every member of the PVSC community is a learner and a contributor to this important endeavor.

Continuing last year's successful introduction of virtual participation, two teams included members who participated in the conference via a Zoom meeting space. Two teams were presenting for the second year in a row, to support their sustained development of engineering skills and identity. Four awards were given: First Place, Social Impact Award, Upcycle Award, and Solar Ambassadors Award.

Participating high school teams included the following:

Augmenting Vertical Farming Using Solar Energy (First Place)
- David U. and Isani P.
- West Lafayette High School, West Lafayette, Indiana
- Mentors: Muhammed Tahir Patel and Allison Perna, Purdue

Combatting Unsafe Drinking Water in the Dominican Republic (Social Impact Award)
- Victor S., Pedro C., Karelly H. G., and Maryan R.
- Sevilla West Middle School, Phoenix Arizona
- Teacher-Facilitator: Mia DeLaRosa
- Mentor: Sebastian Husein, Arizona State University

Solar Can Solar Cells (Upcycle Award)
- Jasmine M. C.
- Bioscience High School, Phoenix Arizona
- Teacher-Facilitator: Milton Johnson
- Mentor: Emma Renteria, University of New Mexico

Using Solar Energy to Charge Robot Batteries (Solar Ambassadors Award)
- Molly M., Johan A., Arick N., Osmar M., Alexis T., Maggie L., and Arturo G.
- Bioscience High School, Phoenix Arizona
- Teacher-Facilitators: Milton Johnson and Pope Enrique
- Mentor: Alex Routhier, Arizona State University

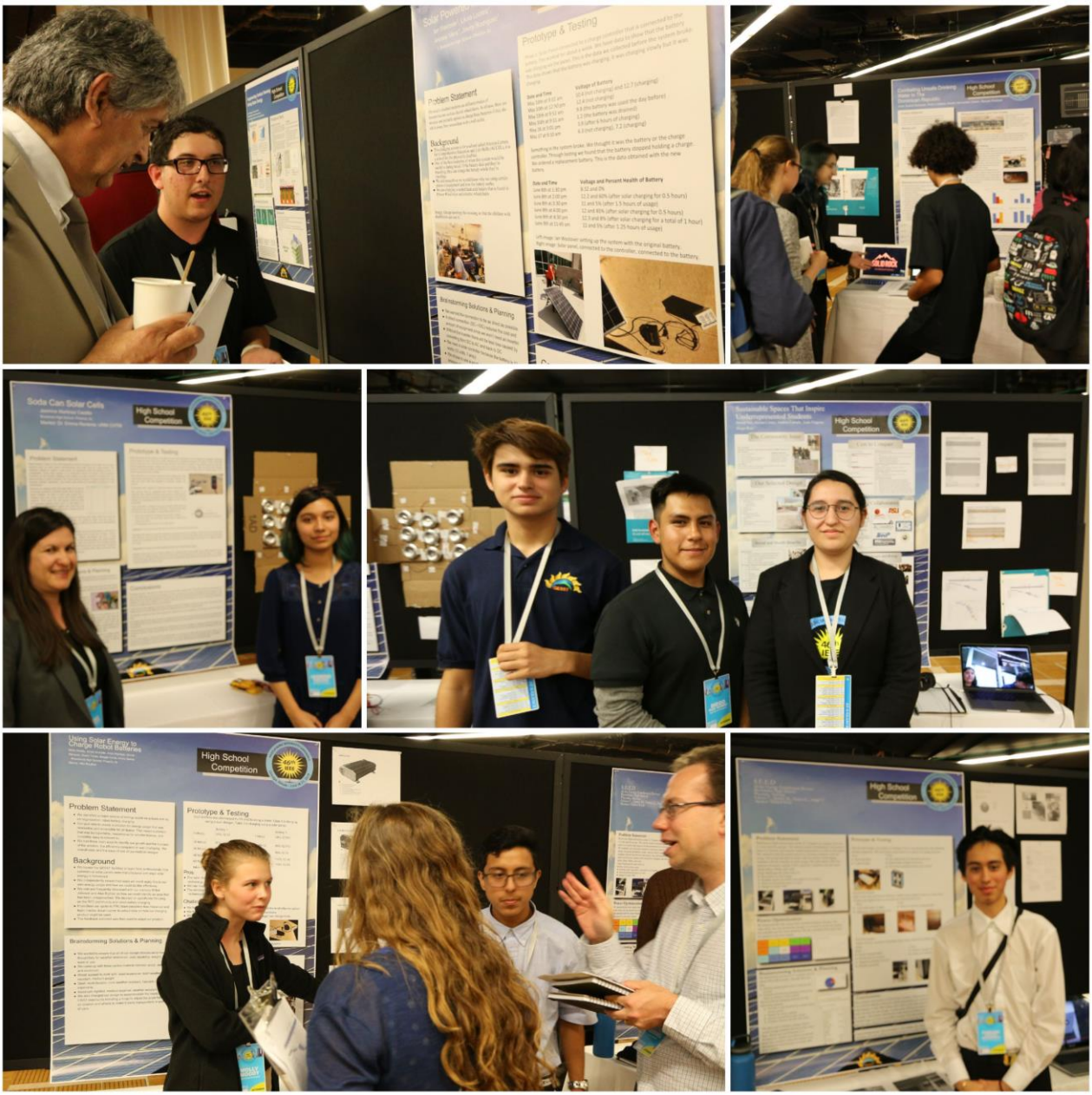
Sustainable Places that Inspire Underrepresented Students
Jawed N., Alyssa C., Andrea E., Luis F., Diego R.
QESST Youth Scholars, Phoenix Arizona
Teacher-Facilitators: Mia DeLaRosa & Michelle Jordan
Mentor: Alex Killam, Sundad Bhat, and Karan Shah, Arizona State University

Calibration of a Low-Cost Irradiance Detector and Comparison with Pyranometer
Andrew V.
Bioscience High School, Phoenix Arizona
Teacher-Facilitator: Milton Johnston
Mentor: Joe Karas, Arizona State University

Solar Powered Mustang
Ian W., Laura L., Andrew V., and Jimmy R.
Bioscience High School, Phoenix Arizona
Teacher-Facilitator: Milton Johnson
Mentor: Mathew Levar, ACCEL

Solar Powered Record Player
Northwestern High School, Kokomo Indiana
Rylund M., London S., Emily R., and Thomas W.
Teacher Facilitator: Craig Williams
Mentor: Joseph Andler, Purdue

S.E.E.D.: Solar Energy Enrichment Device
Fabian C., Jimmy D., Victor G., and Angel V.
Bioscience High School, Phoenix Arizona
Teacher-Facilitator: Milton Johnson
Mentor: Nick Irvin, Arizona State Univers

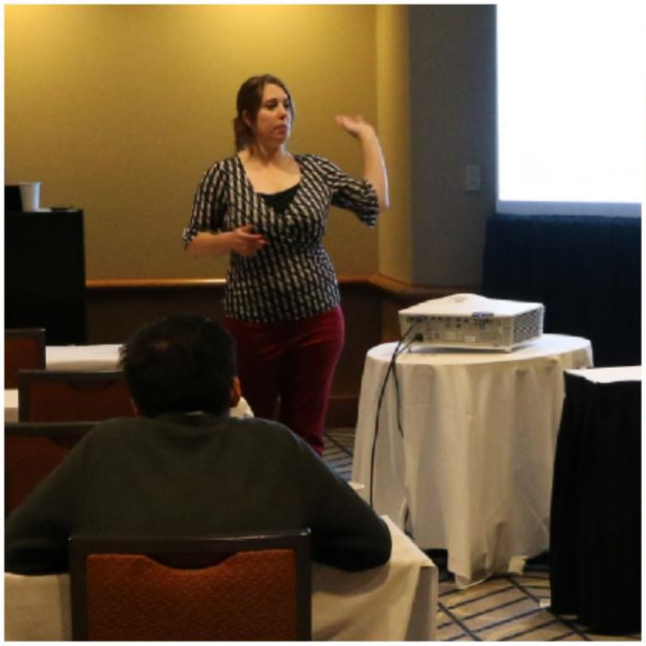


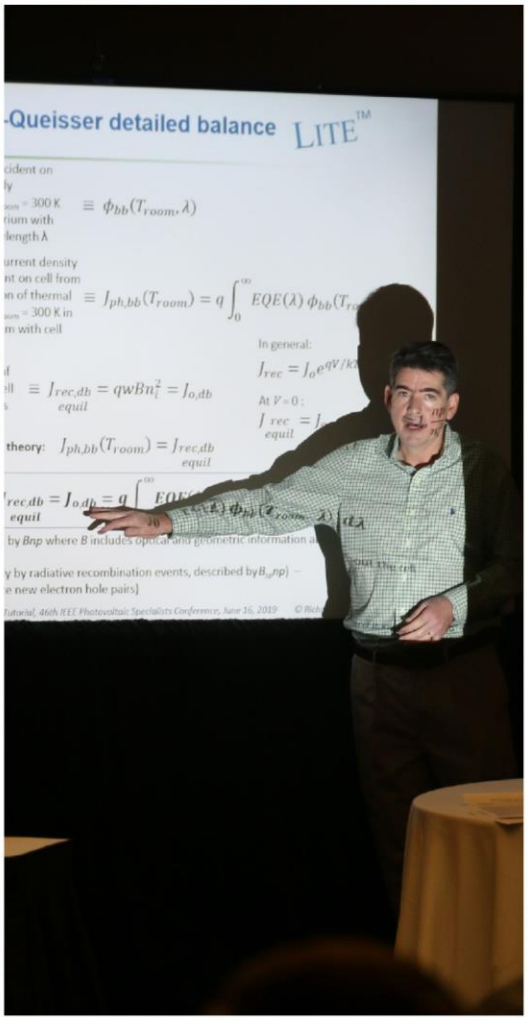
This year, Peter Bermel (Purdue), Michelle Jordan (ASU, QESST), and Silvana Ayala (NREL), organized and co-coordinated the event. Peter Bermel, Silvana Ayala, Kaitlyn VanSant (Colorado School of Mines) and Geoff Bradshaw (AFRL-Kirtland AFB) helped judged the competition. The organizers thank all the dedicated judges, team mentors, teacher-facilitators, and PVSC organizers and attendees who helped each team rise to new heigh Asdfasdf

SUNDAY TUTORIALS

Sunday tutorials were a great way to brush on on various PV concepts, from fundamentals to utility scale system issues. Many thanks to our tutorial presenters.

- “Fundamentals of Photovoltaics”, Prof. Ned Ekins-Daukes, Imperial College, UK
- “Introduction to Device and Module Characterization”, Ronald A. Sinton, Sinton Instrument, Boulder CO USA
- “Status and Issues in Si PV”, Silvana Ayala Pelaez, National Renewable Energy Laboratory, Golden CO, USA
- “Hybrid Perovskite PV”, Dr. Joseph Berry, National Renewable Energy Laboratory, Golden CO, USA
- “High Efficiency III-V PV”, Richard R. King, Arizona State University, Tempe AZ, USA
- “Introduction to Photovoltaic Device Modeling", Dr. Jeff Bailey, MiaSolé Hi-Tech Corp., Santa Clara, CA USA
- “Introduction to Photovoltaic Materials Characterization”, Dr. Harvey Guthrey and Dr. John Moseley, National Renewable Energy Laboratory, Golden CO, USA
- “Module Stability and Reliability”, John Wohlgemuth, PowerMark Corporation, Union Hall, VA, USA
- “Utility Scale System Issues”, Dr. Mahesh Morjaria, First Solar, USA
- “Thin Film PV: Overview of CdTe, Cu(InGa)Se2, Cu2ZnSn(S,Se), and Related Material and Device Technologies”, Mike Scarpulla, University of Utah, Salt Lake City, UT, USA




-Queisser detailed balance
LITE™
In general:
At V = 0 :