

“Solar Energy. Now”. Anticipating and Fostering the Energy Transition at the Sun New Energy Conference

Mario Pagliaro,^{*,a} Rosaria Ciriminna,^a Francesco Meneguzzo,^b Vittorio Lodo,^c and Leonardo Palmisano^{*,c}

^a *Istituto per lo Studio dei Materiali Nanostrutturati, CNR, via U. La Malfa 153, 90146 Palermo, Italy*

^b *Istituto per la Bioeconomia, CNR, via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy*

^c *“Schiavello-Grillone” Photocatalysis Group, Dipartimento di Ingegneria, Università di Palermo, viale delle Scienze, Ed. 6, 90128 Palermo, Italy*

Email: mario.pagliaro@cnr.it (M. P.), leonardo.palmisano@unipa.it (L. P.)

Abstract The outcomes of gathering leading scholars in solar energy, materials science and energy efficiency at the beginning of the world’s energy transition to renewable energy at the “SuNEC—Sun New Energy Conference” held in Sicily between 2011 and 2016 suggest two major achievements and have two lessons to teach.

Keywords solar energy, sustainable development, SuNEC, renewable energy

Introduction

Inspired by the publication of the article on solar hydrogen as the fuel of the near future in the 2010 themed issue on solar fuels of *Energy & Environmental Science*,^[1] the “SuNEC—Sun New Energy Conference” was held for the first time in Sicily, on July 5—7, 2011.

Jointly organized by Italy’s Research Council and Palermo’s University in 6 consecutive editions between 2011 and 2016, the meeting gathered in Sicily some of world’s leading scholars in solar energy, materials science and energy efficiency including Bernard Kippelen, Vincenzo Balzani, Ralph Nuzzo, Aldo Steinfeld, Thomas Brown, Keith Barnham, Ruud Schropp, Bao-Lian Su, Kisuk Kang, Ranjit Koodali, Francesco Meneguzzo, Jesper Jacobsson, Philipp Rudolf von Rohr, Soon Moon Jeong, Marco Raugei, Yuri Baurov and Levente Csoka (Figure 1).



Figure 1 The cover of the Book of Abstracts in SuNEC 2015.

Conforming to the motto of the conference (“Solar energy. Now”), the organizers emphasized the societal and economic relevance of solar energy technologies inviting contributions on the latest developments in clean energy science and technology suitable to find practical applications.

Reviewing the outcomes of the conferences suggests two major achievements and has two lessons of general relevance to teach.

Anticipating and Fostering the Energy Transition

When the first SuNEC conference was held, times in Europe were uneasy. A few days before SuNEC 2011, invited speaker Athanasios G. Konstandopoulos, the president of Greece’s CERTH research center, wrote to the organizers:

“I was planning to finalize my trip to Sicily last week, but there was a change in the government. As you might have learned last week, this creates a different landscape in the matters of our research center. The government changes in Greece, which also involves changes in research policy.”

“I am obliged to stay here throughout July, as I have to participate in a series of several requested meetings with new government officials on issues that affect the entire landscape of research in Greece and these issues could affect our research center’s immediate future negatively, given the difficult financial condition that exists in our country.”^[2]

“Once adopted on a massive scale, and starting exactly from sun-drenched countries like Greece,” the Book of Abstracts of SuNEC 2011 reads, “Solar energy will offer a solution to such economic hurdles saving the large amount of financial resources that each industrialized country allocates for purchasing, mostly abroad, hydrocarbons and coal.”^[3]

In his presentation, Francesco Meneguzzo from Italy’s Research Council showed that utility-scale PV plant in Italy, where recently installed PV power exceeded the 10 GW threshold, is actually a sustainable way towards low price electricity. His analysis showed that large ground-based PV installations can already offer their electricity into the Italian wholesale electric market at competitive prices at the current and projected prices of PV electrical plants.^[4]

Dr. Meneguzzo concluded that the “grid parity” as well as the viability and sustainability of a solar PV-based economy emerge as a present-day milestone along the way to a cheaper energy and environment-friendly economy.^[5]

Professor Ralph Nuzzo from University of Illinois at Urbana Champaign gave a fascinating talk on the new nanochemistry-based technology developed by his team enabling printing-

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based manufacturing of concentrator photovoltaic (CPV) systems by exploiting synergies within additive and physical means of patterning and fabrication (Figure 2).^[6]



Figure 2 Professors Ralph Nuzzo (left) and Vincenzo Balzani lecturing at SuNEC 2011, Santa Flavia, Sicily, July 5—7, 2011.

In a visionary lecture, Professor Vincenzo Balzani, now emeritus professor at the University of Bologna, explained why renewable energies directly or indirectly related to sunlight are the only abundant and inexhaustible resources, on which we can trust to replace fossil fuels causing severe environmental damages and contributing to establish disparities and inequities in the human society.^[7]

A most important achievement that will enable to counter the two intrinsic defects of sunlight: low spatial density (in W/m^2) and intermittency, will be the production of powerful, clean fuel hydrogen directly from water and sunlight.^[8]

Bernard Kippelen, head of the Center for Organic Photonics and Electronics at the Georgia Institute of Technology, illustrated why organic photovoltaics will be one of the key clean energy technologies in the 21st century.

Ten percent (10%) efficient plastic solar cells are very close, explained Professor Kippelen, and will be reached within the next 18 months or so. However, the market for portable device is only 60 MW, so that at 1 \$/W this will not be a significant market for this technology.^[9]

The need to produce MW scale power from organic photovoltaic devices, Professor Kippelen insisted, requires the development of green manufacturing processes and materials affording PV products both biodegradable and recyclable. One such renewable and biodegradable material to be used as transparent substrate, he argued, could be cellulose nanofiber.

Aldo Di Carlo, head of CHOSE, University of Rome Tor Vergata, in his presentation, explained how dye solar cells (DSCs), being efficient, colored, transparent, thin and showing PV conversion efficiency lesser dependent on the angle of incoming sunlight rays, are ideally suited for building integration (BIPV) applications, as well as to power portable electronic devices.^[10] He then discussed efforts to scale-up this technology from single, small area, cells to large area modules (Figure 3).



Figure 3 Professors Aldo Di Carlo (left) and Bernard Kippelen lecturing at SuNEC 2011, Santa Flavia, Sicily, July 5—7, 2011.

Giuseppe Calogero from Italy's Research Council presented the dye solar cells using natural pigments extracted from bougainvillea flowers, red turnip and purple wild prickly pears fruit sensitizing the nanostructured titania films.^[11]

Levels of the photovoltaic (PV) conversion efficiencies approaching 2% make the modules that could be produced, he concluded, suitable for instance in all those natural contexts where PV electricity is required with no environmental impact of the technology.

The 2nd edition of the SuNEC was organized again in Santa Flavia, Sicily, on September 4—6, 2012. Opening the conference, Professor Sebastiano Tusa, Sicily's Superintendent of the Sea, emphasized the historic importance of sun's energy for Sicily where most Italy's grain is produced, as well as for making the fish-based sauce "garum" widely traded by the Romans. Today, he concluded, the focus should be on the proper integration of solar technology in the built environment and landscape, especially in protected areas (Figure 4).



Figure 4 Professor Sebastiano Tusa (right) opening SuNEC 2012, Santa Flavia, September 4, 2012.

On September 4 2012, Aldo Steinfeld, chair of renewable energy carriers at Zurich's ETH Polytechnic, opened the conference with a lecture on the thermochemical production of solar hydrogen and carbon monoxide directly by water splitting coupled to carbon dioxide reduction.^[12]

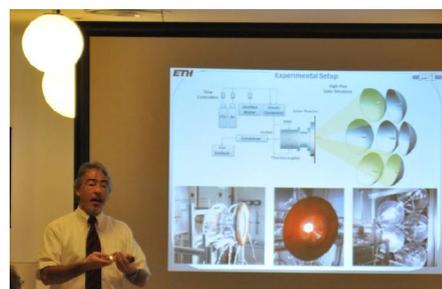


Figure 5 Professor Aldo Steinfeld lecturing at SuNEC 2012, Santa Flavia, September 4, 2012: "Thermochemical Fuel Production from Water, CO₂, and Concentrated Solar Energy".

Heterogeneously catalyzed by ceria, the reaction takes place concentrating sunlight in a solar reactor developed by his Group in co-operation with scientists in the US. The original 0.8% efficiency^[13] is now four times higher, standing at 3.2%. When the 10% efficiency threshold will be reached, he further explained, this technology will find practical application.

True sustainability, Professor Steinfeld emphasized, is about to close materials cycle, and not about efficiency. Efficiency concerns the economy of processes, and thus industry. Hence, the source of CO₂ for sustainable syngas (CO + H₂) generation must be CO₂ from ambient air.

This requires the development of a suitable material for CO₂ adsorption and release. Thus, Professor Steinfeld showed the remarkable results lately obtained with sol-gel aminosilica as

reversible CO₂ adsorber optimally working at 90 °C. An ETH spin-off company (Climeworks) was established to commercialize the technology for CO₂ capture from ambient air.

The same day, Keith Barnham, emeritus Professor at London's Imperial College, gave a remarkable talk on the latest developments concerning 3rd generation solar cells based on the triple-junction (III-V) concentrating PV technology using GaAs, developed in his Lab since 1990 (Figure 6).^[14]

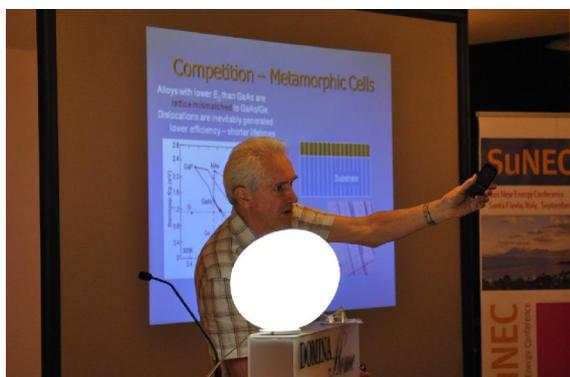


Figure 6 Professor Keith Barnham lecturing at SuNEC 2012, Santa Flavia, September 5, 2012: “A new approach to high-efficiency multi-band-gap solar cells”.

He briefly told the story of QuantaSol, the company spun off from his Lab recently sold to a large semiconductor US company, and explained that in order to obtain a reduction in manufacturing cost for these cells similar to that experienced by Si-based traditional cells, production must rapidly and largely grow.^[15]

The reactors to make LEDs or III-V solar cells, he explained, basically use the same process. Since a large number of large Chinese electronic companies recently purchased these reactors on a massive scale, the route to 40% efficient solar cells might be open.

On September 5 2012, Professor Ruud Schropp described a number of ultrathin thin film silicon solar cells developed at his Labs, first at Utrecht University, and more recently to the new ECN Labs in Eindhoven, where part of his team recently accepted to relocate (Figure 6).



Figure 6 Professor Ruud Schropp lecturing at SuNEC 2012, Santa Flavia, September 5, 2012: “Ultrathin Thin Film Silicon Solar Cells”.

Professor Schropp's presentation ranged from the remarkable 8% efficiency of hydrogenated Si solar cells deposited over Ag-coated ZnO nanorods long 25 nm, to tandem a-Si/nc-Si cells based on plasmonic back reflectors.^[16]

The subsequent day, Professor Bao-Lian Su from University of Namur gave a fascinating presentation on silica-entrapped biological species for solar energy conversion by photosynthesis (Figure 7).^[17]



Figure 7 Professor Bao-Lian Su lecturing at SuNEC 2012, Sicily, September 6, 2012: “Leaf-Like Materials Capable of Solar Energy Conversion by Photosynthesis”.

A number of different high value-added sugars are indeed directly obtained from sunlight, water and carbon dioxide.^[18] These leaf-like materials, he explained, currently retain their performance up to 3 consecutive months.

When the threshold of 6 months will be reached, a number of companies, including European and Chinese companies co-operating with his Group, will start commercialize this technology.

Professor Su, who also runs a research Group at the Wuhan University of Technology in China, insisted that for each Si atom in a traditional solar cell, 4 atoms of chlorine are released as hydrogen chloride.

In China, where some 90% of solar grade silicon is nowadays manufactured, this is posing a serious threat to the environment. Hence, he concluded, we must identify alternative means to exploit solar energy that are not harmful to the environment and to human health.

On September 6 2012, Professor Kisuk Kang from Seoul National University gave a remarkable presentation on newly developed battery materials for storage of solar energy (Figure 8).^[19]



Figure 8 Professor Kisuk Kang lecturing at SuNEC 2012, Sicily, September 5, 2012: “Storage of Solar Energy: Design of Battery Materials”.

The Mn-based olivine structure of LiMnPO₄ as a cathode material for rechargeable Li-ion batteries features extremely high structural stability and dependable safety due to its strong P—O covalent bonds and high capacity,^[20] he explained.

By merging quantum chemistry computation and chemical synthesis of materials, he showed how his Group has devised new compounds, with new crystal structures, in which not only is the Li ions diffusion improved (higher voltage) and the crystal structure is more resistant to degradation upon multiple recharge cycles, but also the need for potentially explosive Co³⁺/Co⁴⁺ is eliminated.

Professor Thomas Brown from University of Rome Tor Vergata described in detail the design and development of the

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first large area dye solar cell modules, addressing the requirements of both the device and the manufacturing processes in sight of market applications of organic photovoltaics (Figure 9).^[21]



Figure 9 Professor Thomas Brown lecturing at SuNEC 2012, Sicily, September 6, 2012: "Design and Development of Large Area Dye Solar Cell Devices and Processes".

Professor Brown reported the latest data on flexible modules based on plastic substrates covered with the DSC cells, showing a remarkable 4.2% efficiency in outdoor testing. The CHOSE Group led by Professor Di Carlo, he explained, has developed considerable knowledge on scale-up of the technology, including laser sintering for glass cells, and UV irradiation for plastic devices.^[22]

The third SuNEC conference was held in Santa Flavia, Sicily, on September 10–12, 2013. Invited speakers at SuNEC 2013 included Wai-Yeung Wong, Yuri A. Baurov, Ottavio Cappellani, Francesco Meneguzzo and Antonino Aricò.

The Conference scientific program opened on September 10 2013, with the opening lecture of Professor Wai-Yeung Wong from Hong Kong Baptist University, who described the latest developments in organometallic photovoltaics using polyplatins and related polymers for harvesting solar energy (Figure 10).^[23]



Figure 10 The solar based distillery for essential oils extraction from medicinal plants presented by Waseem Amjad, University of Kassel, Germany, at SuNEC 2013, Santa Flavia, Sicily, September 12, 2013. A video of the system during a real distillation, courtesy of Professor A. Munir, University of Agriculture Faisalabad-Pakistan, can be seen at the URL: <http://shorturl.at/iosK6>

Professor Wong highlighted remarkable recent progress in the development of some metallated complexes and polymers exhibiting easily tunable photophysical and electronic proper-

ties.

Professor Yuri A. Baurov, former head of laboratory for frontier energy systems at the Cosmic Physics Institute of the Central Research Institute of Machines Constructions in Korolyov Town, Russia, gave a fascinating lecture describing coupling of the new force emerging from the byuon theory.^[24]

The theory predicts the global anisotropy of the physical space through the cosmological vector potential \mathbf{A}_g as well as a new interaction of natural objects with physical space. He described the basics of the theory explaining, for example, how the resulting new nature force couples with solar energy, as well as with the change of the Sun's magnetic poles.

On the same day, Francesco Meneguzzo from Italy's Research Council described the outcome of the experiments aimed at identifying and exploiting the new traction for boats and spacecrafts derived from the byuons theory.^[25]

Dr. Meneguzzo showed details of the elegant experimental setup developed by his team, consisting of a model of semi-spherical ship with the new prototype thruster onboard. Displaying a video of the prototype thruster in action, he further showed that the thruster has a remarkable specific power (power per unit traction force, in Watt per gram-force) at the level of 1–4 W/gf against the typical values above 130 W/gf of Hall Effect plasma space thrusters.^[26]

On the subsequent day, Dr. Antonino Aricò from Italy's Research Council presented the remarkable results of the solar-driven photo-electrochemical reduction of CO_2 into high energy density fuels obtained by his group by using a continuous flow cell based on a combination of high surface area photo-anode semiconductor to assist oxygen evolution, gas-diffusion cathode for CO_2 reduction from the gas-phase separated by an ion exchange membrane.^[27]

After proper optimization of the gas-diffusion electrode, he explained, the team achieved a suitable CO_2 conversion and a high productivity of organic fuels at low over-potentials, which is a pre-requisite to achieve an efficient solar-driven transformation of CO_2 into energy-rich fuels.

On September 12 2013, renown Italian novelist Ottavio Cappellani gave a talk on the end of the culture of oil.^[28] Starting from *The Prison Island*, one of his novels published in 2011 by Italy's largest publisher, wherein he described the "culture of oil" as a culture of war to the extreme, he explained why energy choices, today, are no longer a simple matter of economic, but rather of survival (Figure 11).



Figure 11 Ottavio Cappellani talking at SuNEC 2013, Santa Flavia, Sicily, 12 September 2013: "The End of the Culture of Oil: Rethinking Our Society Model in Time".

Italy's and Europe's economies and societies, he insisted, are now on the brink of the next crisis which, he added, gives us a theoretical advantage: rethinking the energy model just in

time before it is too late.

In this context, he concluded, solar energy is the only option for avoiding otherwise an inevitable global clash not of different civilizations, but rather of energy-eager economies and countries.

Held again in Santa Flavia, Sicily, the 4th edition of SuNEC was opened on September 8, 2014 by Professor Ranjit Koodali from University of South Dakota with a fascinating talk on the design of an artificial leaf obtained from the encapsulation of semiconductor clusters in mesoporous silica (Figure 12).^[29]

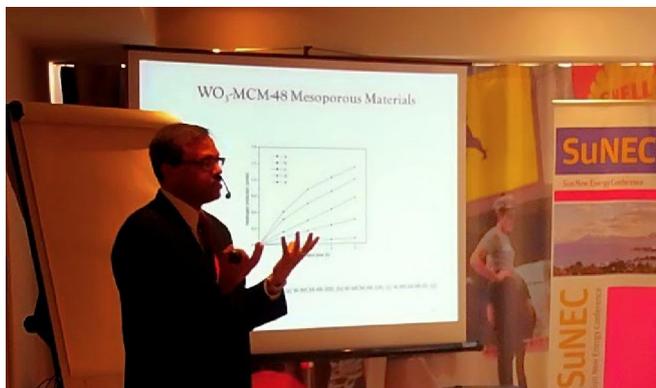


Figure 12 Professor Ranjit Koodali lecturing at SuNEC 2014, Santa Flavia, Sicily, September 8 2014: "Semiconductor Clusters Dispersed on Mesoporous Supports: Design of an Artificial Leaf".

Professor Koodali, chair of the Energy and Fuel Division of the American Chemical Society, showed how confining semiconductors such as cadmium chalcogenides within the pores of a high surface area mesoporous material such as MCM-48 constrains them to small particle sizes and also helps to prevent photocorrosion.

The resulting material contains spatially isolated and highly dispersed semiconductor clusters, and is able to generate hydrogen and oxygen from the overall photocatalytic splitting of water.

Dr. Jesper Jacobsson from Uppsala University presented further progress concerning the new monolithic device for solar water splitting based on three CIGS cells interconnected in series reaching over 10% solar-to-hydrogen efficiency (Figure 13).^[30]



Figure 13 Dr. Jesper Jacobsson lecturing at SuNEC 2014, Santa Flavia, Sicily, September 9 2014: "An efficient approach to solar water splitting based on $\text{CuIn}_x\text{Ga}_{1-x}\text{Se}_2$ reaching beyond 10% solar-to-hydrogen efficiency: From photoelectrochemical cells to PV-electrolysis and back again".

Dr. Jacobsson showed how further investigation in the similarities and differences between photoelectrochemical cells and PV-electrolyzers for solar hydrogen production, led to re-design of the entire process of solar hydrogen production based

on the underlying physical processes of absorption, charge carrier separation, charge carrier transport, and catalysis.

On behalf of Professor Michael Detty in State University of New York at Buffalo, who could not reach the conference venue eventually, Mario Pagliaro from Italy's Research Council gave a talk on newly developed sol-gel coatings as anti-fouling and fouling-release surfaces.^[31]

Dr. Francesco Meneguzzo from Italy's Research Council ended the SuNEC 2014 invited lectures, describing the very first use of controlled hydrodynamic cavitation obtained via an industrial scale hydrocavitation reactor prototype developed at his Lab for the inactivation or abatement of *Saccharomyces cerevisiae* yeast.^[32]

The process, Dr. Meneguzzo concluded, opens the route to a new process for the sterilization of numerous beverages, starting from beer. The best poster presentations were awarded a prize at each of the first five editions of the Conference (Figure 14).



Figure 14 PhD student Gerroo Prinsloo, Stellenbosch University, awarded the best SuNEC 2014 poster presentation prize by Professor Ranjit Koodali, Santa Flavia, Sicily, September 10, 2014, for his poster "Combined Solar Heat and Power With Microgrid Storage and Layered Smartgrid Control Towards Supplying Off-Grid Rural Villages".

SuNEC 2015 was opened in Santa Flavia, Sicily, on September 9 2015 by Professor Philipp Rudolf von Rohr, ETH Zurich and Swiss Competence Centre for Energy Research, with a presentation on energy efficiency in industrial processes (Figure 15).^[33]



Figure 15 Professor Philipp Rudolf von Rohr lecturing at SuNEC 2015, Santa Flavia, Sicily, September 9, 2015: "Efficiency in industrial processes: A national effort to reduce the energy consumption".

Switzerland, he explained, today operates eight so-called Competence Centers for Energy Research, which are developing solutions for the technical, social and political challenges arising out of the Swiss Energy Strategy 2050.

After an overview of the approaches of the Swiss Efficiency of Industrial Processes center to research and development together with industry of energy efficient industrial processes (about 20% of Switzerland's energy consumption), Professor von Rohr showed practical examples from his Lab at ETH in the area of continuous manufacturing and production enabling the transition from batch to continuous manufacturing in the pharmaceutical and chemical industry minimizing waste, energy consumption and raw material utilization.

In a most interesting talk, Professor Marco Rauegi from Oxford Brookes University explained why and how the quantification of the overall life-cycle energy and environmental profile of PV electricity based on life cycle assessment and net energy analysis is critical to enable decision makers to make informed and sound choices amid competing renewable energy alternatives.^[34]

Ending his presentation, Professor Rauegi called for a concerted effort aimed at further standardizing net energy analysis and fostering its integration with life cycle assessment, so as to enable methodologically consistent and reliable comparison of PV and competing energy technologies.^[35]

On the subsequent day, Dr. Soon Moon Jeong from Daegu Gyeongbuk Institute of Science and Technology in South Korea described the mechanoluminescent devices based on silicone-embedded ZnS (Figure 16).^[35]

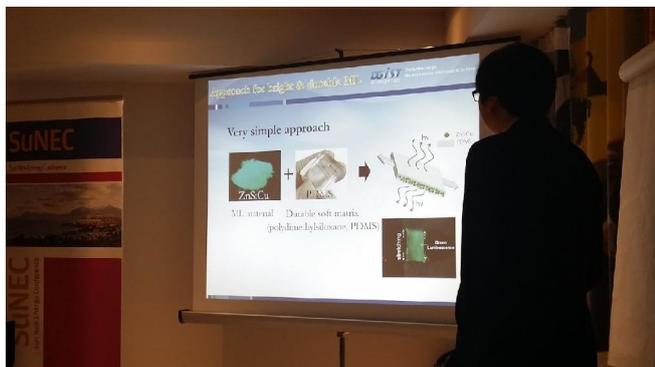


Figure 16 Dr. Soon Moon Jeong lecturing at SuNEC 2015, Santa Flavia, Sicily, September 10, 2015: "Development of wind-powered mechanoluminescent devices".

Mechanically-driven light generation, he explained, is an exciting and under-exploited phenomenon with a variety of possible practical applications in colorful displays and white-light sources driven by vibrating mechanical actions.

He showed how his team succeeded in obtaining intense, durable and colour-tunable mechanoluminescent structures with potential use in harvesting wind power for displays as well as for lighting systems based on renewable wind energy.

On the same day, Professor Levente Csoka from University of West Hungary gave a talk on wastewater remediation *via* hydrocavitation technology (Figure 17).^[36] As Professor Csoka explained, water is also a matrix and has huge storage capacity for harmful, toxic chemical and biological compounds.

In hydrocavitation technology, cavity formation and collapse are the main cleaning energy source for wastewater remediation. The hydrocavitation process thus does not generate harmful side products, and it can be effectively coupled to clean oxidants such as aqueous H_2O_2 .

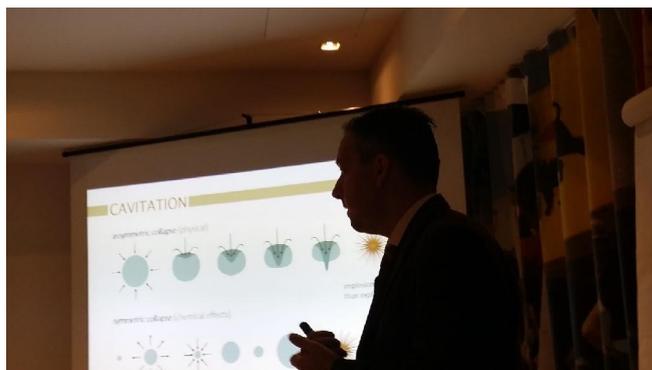


Figure 17 Professor Levente Csoka lecturing at SuNEC 2015, Santa Flavia, Sicily, September 10, 2015: "Wastewater remediation with cavitation technology".

Professor Csoka thus showed the impressive results of applying the technology in to remediate Hungary's sewage and wastewater industrial effluents. Cavitation wastewater treatment technology, he concluded, is economically and technically feasible and will shortly become ubiquitous.

Held in Palermo, Sicily, the 6th edition of SuNEC was opened on September 7 2016, with the plenary talk of Percival Zhang from VirginiaTech on the high-energy efficiency electricity-carbohydrate-hydrogen cycle bridging between primary and secondary energies (Figure 18).^[37]



Figure 18 Professor Percival Zhang lecturing at SuNEC 2016, Palermo, Sicily, September 7 2016: "Constructing the electricity-carbohydrate-hydrogen cycle for a carbon-neutral future".

Synthetic starch obtained from water and CO_2 fixed with the aid of electricity, Professor Zhang explained, is the best solar fuel, namely the most suited energy storage compounds. According to this approach, carbohydrates are renewable materials and high-density hydrogen carriers, which can be used for direct electricity generation *via* biobatteries demonstrated by his team, as well as in microbial fuel cells.

The electricity-carbohydrate-hydrogen cycle, Professor Zhang concluded, will not only supplement future primary energy utilization systems by facilitating electricity and hydrogen storage and enhancing secondary energy conversion efficiencies, but also address such sustainability challenges as transportation fuel production, CO_2 utilization, and fresh water conservation.^[39]

Professor Wouter Maes from University of Hasselt offered an insight on organic PV technology presented from a materials chemist point of view, which suggests clearly the main challenges to render organic photovoltaics a competitive technology (Figure 19). Besides intelligent material design, dedicated material synthesis enhancing purity and yields of newly tailored molecular structures of longer lifetime, he explained, is key to any forthcoming practical application.^[38]



Figure 19 Professor Wouter Maes talking at SuNEC 2016, Palermo, Sicily, September 8, 2016: “Organic Photovoltaics from a Materials Chemist Point of View: Impact of Molecular Structure and Purity on Photovoltaic Performance”.

Reproducibility, especially when upscaling the synthesis of the organic molecules required for making organic PV devices, remains an issue, with the latter technology “struggling to survive” in face of the spectacular growth of PV uptake based on crystalline based on the uptake of crystalline silicon and thin film inorganic semiconductor technologies.

Discussing solar hydrogen production by direct photoelectrolysis of water, Dr. Henning Döscher from Philipps-Universität Marburg and National Renewable Energy Laboratory presented the outcomes of his Lab’s advanced photoelectrochemical testing protocols. It ensured the highest characterization accuracy, where indicated solar-to-hydrogen conversion efficiency matches well with independent incident photon to current efficiency measurements.^[39]

Verified results, he further explained, now exceed 15% solar-to-hydrogen efficiency with pathways towards 20% clearly in sight.

Following this approach, direct photoelectrolysis of water is obtained via tandem absorber structures based on novel inverted metamorphic III-V structures consisting of GaInP (top, 1.8 eV) and GaInAs (bottom, 1.2 eV) junctions and their epitaxial integration enabled by a transparent AlGaInP step graded buffer.

The researches of Dr Döscher and co-workers demonstrated that established solar-to-hydrogen efficiency measurement protocols are often flawed due to spectral mismatch of laboratory light sources and by inadequate device area definition.

Outlook and Conclusions

Between 2011 and 2016, prominent scholars in solar energy science and technology, materials science and energy efficiency gathered in Sicily on the occasion of the “SuNEC—Sun New Energy Conference”.

All were asked to focus on the practical implications of the solar energy and new energy technologies developed at their respective labs and research centers. The motto of the conference (*Solar energy. Now*) indeed pointed to the immediate (*i.e.*, not only tomorrow’s) relevance of solar energy in the context of the unfolding global energy transition from fossil fuels-derived energy to renewable energy.

Reviewing the outcomes of the conference suggests two major achievements and has two lessons to teach.

The first outcome is that concepts and technologies anticipated at SuNEC are now taught to undergraduated

students across the world and practically used to manufacture the clean energy generation and energy storage devices.

Examples include new generation Li-ion batteries discussed by Kang at SuNEC 2012 developed in co-operation with the largest steel and electronics manufacturers in South Korea,^[19] solar hydrogen discussed by Steinfeld,^[12] Balzani,^[7] Koodali,^[29] and Jaccobsson,^[40] utility-scale PV generation presented by Meneguzzo^[4] as well as the need for renewed solar energy^[40] and energy management education.^[41]

The second, and not trivial, result is that some of the new energy science firstly presented at SuNEC have progressed to technology uptaken by industry.

Examples include solar-driven essential oil distillation presented by Amjad and Munir at SuNEC 2013,^[42] hydrocavitation technology for beer making first discussed at SuNEC 2014^[30] and now commercial,^[43] and the first mechanoluminescent fibers (based on the PDMS+ZnS composite discussed by Jeong at SuNEC 2015)^[35] now ready to produce wearable light-emitting fabrics powered by body movement and muscle stretching.^[44]

The first lesson taught by the organization of the international SuNEC conference in Sicily (delegates from over 20 countries, from Saudi Arabia to Australia), is that the outcomes of research and studies in solar energy science and technology are no longer confined to regional or to country-level but have a global economic, social and environmental impact.

When SuNEC was inaugurated in 2011, few scholars and even less energy professionals would expect any significant impact of solar photovoltaics on the global energy production. Uptake in Germany, Spain and Italy was entirely ascribed to the Feed-in-Tariff incentives temporarily deployed in those countries, and PV was expected to vanish with the end of the public incentives, as it had done in the 1970s and in the 1980s.

On the contrary, global solar boom started.^[45] By the end of 2018, the amount of PV power installed across the world had crossed the 500 GW threshold, with 1.6 GW solar parks currently being built in Egypt’s desert in slightly more than a year.^[46]

The second lesson taught by organizing the SuNEC conference is that, even in the era when communication mostly flows through computer and mobile phone networks, attending scientific conferences in solar energy science and technology is of instrumental importance to foster international collaboration, share knowledge and establish personal connections not only with researchers of similar interests but also with participants from different backgrounds beyond academy (*i.e.*, industry, energy professionals, students, civil servants, policy makers and environmentalists).

Organizing the conference in a region (Sicily) known also for its natural beauty and the richness of its historic heritage allowed to achieve the aforementioned goals while enjoying also the extra-curricular conference program.

At the end of the conference program, the delegates at the first five editions of the SuNEC conference explored the ancient Norman town of Cefalù firstly, and then took part in the social dinner served at an ancient Abbazia next to a large winery visit during a guided tour before dinner. Scientific exchange and networking were further eased by the unique conference venue in front of Sicily’s sea.

“I think that this conference, wrote SuNEC 2011 conference delegate Dr. Ibraheem Al-Mofeez from University of Dammam in Saudi Arabia submitting a report to Saudi Arabia’s Ministry of Higher Education as well as to the Ministry of Water and Electricity, was an eye-opener to see Italy at the cutting edge of solar energy materials science”.^[47]

Acknowledgements

This article is dedicated to the memory of Professor Sebastiano Tusa, who opened with his greetings two of the six SuNEC conferences, for all he has done also to promote the adoption of solar energy in Mediterranean countries. We are grateful to all participants to the SuNEC conferences as well as to Piera Demma Carà, now at IOP Publishing, Marzia Sciortino, currently at CNR-ISMN, and Riccardo Delisi, now at Renovo, for their generous organizative collaboration. Thanks to Lorenzo Giuggiolini, StreetLib, for his excellent work in producing the SuNEC Book of Abstracts.

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

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