ACAP 10 YEARS

Creating a pipeline of opportunities

ACAP

THE AUSTRALIAN CENTRE FOR ADVANCED PHOTOVOLTAICS

Ten years of research and technology development in solar photovoltaics

Public Dissemination Report 2013-2023

PURPOSE

The Australian Centre for Advanced Photovoltaics (ACAP) is a national collaboration on research and development in solar photovoltaics, aimed at providing a pipeline of opportunities for performance increase and cost reduction in solar technologies.

Australian Government
Australian Renewable Energy Agency

This Project, the Australian Centre for Advanced Photovoltaics (ACAP), received funding from the Australian Renewable Energy Agency (ARENA).

www.acap.org.au

This report was written and produced by Professor Renate Egan and Alison Potter and submitted to ARENA 12/11/2023.

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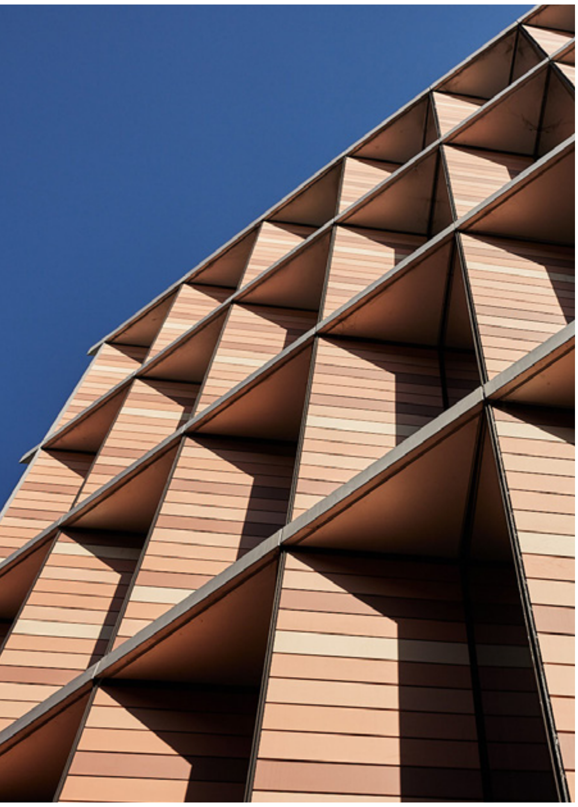

Darren Miller
Chief Executive Officer,
Australian Renewable
Energy Agency
(ARENA)

“It is simply impossible to tell the story of the energy transition without telling the story of solar, and few institutions have been more critical to the enormous progress we have seen in the solar space than ACAP.

“Since the invention of the PERC solar cell right here in Australia in the 1980s, the cost of solar photovoltaics has continued to fall, while efficiencies have only risen. If we can accelerate these trends, we can achieve the ultra-low-cost solar ambition that will be critical to Australia taking our place as a renewable energy superpower.

“Delivered by my alma mater, the University of New South Wales, ACAP brings together researchers from Australia’s top universities to deliver world leading research at the cutting edge of innovation. When ARENA renewed its financial support for ACAP in 2022, it did so recognising ACAP’s long history of achievements. We look forward to the breakthroughs that the efforts over this next decade will bring.”

Dr Gregory Wilson
Independent Chair of ACAP Infrastructure Fund Working Group, Former Director of US National Center for Photovoltaics (NREL)

“This grouping, for a common national purpose, is unique internationally and puts Australia in a strong position to maintain a leadership position in photovoltaics.

“Australia has a remarkable track record of PV technology accomplishments that are very visible in the PV industries and products that exist today.”

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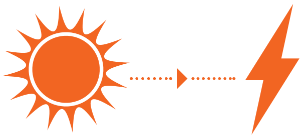
INTRODUCTION



Solar cells convert sunlight into electricity with no moving parts.

When sunlight hits silicon, the material most commonly used in solar cells, its energy frees up electrons in the silicon, that are then able to move within the material and deliver energy.

Electricity is generated by sunlight, just as energy is generated chemically in batteries – but solar cells won't go flat, as long as the sun keeps shining.

Solar now offers the lowest cost technology for new electricity generation and, when combined with storage solutions, offers a clean and competitive solution for 24/7 electricity supply.

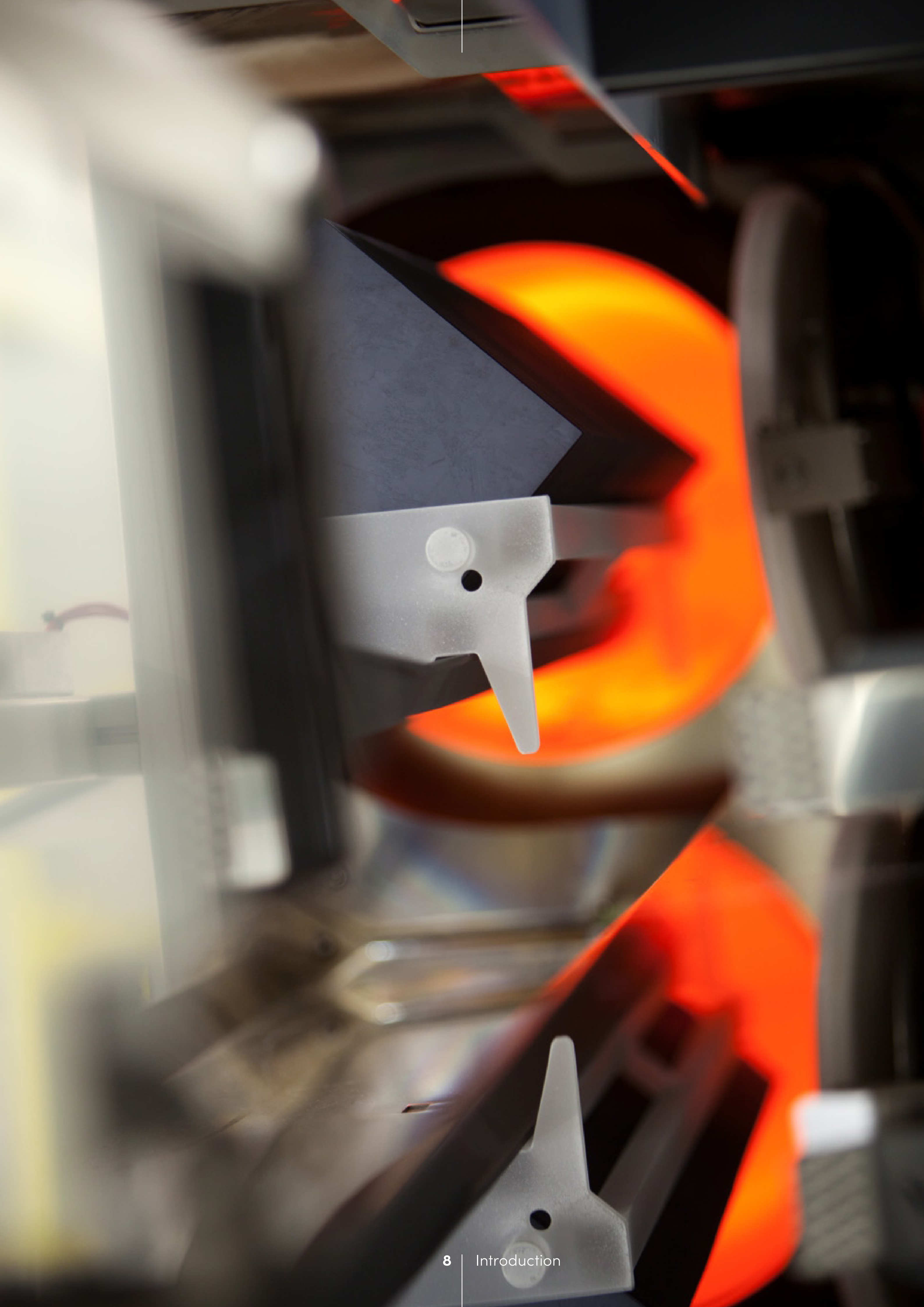
Incredible progress in solar technologies has been achieved over the last decade in research, technology development and industrialisation. As a result, solar is now being installed globally at a rate ten times greater than new coal additions, and one hundred times faster than new nuclear.

Australia has played a major role in the solar technology development and is well positioned to benefit from a greatly expanded role of solar in delivering a zero-emissions energy future.

The Australian Centre for Advanced Photovoltaics (ACAP) was established in 2013 to bring together the leading solar research institutes from across Australia and to build on Australia's strengths in solar research.

ACAP has delivered on its mission to:

- accelerate PV technology development, leveraging past and current funding,
- develop the next generation photovoltaic technologies, to provide a pipeline of opportunities for performance increase and cost reduction, and
- increase capability, to provide high quality training opportunities for next generation scientists, engineers and technologists.



Over 90% of the world's silicon module manufacturing relies on Australian-invented solar cell technologies with cumulative module sales of over $120 billion. The rapid escalation in production volumes means that over 50% of the world's deployed solar panels rely on fundamental technologies that were developed in Australia.

Led by the University of New South Wales, founding ACAP partners include the Australian National University, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Manufacturing Division, University of Queensland, University of Melbourne and Monash University. With recent success in extending the program of work to 2030, ACAP has been joined by the University of Sydney and CSIRO (Energy).

Many world-firsts have been achieved because of the establishment of ACAP, along with the development of new technologies and partnerships. Continuity of research, through ongoing funding, has ensured Australia maintains an international leadership position in solar research and development, with significant global impact in fundamental science and engineering, in technology transfer and commercialisation.

This report includes case studies and snapshots that highlight some of the important achievements and impacts from the first ten years of ACAP's critical work. It is not a comprehensive report of work done and we invite readers to find out more about ACAP members' projects, programs and research plans out to 2030 on the website www.acap.org.au and in the Annual Reports.

DIRECTOR'S REPORT

Professor Martin Green
Scientia Professor at the University of New South Wales, Sydney, and Director of the Australian Centre for Advanced Photovoltaics 2013-2023

Photo by Anna Kucera

It is with great pleasure that I report on the first ten years of ACAP, where we saw the team build on a long tradition of excellence in R&D into solar PV. ACAP has delivered exceptional value on the national and international stage, setting the team up to continue to deliver out to 2030. Highlights of the first phase of ACAP include:

- A national research collaboration that can respond co-operatively to address new opportunities.
- A critical mass of expertise that forms an ecosystem for innovation with direct and indirect benefits.
- Internationally competitive laboratory facilities, distributed between the ACAP partners.
- Innovations in next generation materials that create pathways to 30% efficient module technologies and to widescale deployment of PV technologies.
- Advances in characterisation and performance analysis, delivering new program activities, patents, licences, as well as technology spin-offs and start-ups.
- Students and fellowship training outcomes, that deliver the innovators and workforce needed for the energy transition.
- International recognition through prizes and awards including, most recently, the 2023 Queen Elizabeth Prize for Engineering to the team that invented today's leading solar cell technology.

The outcomes have been made possible by the longer term planning, research initiatives and partner development that comes from long term funding made possible by ARENA, and research and industry partner commitments to the ACAP program.

Partnerships have been forged that have seen new work programs develop between universities, nationally and internationally, and have accelerated development in technologies, meeting milestones on-time and on-budget.

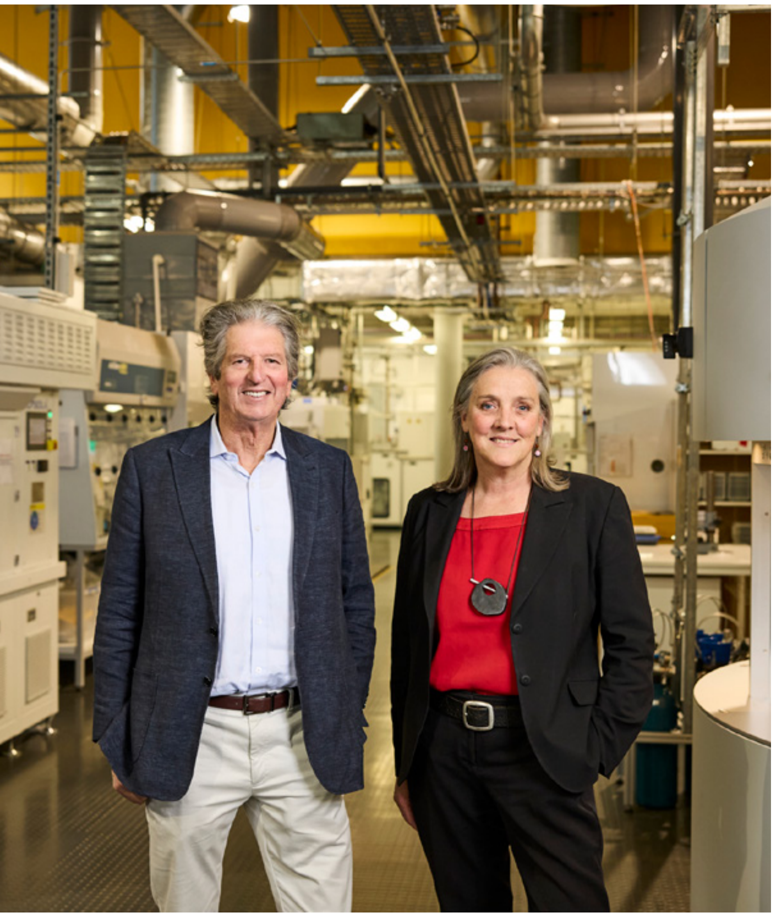
The program and partnerships have evolved with the changing market and industry developments. At the same time, the team has consistently delivered outstanding outcomes on the national and international stage, making a low-emissions technology future possible through the low-cost of photovoltaics.

As the founding Director of ACAP, I would like to thank ARENA for its ongoing support of ACAP, including through the terrific team at ARENA who champion research, development and deployment.

I'd also like to thank the ACAP National Steering Committee, the International Advisory Committee and the support teams at UNSW in the Research Grants Office and Research Finance who have taken on the challenge of managing a diverse portfolio of projects.

Importantly, I would like to thank all of the researchers and the university and industry partners for their contributions to the broad range of progress in advancing photovoltaics.

Finally, I am pleased to be able to see ACAP positioned to thrive in its second phase of research out to 2030, with ongoing support from ARENA, the universities and industry partners, and under the new leadership of Professor Renate Egan, who has taken on the role of Centre Director. I look forward to seeing ACAP thrive and grow, albeit more from the sideline.



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Prof Martin Green with incoming Centre Director, Prof Renate Egan, in the UNSW Solar Industrial Research Facility.

EXECUTIVE SUMMARY

Governance: ACAP is led by an executive team that takes direction from a National and International Steering Committee. A Management Committee coordinates participation of the different partner research institutions.

The group has been effective in maintaining the connection and profile of Australian research in solar technologies with international progress in research and industrialisation, as well as with deployment and integration of solar technologies in Australia.

ACAP has established itself as Australia's leading national collaboration in solar research and development, commercialisation and deployment. It provides the foundation for a broader research program and partnerships, by coordinating national capabilities, in research, facilities and partnerships that form the springboard for outcomes beyond the ACAP program, with a worldwide impact.

In its first ten years, ACAP has delivered on its mission to conduct research and development in photovoltaics technologies to provide a pipeline of opportunities for performance increase and cost reduction.

With ongoing support from ARENA, the universities and industry partners, ACAP is set to continue to deliver on the mission out to 2030, targeting ultra-low-cost solar technologies that are critical to enable a net zero emissions future.

Solar energy is now recognised to provide the lowest cost form of new energy generation, with the Director of the IEA declaring "Solar is King" in 2021, offering a low-cost solution to decarbonisation, and opening up new opportunities in battery storage, transport, green-minerals processing and a hydrogen economy.

The success of solar was made possible by an international effort in research, market development, investment,

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Solar technologies are only at the beginning of their development with solar expected to deliver close to 50% of electricity needs by 2050 (IEA 2023).

and industrialisation. These advances were only possible due to fundamental technology developments, research, education and training in solar technologies, much of it with a basis in the work initiated in Australia and made possible by the ongoing support for research and development.

Solar technologies are only at the beginning of their development, integration and deployment phase, with solar now providing around 5% of the world's global electricity generation. Solar is expected to contribute close to 50% of electricity needs by 2050 (IEA 2023).

There is still much to be done to improve performance, reduce cost and ensure a reliable supply of electricity for homes, businesses and industry. With abundant solar resources, Australia is particularly well placed internationally to benefit from the solar-led energy transition.

Australia's contribution to the development of solar energy technologies has been recognised internationally in the award of significant energy and engineering prizes to members of the ACAP research team, including the 2023 Queen Elizabeth Prize for Engineering to the team that invented today's leading solar cell technology: Scientia Professor Martin Green, Professor Andrew Blakers, Dr Aihua Wang and Dr Jianhua Zhao.

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ACAP is delivering on its mission to provide high quality training opportunities for next generation scientists, engineers and technologists.

In addition, the 2022 Millennium Prize for Engineering, the 2021 Japan Prize and the 2018 Global Energy Prize were awarded to Scientia Professor Martin Green, recognising his contributions to solar technology development.

Further, the wider national ACAP team has been recognised, with recent accolades including:

- Australian 2022 Prime Minister's Prize for New Innovators to A/Professor Brett Hallam
- Germany's 2022 Ulrich Gösele Young Scientist Prize going to Dr AnYao Liu
- Vietnam's 2022 Ten Outstanding Young Faces to Dr Hieu Nguyen
- US 2021 IEEE Cherry Award to Professor Thorsten Trupke
- Vietnam's 2021 Golden Globe to Dr Hieu Nguyen
- Australian 2020 Prime Minister's prize for Science to A/Professor Xiaojing Hao
- Australian 2021 Bragg Award to A/Professor Xiaojing Hao
- Australian Eureka Prize for Environmental Research in 2018 to Matt Stocks, Bin Lu and Andrew Blakers.

SNAPSHOT

IMPACT

16 INTERNATIONAL AWARDS

36 HOT PAPERS (top 0.1% in their field)

15 NATIONAL AWARDS

216 NEW PATENTS

16 NEW RECORD OR BENCHMARK EFFICIENCIES

79 HIGHLY CITED PAPERS (top 1% in their field)

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RESEARCH

Delivering the next generation of cheaper, greener, more efficient solar cells

Solar cell technology is dominated by silicon, with 95% of all solar modules manufactured and deployed being based on the material silicon. With a long history of silicon-based research, ACAP attracts and supports world leading researchers and partners in the research, development and commercialisation of silicon based solar cell and module technologies.

Solar photovoltaics is on a fast growth curve, with the amount of solar being deployed doubling at least every three years. When ACAP started in 2013, the total annual installs globally were 30GW and the total installed capacity worldwide was 100GW. In less than ten years, to the end of 2022, total installed solar had grown tenfold to over 1TW, with over 200GW installed in 2022 alone. The industry is now valued at over US$350 billion per annum and growth is projected to continue, with the annual manufacturing capacity expected to hit 1TW per annum well before 2030.

The rapid industrialisation and the significant investments in silicon based solar manufacturing continue to drive advances in technology. The research team at ACAP remains actively engaged in the incremental technology development that is happening in industry, as well as leading in research on step-change developments. With significant growth potential across the sector, the team contributes to improvements in materials and device technologies, in sustainability, in new methods of manufacturing and deployment, and in innovations in process optimisation, independent quality assessment and performance monitoring.

The past and future success of solar for low-cost energy generation lies in the use of abundant, low-cost materials, and the reliability and scalability of the technology. As a result, silicon-based technologies are expected to remain at the heart of future solar cell technologies for at least the next decade.

Silicon is:

Abundant
Close to 95% of the solar modules ever made rely on the material silicon, and we are unlikely to ever run out of silicon as it is the second most abundant material on earth, after oxygen.

Reliable
Solar modules are robust and reliable, with modules designed and built to deliver within 10% of their original power after 25 years.

Low cost
With decades of research and huge investments in manufacturing, the price of solar modules has plummeted, from $20/W to 0.20c/W since 2000, making silicon photovoltaics the lowest cost form of energy generation. A constant drop in the price of batteries means locally generated solar plus storage can now compete effectively 24/7 with electricity delivered through energy networks.

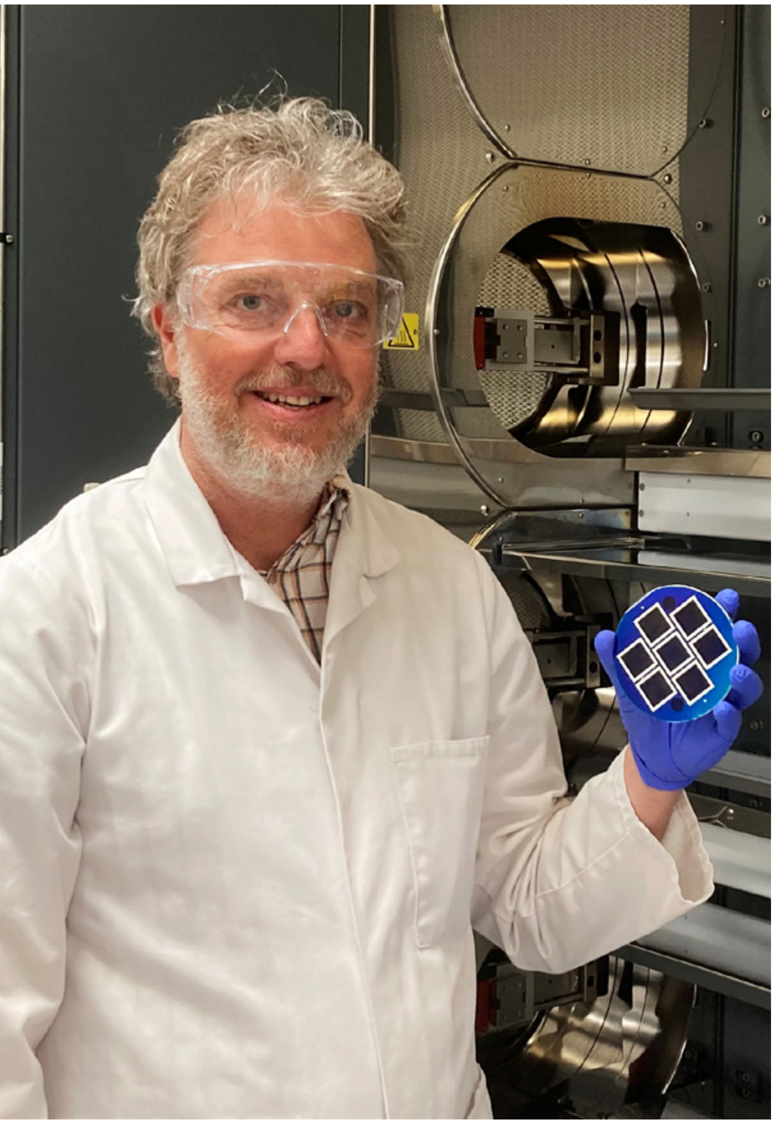
Scalable
The solar cell working in tiny sensors is the same as the solar cell working as one cell in a million in a large-scale array. The reproducibility and scalability of silicon cell technology is a significant factor in the increasingly competitive costing of silicon solar cells.

Reflecting the strengths of silicon-based technologies, ACAP research has focused on improving the performance of solar cell technologies through advances in materials and device processing.

Professors Dan Macdonald at ANU and Bram Hoex at UNSW co-lead an ACAP collaboration on silicon solar cell technologies, contributing to international progress on improving material quality and improving device performance.

ACAP SUPPORT PROPELS AUS SILICON PV R&D TO WORLD RECORD EFFICIENCIES

Dan Macdonald
Associate Professor, ANU College of Engineering, Computing and Cybernetics



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With the support of ACAP funding Associate Professor Dan Macdonald and his team at ANU have built and maintained critical mass in several key areas of silicon research.

Associate Professor Daniel Macdonald co-leads the silicon solar research at ANU as well as that University's engagement with ACAP. He says ACAP's sustained funding support has enabled critical planning, investment, coordination and collaboration amongst silicon PV researchers.

"The real advantage of ACAP comes from the fact that it enables collaboration and provides continuity. During ACAP1.0 we built up capacity in terms of skills, people and equipment," says the world-leading expert in silicon materials and solar cells.

"Now we've got that critical mass, we're ready to go and start making the most of ACAP2.0 from day one."

The silicon solar cell research team at ANU consists of 25 researchers, including academics, post-doctoral fellows, PhD students and technical staff.

Support through ACAP1.0 has enabled ANU to build and maintain critical mass in several key areas of silicon research. These include silicon materials, device modelling and characterisation, new materials and architectures for high efficiency solar cells, and transfer of technology to industry.

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ANU's Silicon Research Group, led by Associate Professor Dan Macdonald.

MacDonald says ACAP's sustained funding support has enabled critical planning, investment, coordination and collaboration amongst silicon PV researchers.

One of Macdonald's major contributions to solar PV development has been demonstrating that many metal impurities are much more detrimental in p-type silicon (used in the mainstream PERC cell technology) than n-type silicon, because of their charge state. This is one of the reasons why n-type cells (TOPCon and heterojunction) are now emerging as the dominant technology in industry.

His team at ANU showed that trace quantities of iron impurities limit the electronic quality of Ga-doped p-type Cz wafers, which are used in industrial PERC cells. Fortunately, these iron impurities move to the surface of the wafer during high temperature cell process steps, where they are trapped by heavily doped layers, rendering them inactive.

This beneficial 'gettering' effect is also present in TOPCon cells fabricated with n-type Cz wafers, in which iron has a reduced, but still important, impact. The presence of this iron means that a special pre-gettering step is required for the fabrication of heterojunction cells, which do not have their own high temperature processing steps.

> "I'm proud to think that through basic scientific discovery, we were able to have an impact on the direction of the industry," says Dan Macdonald.

Dr Anyao Liu from the ANU silicon group won the 2022 Ulrich Gösele Young Scientist Award for her pioneering work on impurity gettering.

They are also working to better understand the formation and impact of so-called 'ring' defects in Cz wafers, which are often observed during cell processing, and can be highly detrimental to cell performance. These defects are caused by oxide precipitates, but the conditions required to trigger their formation remain poorly understood.

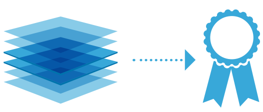
The silicon team at ANU also has a strong presence in device modelling and characterisation. They use 3-dimensional simulations to identify the primary sources of power losses in solar cells. Combined with advanced luminescence-based characterisation methods, some of which were developed jointly between the ANU and UNSW teams, they can accurately trouble-shoot cell fabrication processes.

In the first round of ACAP Infrastructure funding, ANU installed an advanced optical characterisation cluster, expanding the ability to study the many structural, morphological, and optical properties of solar cells to understand the causes of losses in efficiency.

ANU's silicon group also explore new materials and architectures to further improve the efficiency of silicon solar cells.

With the second round of funding ANU was able to purchase a cluster of next generation processing tools that enable rapid development and testing of new materials and designs for solar cells. Researchers can create thin films of materials with precise control over their thickness and composition. The facilities are available for use by other ACAP nodes.

"Our ultimate goal here is to discover the ideal passivating contact structure ... That's a long term quest, a five-to-eight-year mission, and under ACAP, we can go ahead and get started."



The ANU silicon team contributed to the commercialisation of n-type TOPCon cells and modules, leading to multiple world record efficiencies for full-size cells.

"Our ultimate goal here is to discover the ideal passivating contact structure, which simultaneously allows outstanding surface passivation, electrical contact, and optical transparency – a combination which is very challenging to achieve in practice," says Macdonald.

"That's a long term quest, a five-to-eight-year mission. And under ACAP, we can go ahead and get started. Whereas, if we were funding it through smaller projects, it stops and starts, staff move on, and it would be a lot more disjointed."

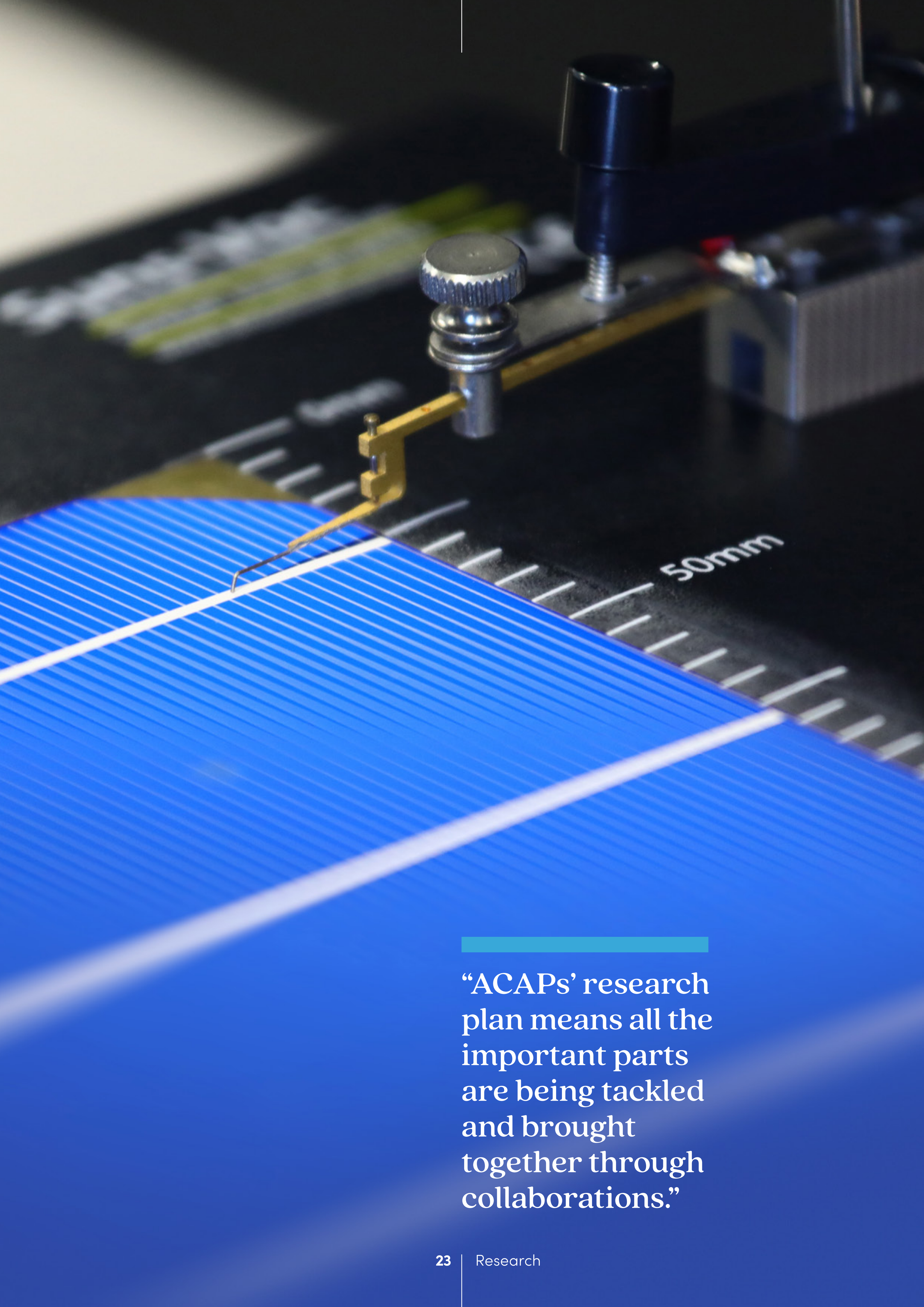
Most of this work is focused on doped poly-silicon films formed at high temperatures, and doped metal-oxides such as titania and copper oxides formed at low temperatures. Macdonald says they apply these new materials to small-area prototype solar cells made in the laboratories at ANU.

The ANU silicon team also works closely with industry to bring new solar cell technology to mass production. They have a longstanding partnership with Jinko Solar and contributed to the commercialisation of n-type TOPCon cells and modules, leading to multiple world record efficiencies for full-size cells using this technology, including 24.8% in 2020, 25.4% in 2021, and 26.4% in 2022.

Macdonald sums up, "ACAP's systemic funding to several different nodes has helped us work together. ACAP's research plan means all the important parts are being tackled and brought together through collaborations between the partners in a productive way."

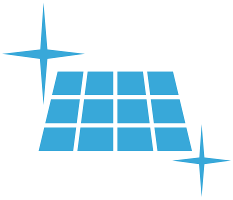
"It really helped to strengthen our collaboration with UNSW," says MacDonald.

"We are now more visible on the global stage, and we're more attractive to industry partners to work with."



“ACAPs’ research plan means all the important parts are being tackled and brought together through collaborations.”

NEXT GENERATION PV OPPORTUNITIES

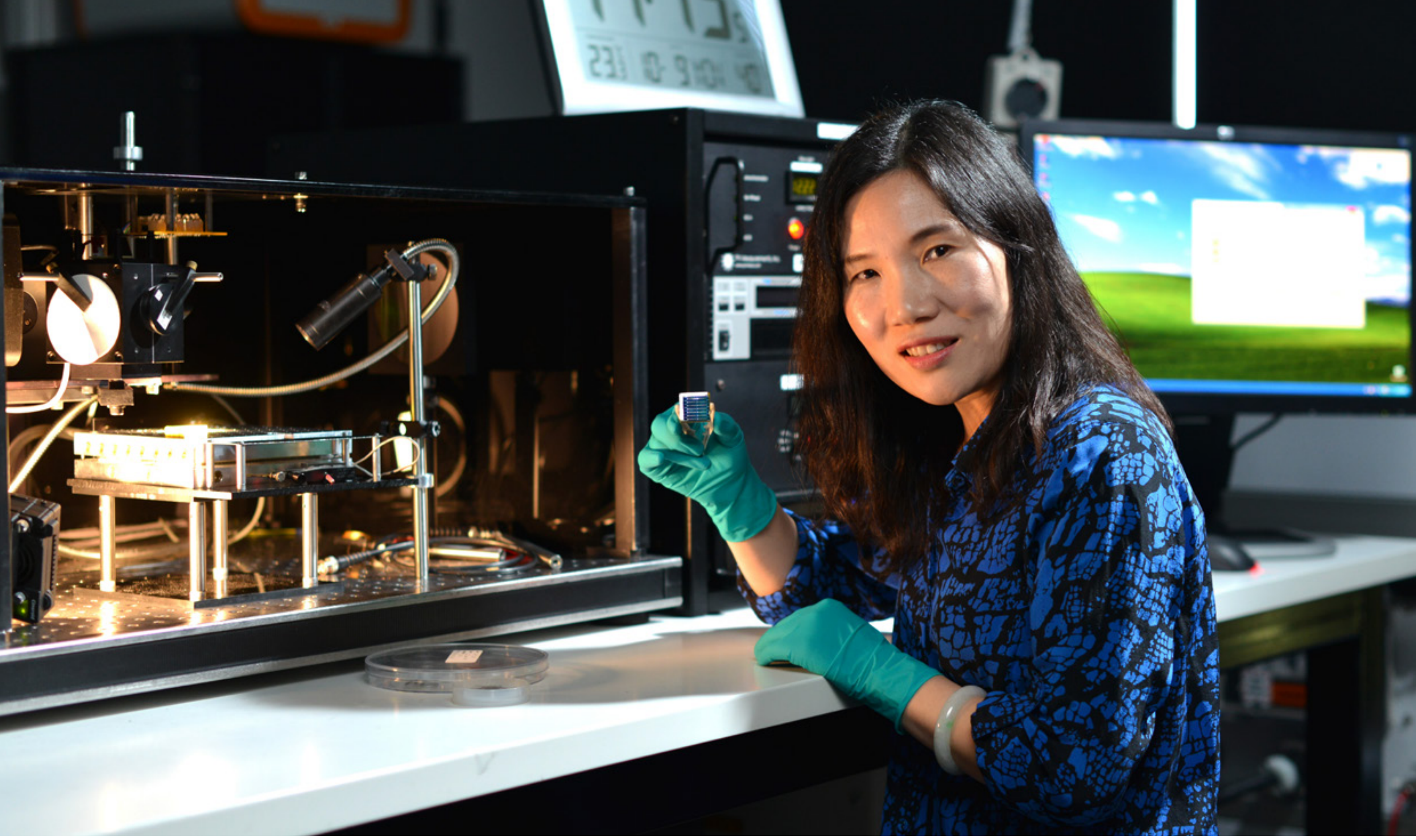


Over the last ten years, research under ACAP has continued into new materials for their applications in photovoltaics. These include: earth-abundant materials groups known as chalcogenides; organic semiconductors; an exciting materials group including perovskites; and the next generation device technology of tandem devices.

While silicon dominates current solar technologies, the potential for better performance from more advanced cell technologies remains an opportunity for increased power, reduced cost and greater uptake of solar.

Next generation opportunities in solar continue to be explored as part of the ACAP pipeline of opportunities, including exciting new materials, new device structures and new applications. Tandem technologies offer the promise of an efficiency boost, by stacking two solar cells, one on top of the other (with silicon normally as the bottom cell) to make the most of the available sunlight and deliver more power per unit area.

Pursuing increased performance in earth-abundant materials groups, Professor Xiaojing Hao and her team have achieved national and international success including setting and maintaining performance benchmarks, and recognition through the 2021 Prime Minister's Prize for Science.



RISING STAR SOLAR CELLS – EARTH ABUNDANT, NON-TOXIC, THIN FILM TECHNOLOGIES

Professor Xiaojing Hao
ARC Future Fellow, FTSE, FAIP, School of Photovoltaic and Renewable Energy Engineering, UNSW

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UNSW's Professor Xiaojing Hao has devoted ten highly successful years to the development of low cost, high efficiency, thin film solar cells and tandem solar cells.

Perovskite and kesterite are rising stars in thin film solar cell development, but they've each posed significant challenges with stability and efficiency, respectively. However, UNSW Professor Xiaojing Hao and her ACAP-supported team have made significant discoveries that are edging these exciting materials closer to commercial-competitive status.

Thin film solar cells can be utilised alone or in tandem with silicon wafer solar cells to achieve higher efficiency. They are potentially cheaper, lighter, flexible and more versatile. These features, together with their short energy pay-back time, means they are crucial to expanding the capacity of solar to meet the world's energy needs. They have the potential to be ubiquitous and, as Hao says, "We have solar energy everywhere."

When Xiaojing Hao was 11 years old and in grade 6 at primary school, her uncle gave her a solar-powered calculator from Taiwan. She was fascinated by its ability to draw power from sunlight and work without a battery and wanted to understand the theory behind it.

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Professor Hao and her team of researchers have achieved five world record efficiencies with novel kesterite solar cells.

"I've always been very curious," says Professor Hao, a Fellow of ATSE. "I'm also always trying to find a better way to do things. When I'm driving my daughter to school, I'm often thinking about a faster way to get there. In my research and daily life, I look for patterns to find a way to improve them, just like the patterns in the traffic."

Professor Hao has devoted 10 highly successful years applying these qualities to the development of low-cost, high efficiency, thin film solar cells and tandem solar cells. Her achievements have garnered multiple prestigious awards including the Australian Academy of Science Pawsey Medal and the Prime Minister's Prizes for Science; the Malcom MacIntosh Prize for Physical Scientist of the Year.

Increasing the efficiency of earth abundant, non-toxic kesterite solar cells

With ACAP funding, Hao and her team of researchers have achieved five world record efficiencies with high bandgap kesterite (CZTS), a potentially transformative semiconductor material for thin film, flexible solar cells and Si-based tandem cells, and one world record

"We all want our children to grow up in a world where the climate is stable and energy is produced without pollution. We are working to accelerate the transition to 100% clean energy," says Hao.

efficiency with low bandgap kesterite (CZTSe). The current highest efficiency for the former CZTS is 11.4% (UNSW) and that of the latter is 14.9% on lab scale cells, moving it ever closer to a stable, commercially acceptable efficiency.

The current commercialised high efficiency thin film PV technologies that can be applied to flexible surfaces are either expensive or have toxic components. Kesterite, on the other hand, is a copper zinc tin sulfide mineral (CZTS) whose elements are all earth abundant, and have proven long term stability. And very importantly, it's non-toxic.

"We all want our children to grow up in a world where the climate is stable and energy is produced without pollution. We are working to accelerate the transition to 100% clean energy," says Hao.

Kesterite's theoretical efficiency is over 30% but progress in getting there has stagnated in recent years. Hao and her team have reset the path towards beyond 20% efficiency by changing the focus of their research to control defects and microscale inhomogeneity, as the properties of the material can vary significantly from crystal-grain to crystal-grain and the grain boundaries can trap the photo-carriers.

In the past this has been ignored because it is hard to study and measure. But Hao's team have found it to be a dominating defect through their developed performance diagnosis and optimisation platform via linked advanced characterisations and 3D device simulation. She says, "We discovered that severe grain boundary recombination is the current limiting factor of these CZTSe solar cells."

Nonradiative recombination is a process where electrons and holes, that a solar cell

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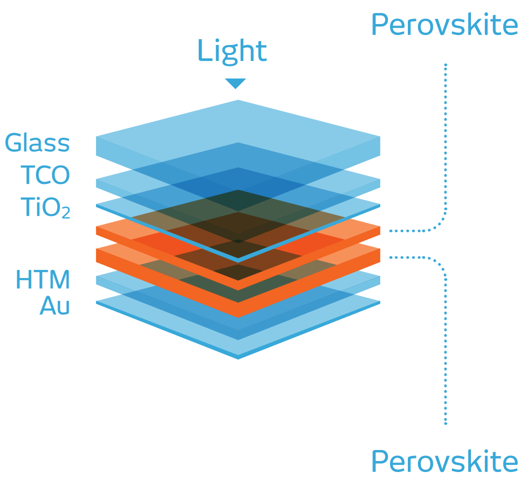
ACAP funding has been critical for developing and retaining valuable researchers, says Professor Xiaojing Hao, seen here in the lab with Dr Chang Yan.

needs to separate and send to opposite contacts, recombine, releasing energy in the form of heat, and thereby reducing the energy conversion efficiency of solar cells. Recombination often occurs at grain boundaries, where charged carriers are trapped due to defects and imperfections. Additionally, microscale inhomogeneity within the material further complicates the situation as the defects may vary. To tackle these micro-scale challenges effectively, a fundamental prerequisite is a comprehensive understanding of them.

Hao says, “The results of this work have cleared the mist in the path to >20% efficiency kesterite.”

Device structure



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Device architecture of a simple, thin-film perovskite solar cell.

Improving the stability of perovskite solar cells

Perovskite has shown high efficiencies of 26.1%, but one of the critical issues limiting the development of perovskite solar cells (PSC) is instability. Hao and her team came late to working with perovskites, but they've applied the strategies and knowledge they've accumulated improving the efficiency of kesterite solar cells and, after just three years of work, they've achieved PSC stability rates that are among the best in the world.

Despite being heavily used in world record efficiency perovskite solar cells, the hole transport layer material (HTM), Spiro, usually requires a lithium-containing dopant to improve its electrical properties. Unfortunately, the mobile lithium ions decrease the cell stability.

Hao's team were aware that sulphur and lithium coordination made stable compounds, so they developed a doping method that uses a cheap sulphur-based additive that 'locks-in' the lithium in the hole transport layer, improving Spiro's conductivity and achieving the high efficiencies.

Happily, they then discovered that the addition of sulfur containing material, DDT, also makes the dopant an oxidation agent with a quick, controllable oxidation process and the potential to speed up production of perovskite cells.

Additionally, the addition of DDT makes the hole transport layer repel water and prevent water ingress. These are all important for cell stability.

Hao and her team have shown that perovskite cells fabricated with the novel additive were able to maintain more than 90% of the initial efficiency after operating at maximum power point under one sun illumination for 1,000 hours.

Further, they maintained more than 93% of the initial efficiency after staying at open circuit condition under one sun illumination for 2,000 hours. This reported stability result is the best in Australia and among the highest in the world. The UNSW team have a provisional patent in place for the DDT additive.

> “ACAP funding holds particular importance for Australia as it plays a vital role in retaining local PV skills and talents.”

ACAP’s role retaining valuable skills in solar cell development, and in Australia

Professor Hao says she has outstanding ACAP fellows in her team working on kesterite and perovskite solar cell and tandem cells development and stresses the importance of ACAP funding for retaining valuable researchers.

She says, “ACAP funding holds particular importance for Australia as it plays a vital role in retaining local PV skills and talents. Without adequate funding to secure our early career researchers, we risk losing them to overseas opportunities or even entirely different fields at a rapid pace.”

“ACAP also provided grants that enabled us to delve into new ideas and kickstart fresh research partnerships, especially on an international scale, where a multitude of diverse perspectives and competencies converge to tackle complex research problems.”

With a vision to low-cost, printable solar cells, the team at CSIRO, working with University of Melbourne and Monash University have been developing innovative production capabilities in roll-to-roll printing. Success with printed solar cells would enable a vision for low-cost coatings on flexible surfaces that is positioned to open up new markets and new applications for solar cells.

ACAP INFRASTRUCTURE FUNDING TAKES PEROVSKITES TO THE CUSP OF COMMERCIALISATION AT CSIRO

Dr Anthony Chesman
Principal Research Scientist in CSIRO Manufacturing and Group Leader of the Renewable Energy Systems Group at CSIRO Manufacturing

"Solar for everyone everywhere" – that's the ambition of the Printable Photovoltaics (PPV) Team at Australia's national science agency, CSIRO, who are passing critical milestones in making flexible perovskite solar cells (PSCs) cheaper and easier to manufacture.

With the support of ARENA via ACAP, the PPV Team have taken thin-film PSC technology from the laboratory and developed cost-effective roll-to-roll printing and coating techniques that have the potential for large-scale manufacturing in Australia. And, with an ACAP-funded pilot printing facility due for completion in early 2024, they'll be demonstrating PSC production at scale, showing industry that this technology is on the cusp of commercialisation.

PSCs emerged in laboratories 15 years ago. They've been shown to be just as efficient as silicon solar cells for small-scale devices. Their value lies in the fact they can be fabricated using flexible substrates with the potential for cheaper production, a higher power-to-weight ratio, and broader application. Market applications are expected to include extra-terrestrial devices, transport, and anywhere solar cells would need conform to a curved surface.

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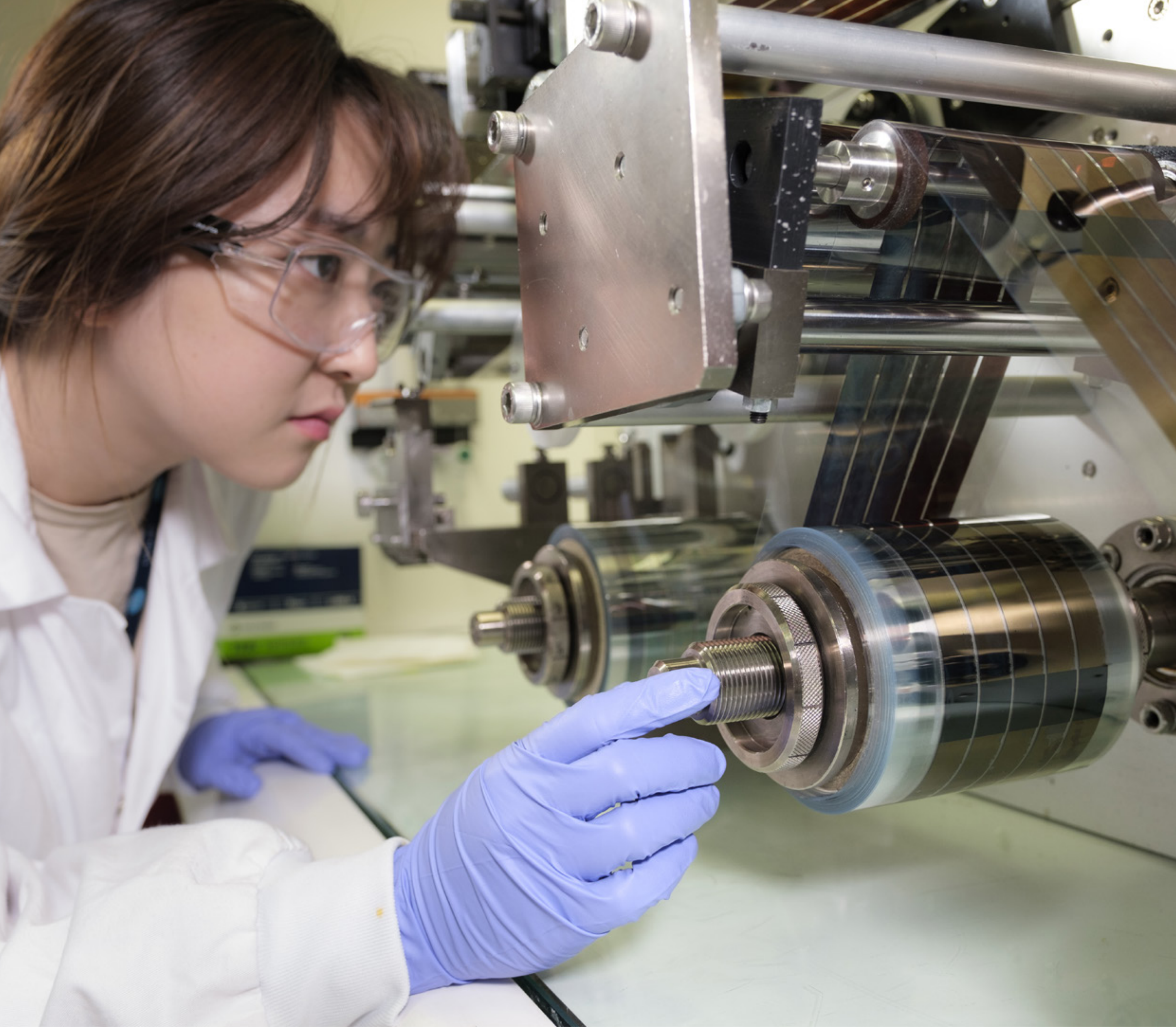
Régine Chantler of the Renewable Energy Systems Group, CSIRO Manufacturing, holding flexible organic solar cells produced at the Flexible Electronics Laboratory, Clayton.



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Dr Juengeun Kim from the Printable PV Team, CSIRO Manufacturing, fabricating flexible perovskite solar cells at the Flexible Electronics Laboratory, Clayton.

"A lot of these solar cells are fabricated in a laboratory using methods which aren't scalable or affordable," says Dr Anthony Chesman, Group Leader of the Renewable Energy Systems Group at CSIRO Manufacturing. "Our challenge is to go from something smaller than your fingernail up to large sizes that can be tailored for real world applications."

"These new methods can be undertaken in ambient conditions, with high throughput, and are ultimately cheaper," says Chesman. "At commercial production scales, we think 30 cents per watt is achievable."

“We’re working on demonstrating that this simple, low-cost process can be done at scale.”

Flexible electrode fabrication without solvents and heat

A particular hurdle for the team was developing an affordable substitute for the gold electrode that could be deposited without causing solvent and heat damage to the cell.

At the laboratory scale, a gold electrode is typically evaporated to complete the device. However, if this technique is used for commercial production, this would account for up to 70% of the cost of the module.

Therefore, the team swapped gold for a cost-effective printed carbon and silver-based electrode with high electrical conductivity. They fabricated the electrode with carbon and silver pastes printed on a detachable plastic substrate. The beauty of this technique is that the pastes could be pre-treated on hot plates to evaporate any of the harmful solvents before being laminated onto the perovskite cell with a press. The carbon electrode strongly adhered to the PSC and the plastic substrate was removed and could be re-used.

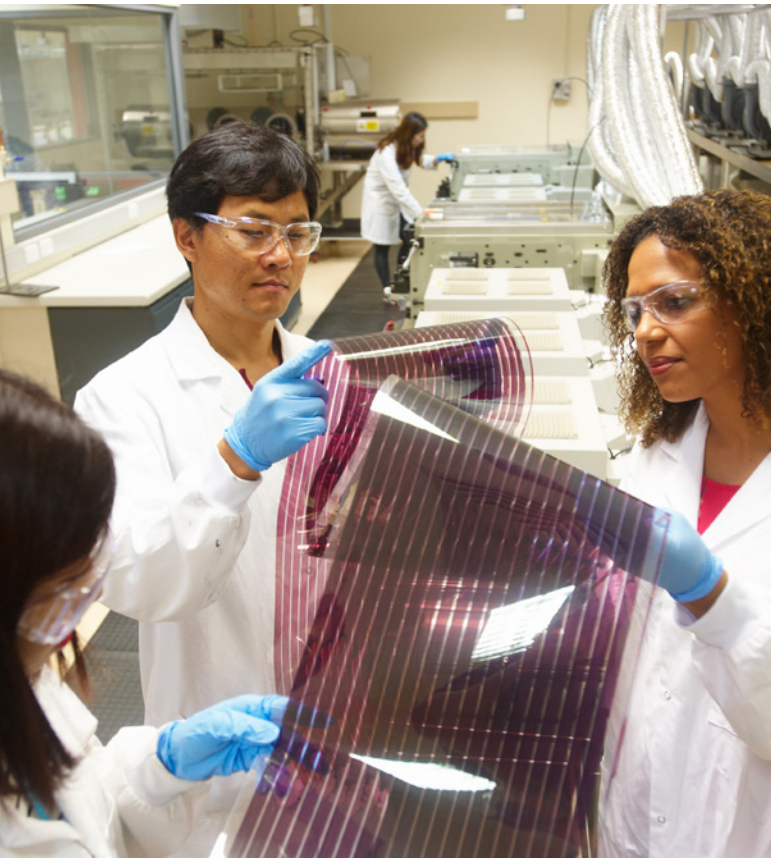
This process doesn’t require a vacuum environment, uses cost-effective materials, and eliminates the need for solvents and heat during the deposition process, thereby eliminating degrading effects.

Printing perovskite solar cells in an ambient environment

The best performing PSCs made in a laboratory setting use a spin-coating process to make the perovskite layer. This involves heating and conditioning steps to control the crystallisation of the perovskite films and is commonly performed in an inert environment. This fabrication process is not technically or commercially feasible for large-scale PSC production.

To tackle this challenge, the PPV Team has adapted existing roll-to-roll printing processes to prepare flexible PSCs. These processes include slot die coating, reverse gravure coating, and screen printing, all of which are already used in industry for commercial products.

"We've had to formulate inks that work well with these methods and will give us highly crystalline films with precise layer thicknesses. That's where the challenge is," Chesman explains.



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Members of the Printable PV team in CSIRO Manufacturing examine flexible solar cells prepared at the Flexible Electronic Laboratory, Clayton. The team has developed cost-effective roll-to-roll printing and coating techniques that have the potential for large-scale manufacturing in Australia.

The new printing and fabrication methods produced flexible PSCs achieving a record high power conversion efficiency of 16.7%. And even after testing with 3000 cyclic bends, the flexible, roll-to-roll-fabricated PSC showed outstanding mechanical stability and minimal loss of solar cell performance.

Pilot-scale printing facility takes flexible PSC to the cusp of commercialisation

"One of the big-ticket items to come out of ACAP for us is the ACAP Infrastructure Funding," says Chesman. "That funded a substantial portion of our pilot-scale facility which is in the process of being commissioned."

"This is a bespoke printing facility to bridge the gap between laboratory and industry-scale production. We will be using that facility to its fullest to demonstrate to industry that this technology is on the cusp of commercialisation."

"Internally, we've also been working a lot on using machine learning and AI to predict optimal formulations and deposition conditions. Several members of the team have developed high-throughput production methods which have really

> "Where an individual would normally create 20 solar cells by hand in a day, this can now be increased to 15,000 using the automated setup."

accelerated solar cell production and characterisation."

"Results from these cells can then train a machine learning model, which will predict what's going to be the best formulation and deposition conditions for high efficiency solar cells."

"We hope that this, coupled with the large-scale print facility, will really propel the technology forward."

"It is a process of iteration and constant improvement. There are opportunities for improvements in ink formulations, improvements in deposition processes. There are also opportunities in encapsulation, which is really important to extending the lifetime."

"When we improve all of these factors in parallel, we get increased efficiencies and increased lifetimes, and also reduce the cost."

Developing Australian industry

Dr Chesman is particularly excited about this, developing a technology that can be produced in Australia.

He says, "There have been challenges in producing renewable energy technologies in Australia, particularly silicon solar cells, which involve production methods which are quite energy intensive, and high capital costs to commission these facilities."

"To work on a technology that has a lower threshold is exciting."

"It would be just a fantastic achievement to see a renewable energy technology that is produced in Australia, integrated into applications in Australia, and have the end user in this country. That, to me, would be a real achievement."

ACAP NODES ADVANCE EARTH ABUNDANT SUB-MODULE SOLAR CELLS

Professor Paul Burn
Laureate Fellow, University of Queensland, Director of the Centre for Organic Photonics & Electronics (COPE), School of Chemistry and Molecular Biosciences

Backed by ACAP, Professor Paul Burn and his team at the University of Queensland have developed new techniques to improve the efficiency of large area sub-module organic (plastic) and hybrid perovskite solar cells, and other ACAP nodes have drawn on their work.

"It's quite clear that the annual ACAP meetings, where people present their work, enable research outcomes to be disseminated within the Australian community much faster," says Burn.

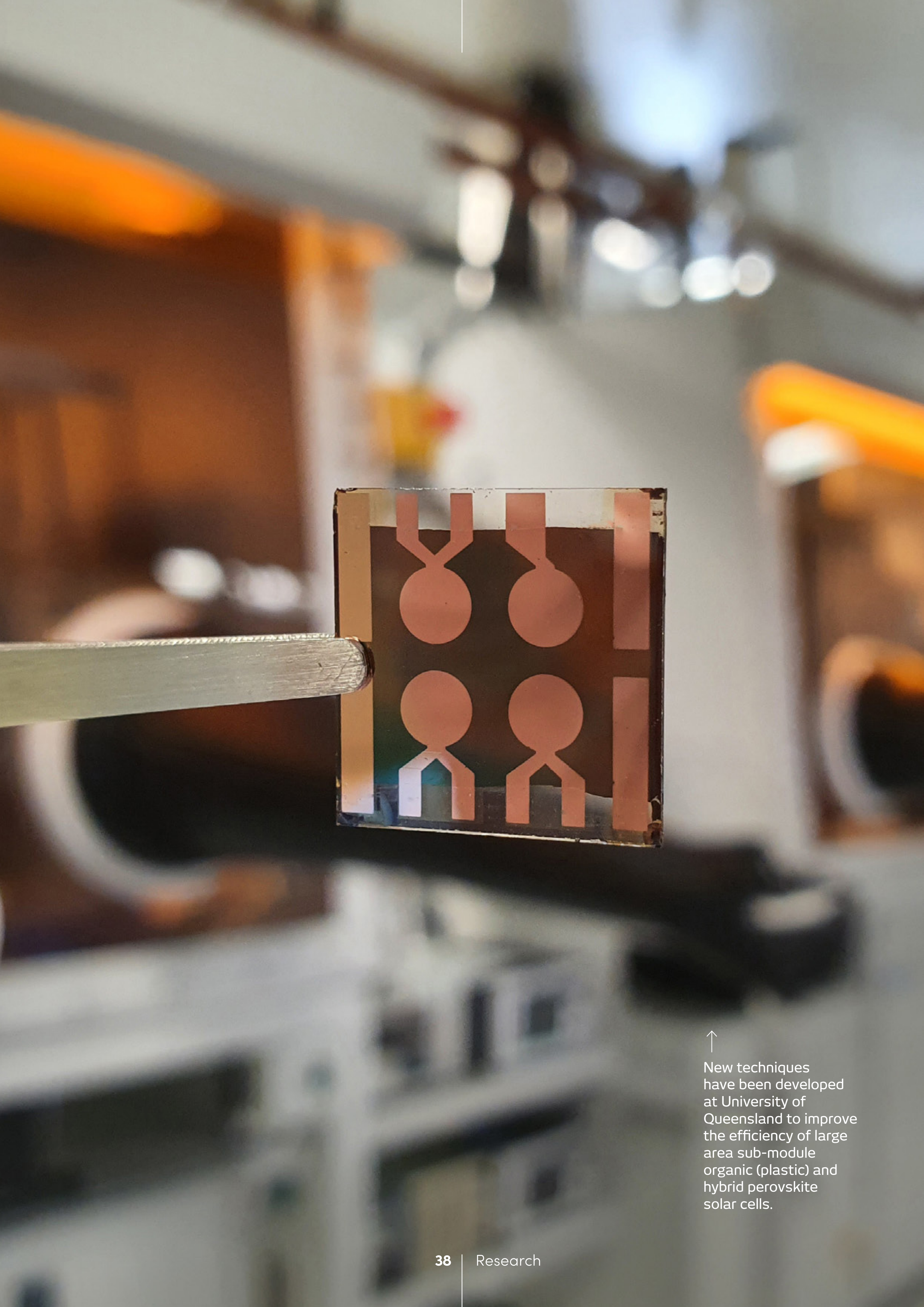
Organic and perovskite solar cells have the potential to be low-cost and flexible. Thin films of the light absorbing materials can be coated over large areas, but there are challenges successfully implementing these into sub-module solar cells.

Professor Burn and his team addressed two of the main challenges facing large area organic and perovskite solar cells: sheet resistance in the transparent conductive electrode materials, and the high defect densities associated with thin semiconductor junctions.

Reducing the impact of electrode sheet resistance on the efficiency of sub-module solar cells

Professor Burn and his team have developed new approaches to electrode materials that enable scaling solar cells from laboratory size to sub-module, whilst maintaining a good efficiency.

Organic and perovskite solar cells require a transparent conductive electrode to let



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New techniques have been developed at University of Queensland to improve the efficiency of large area sub-module organic (plastic) and hybrid perovskite solar cells.

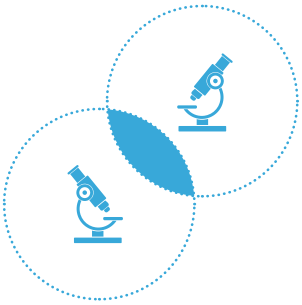
the light into the device as well as collect the electricity. The standard material used is indium tin oxide (ITO), but it has problems for sub-module solar cells. One of these is its relatively high sheet resistance that impedes the flow of electricity when cells have dimensions greater than about a centimetre. Thus, when a device is scaled up from a typical laboratory size of 0.2 cm^2 to the sub-module size of 25 cm^2, the sheet resistance of ITO leads to a significant reduction in the efficiency of the device.

In one approach, Burn and his team used an aluminium grid on top of the ITO to keep the sheet resistance down and maintain the relatively high efficiency of the sub-module devices. The approach they developed was not limited to 25 cm^2 sub-modules but could be scaled to larger areas. They demonstrated that their technique worked for both organic and perovskite cells.

Burn's ACAP Research Fellow Dr Hui Jin then undertook modelling to find out the best arrangement of these electrodes to optimise the amount of electricity extracted.

Burn and his team also developed a new type of organic solar cell that is free of the brittle and relative expensive ITO. Replacing indium-based electrodes will become imperative as easily mineable reserves of indium are depleted. The new cell type uses a transparent semiconductor/metal/semiconductor anode consisting of a molybdenum oxide/silver/zinc sulfide stack.

The new monolithic solar cells with an area of 25 cm^2 could be made on both rigid (glass) and flexible substrates. The new solar cells were found to have a power conversion efficiency 1.8 times higher than the efficiency of equivalent ITO-based organic solar cells.



Burn says that, while solar cell research is a broad church, there is cross over amongst his team and the other ACAP nodes in thin film technologies.

> “Through efficient information exchange, all the nodes benefit … by having knowledge shared faster than the traditional publication route.”

Burn says that while solar cell research and development is a broad church there is crossover amongst his team and other ACAP nodes in thin film technologies, and in particular the perovskite materials.

“We developed a way of stabilising a perovskite layer towards water and moisture using additives. We reported that at one of the meetings and our colleagues at the CSIRO said, ‘That’s really exciting. We make roll-to-roll solar cells. Would we be able to have some of this to test?’

“So, we then made a large batch of the additive and sent it to them so they could fabricate their devices. Gratifyingly, the additive also worked with their larger scale manufacturing process,” says Burn.

Dr Anthony Chesman from CSIRO says, “We don’t develop new materials within our team, so we are always keen to source new materials when they become available to see how they can enhance our device performance.

“When we saw the encouraging results presented by Paul regarding the incorporation of fluorine-containing compounds into their devices, I inquired about the possibility of obtaining some for use in our scalable roll-to-roll coating process. This led to a great improvement in a number of parameters of our solar cells, and this collaboration led to the publication of our first joint perovskite paper with UQ.”

Burn concludes, “Through efficient information exchange, all the nodes benefit either directly through collaboration, or indirectly by having that knowledge shared faster than through the traditional publication route.”

SNAPSHOT

KNOWLEDGE SHARING

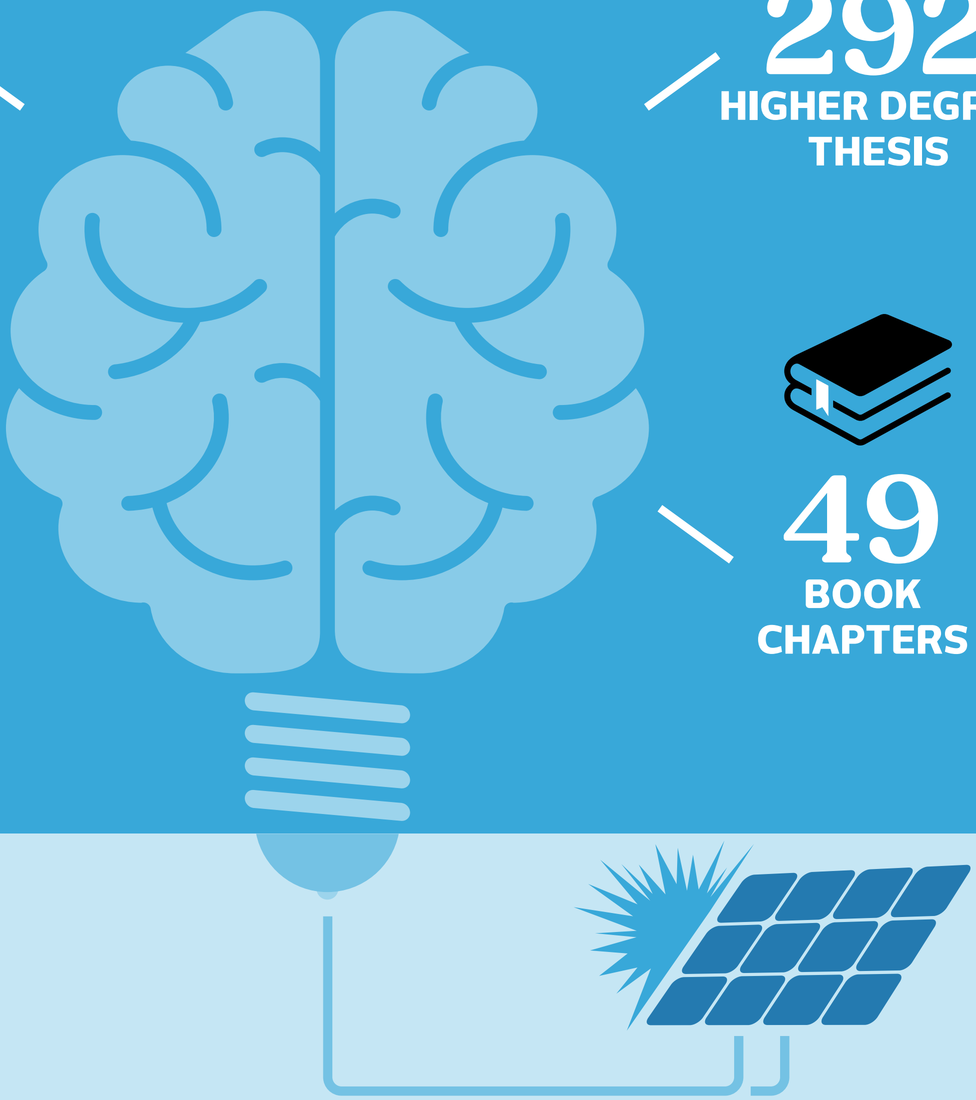
2,026
JOURNAL PAPERS

1,722
CONFERENCE PRESENTATIONS

292
HIGHER DEGREE THESIS

7
BOOKS

49
BOOK CHAPTERS



3

CAPACITY BUILDING

Empowering the next generation of leading engineers and scientists

ACAP alumni have played a leading role in a diversity of successful Australian start-ups including SunDrive, SOLARCYCLE, PV Lighthouse, 5B and Solar Analytics, and gone on to take leading roles in Australian industry from Ausgrid and AEMO to Fortescue and Worley Parsons.

As solar grows to have an increasing role in energy generation worldwide, the demand for skilled engineers and technologists is growing, with evidence now for growing demand for engineers with skills in solar technology, in manufacturing, in deployment and in power engineering.

To meet this need, education, training and capacity building has formed an important part of the knowledge sharing program over the first ten years of ACAP. Significant outcomes include the graduation of over 290 engineers and scientists with higher degree education in solar cell technologies, with ACAP supporting scholarship, research and national and international collaboration.

ACAP trained engineers, technologists and innovators go on to roles in industry, to deployment, to create start-ups and to establish new research initiatives. Our network of alumni can be found worldwide, in research institutions and in solar cell manufacturing, creating a global network of partners for current and future research collaborations.

ACAP alumni can also be found at Australian companies including 5B, SunDrive, Solar Analytics and Sun Cable, and contribute to nearly all significant large-scale solar project activity and in grid integration in Australia.

ACAP has delivered a program of education, training and knowledge sharing including competitive fellowships, workshops and conferences. The Fellowship Program empowers promising young engineers and scientists to develop research initiatives, creating the next generation of leaders.

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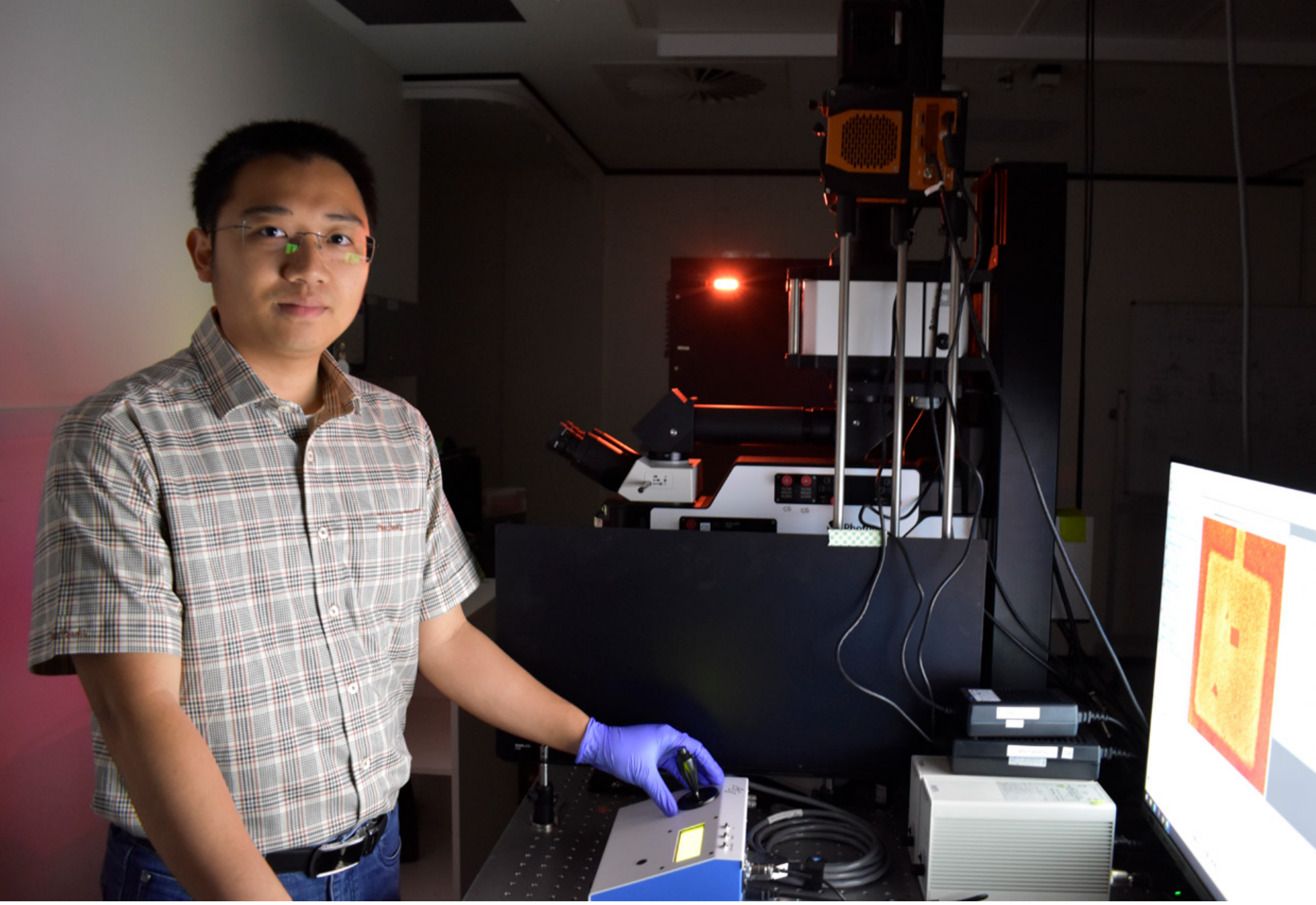
The Fellowship Program empowers promising young engineers and scientists to develop research initiatives, creating the next generation of leaders.

In four competitive rounds 62 fellowships were awarded, developing talent across the full range of research programs and partner institutes. Project activities covered the diversity of research in the ACAP program, including:

- improvements in silicon materials that have contributed to wholesale changes in manufacturing
- investigating new materials opportunities, stability and efficiency of perovskite solar cells
- developing costing methodologies that are now being applied to analysis of investment opportunities in solar manufacturing and deployment in Australia
- innovations in recycling processes that have seen new companies set up, securing millions in investment.

We profile here two of our successful fellows as examples of how the Fellowship program is used to identify talent and can act as a springboard for future success.



UNLOCKING THE SECRETS OF EMITTED LIGHT, AND THE SKILLS OF JUNIOR COLLEAGUES

Dr Hieu Nguyen
Senior Research Fellow and Senior Lecturer in the School of Engineering (SoEN) at ANU

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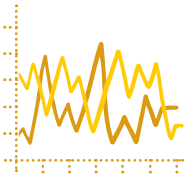
Dr Hieu Nguyen with the hyperspectral imaging tool which was funded by ACAP and is part of the Advanced Optical Cluster at ANU.

ANU ACAP recipient Dr Hieu Nguyen considers his mentoring of many early career solar PV researchers to be as important as the significant contributions he and his team have made to solar development by deciphering the clues that come from light emitted from photovoltaic materials.

Dr Nguyen earned his PhD from the Australian National University (ANU) in



Hyperspectral luminescence imaging provides a richly detailed view of solar cells, allowing researchers to identify many potential problems.

2016, under the guidance of A/Professor Daniel Macdonald and Dr Fiacre Rougieux. Nguyen's doctoral research focused on the science and practical applications of luminescence phenomena in silicon materials and solar cells.

Now a Senior Research Fellow and Senior Lecturer at ANU, Dr Nguyen is advancing solar photovoltaic technologies through a combination of knowledge acquisition, scientific discoveries, and technological innovations. His research activities range from fundamental investigations to practical applications.

He and his team explore the fundamental properties of light-matter interactions within photovoltaic materials and devices, under various conditions. They aim to uncover the intricate relationship between absorbed and emitted light and key material/device properties, including optical, electrical, chemical, and structural characteristics.

Leveraging these findings, the team devises innovative device concepts, advanced characterisation techniques, and defect engineering approaches. Many of these techniques have been adopted by research groups around the world.

One such technique uses hyperspectral luminescence imaging to get a richly detailed view of different solar cells and identify many potential problems. ACAP researchers are working on various solar cell technologies that have the capacity to be more efficient and less expensive than current solar cells, but they still need to undergo a lot of optimisation to reduce defects and degradation.

A hyperspectral camera creates a hyperspectral cube, a type of image that contains information about the light

“I’ve mentored many junior colleagues in ANU’s PV solar group, helping them achieve successes in their academic careers.”

emitted from a material at different wavelengths. This information is used to extract various optical and electrical parameters of the solar cells, such as the bandgap, light absorption, voltage, and carrier lifetime.

The technique allows the researchers to track how the properties of the solar cells change during fabrication and to identify defects or degradation over time. It could be used to improve the performance and reproducibility of new solar cell technologies.

Visiting researcher at NREL through a collaboration grant

In 2017, through the support of an ACAP Collaboration grant, Nguyen spent 9 months at the US’s National Renewable Energy Laboratory (NREL) as a visiting researcher. Nguyen used different microscopy and imaging tools there to understand defects and impurities in silicon solar cells. Since then, this collaboration has grown stronger, resulting in numerous successful joint grants and publications.

ACAP has further supported Nguyen with two consecutive ACAP Fellowships (2018-2022), during which he advanced to a senior position and established himself as a leading name in PV device physics and characterisation.

Additionally, ACAP provided funds for the establishment of two state-of-the-art optical and device characterisation clusters and facilitated networking through small collaboration grants.

Tending solar PV’s brains trust

These initiatives have allowed him to mentor the next generation of PV researchers and scientists by supervising multiple PhD students and junior postdocs.

In fact, Nguyen's dedication to teaching and research supervision has garnered recognition through several awards, including the ANU Dean's Award for Excellence in Supervision, ANU Supervisor of the Month, and Dean's Award for Excellence in Teaching.

"I've supervised three PhD students to completion and another three are on track to complete next year. The PhD graduates have been very successful in their careers, with two working as post-docs at ANU and one landing a position at the University of Queensland. The first PhD student, Mike Tebyetekerwa, won an ARC Discovery Early Career Researcher Award (DECRA) Fellowship 2 months ago."

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ACAP trained engineers, technologists and innovators go on to roles in industry, deployment, to create start-ups and to establish research initiatives.

"I've also mentored many junior colleagues in the ANU's PV solar group and beyond, helping them achieve successes in their academic careers. In particular, I advised and shared my journey with the junior colleagues on how to establish and lead a research group, apply for grants, and I reviewed their grant applications."

"I also shared with them my teaching journey and practices to help them shape their teaching philosophy and practices. Many of them have become key educators for the ANU School of Engineering."

Nguyen's contributions to the field of science and technology led to his receipt of the 2021 Vietnam Golden Globe Awards in Science and Technology for Young Scientists, awarded by the Vietnam Ministry of Science and Technology, and his selection as one of The Ten Outstanding Young Faces of Vietnam in 2021, conferred by the Prime Minister of Vietnam.

Nguyen credits ACAP for enabling the proliferation of understanding, expertise and techniques in his team, all of which are benefiting PV research around the world.

BUILDING A TRUE SOLAR CIRCULAR ECONOMY

Dr. Pablo Dias
Chief Technology Officer
SOLARCYCLE, US
ACAP and SPREE Alumni
UNSW Sydney

"We're not a recycling company, we're a circular economy company," says Pablo Dias, co-founder, and Chief Technology Officer of SOLARCYCLE, a California-based company that offers solar asset owners a low-cost, eco-friendly and patented technology platform for retiring solar panels and repurposing them for new uses.

"We extract 95% of the value out of the panel and return it to the supply chain. That's 95% of the value, not volume," he says. "In simple terms, 50% of the value is in less than 3% of the weight."

Currently, there aren't a lot of commercial solar panel recyclers operating in the market, and most of these companies simply remove the aluminium frame and the wiring, and shred the glass. This extracts about 80-90% of the volume of the panel but the valuable silicon, silver, and copper are more challenging to separate. Instead of being used to their potential these high value materials are often used as filler in concrete or roads, as is the glass.

Dias says, "If there's no supply chain for an extracted material, or no application, then we plan to make the product ourselves to make sure that every resource that is available is being used to its maximum potential, as opposed to being used as a filler material."

The glass is a good example. SOLARCYCLE's process uses advanced technology that separates the glass from the laminate without contaminants. The extracted glass material is very high quality and markets can be found for it. But SOLARCYCLE also plans to make high-value solar glass with the repurposed materials, returning solar materials directly back to the domestic manufacturing supply chain.

From concept to company

Within 12 months of starting SOLARCYCLE in 2022, Dias and his co-founders raised an impressive $US37 million in funding. Since then, they've built their first large, advanced recycling facility in Texas, and they're currently building the second in Arizona. They're also looking at a third facility in the Southeastern region of the US.

Since opening in 2022, the company has signed dozens of recycling agreements with leading renewable energy companies in America. Just this November, the company signed an agreement with EDF Renewables North America, one of the largest renewable developers in North America, to recycle solar panels damaged or broken

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High purity solar glass extracted from end-of-life photovoltaic panels. SOLARCYCLE plans to make high-value solar glass with the repurposed materials, returning solar materials directly back to the domestic manufacturing supply chain.

“We extract 95% of the value out of the panel and return it to the supply chain. That’s 95% of the value, not volume.”

during construction and operation from their grid-scale, distribution-scale, and onsite solar sites.

Dias is a world leading expert in processes and methodologies for recycling and recovering valuable material from photovoltaics and e-waste. Prior to starting SOLARCYCLE, Dias was an ACAP Research Fellow and lecturer at UNSW. His research involved designing, evaluating, and testing new processes for recycling and remanufacturing solar panels.

SOLARCYCLE’s patented disassembly process

SOLARCYCLE’s process starts with collecting solar arrays, determining if the panels are suitable for recycling, and stripping them of their aluminum frame using proprietary technology. The glass is then separated without contaminants from the laminate, using first of its kind technology.

The remaining 10-15% is the ‘sandwich’ structure with the concentrated valuable materials and polymers. Because of its small volume, it’s cheaper to transport to a refinery. The sandwich is shredded and crushed, and proprietary separation techniques are used to separate the higher value particles like silicon, silver, and copper.

“It’s super easy to sell these,” says Dias.

The remaining small volume of low-value plastics are then repurposed in different applications.

The process doesn’t use any chemicals or emit hazardous pollution. The dust created is collected onsite. And the two-step process can be replicated anywhere to reduce transport and logistics costs.

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Laminate after the glass has been fully removed. Over 50% of the material value of a solar panel is in this fraction.

Secondhand solar farms

Solar panels that have been removed from service and sent to SOLARCYCLE's Texas recycling facility may end up powering the facility.

"It's a revolutionary concept," says Dias. "Right now, we're deploying the first secondhand solar farm that I know of in the world, on our recycling site in Texas. It should be ready by the end of the year."

"We test them, and if they still have some life, we deploy them to power the recycling facility. You can't ask for anything more sustainable than that!"

The important role of ACAP

Dias says the work he did with ACAP and the people he met through UNSW were invaluable to advance the SOLARCYCLE technology and innovative processes. "The key is to be able to scale solar recycling so that it works outside of the university walls."

"If you know ACAP and UNSW you'll know that the people there are of a very high calibre. There's a large network of valuable industry partners, and people who work both at the uni and in industry. We were able to ask: what would this look like? Is this feasible? Is it scalable?"

> **"If you know ACAP and UNSW you'll know that the people there are of a very high calibre."**

The ACAP funding allowed for a comprehensive, iterative process to continue testing and seeking solutions that were technically effective, economically feasible and environmentally friendly.

"Often," says Dias, "a narrow approach to research in this space is to design a solution, go into the lab, get your results and publish the data."

"Instead, [at UNSW with ACAP] we'd develop a new process, we'd qualify it, then we'd characterise it. Then we checked what the economics looked like in the lab, and then expanded this into industrial processes to see if it's feasible. If it's not, then we asked, how do we make it better?"

"We also worked with very good people doing the life cycle assessment to check the process. If it's not environmentally friendly, we're not doing it."

"If you start employing techniques like chemical processing to extract the most valuable materials, you're using a bunch of resources and energy. Some of them, like the solvent toluene, are really nasty chemicals."

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Solar panels stacked and palletised inside a storage warehouse, prior to recycling.

Making the solar circular economy feasible

There are many players in managing the end-of-life of solar panels: consumers, manufacturers, un-installers, transport, government regulators, waste management, and materials processors. Additionally, regulations vary across the world.

"The US has little to no recycling regulations and asset owners need to be willing to recycle for it to happen," Dias explains.

"The industry wants to do the right thing. Our job is to lower the cost of recycling to compete with the cost of landfilling the panels. This would negate the need for regulation."

EU regulations require 85% collection and 80% recycling of the materials used in PV panels.

"In Victoria, in Australia, landfilling of PV is banned. This eliminates the main low-cost and environmentally 'unfriendly' competitor: landfill. It allows businesses to approach the problem and compete."

Dias reflects, "It was lucky that something I cared about became so important today. I am ten years ahead of anybody that's starting today looking into these things."

"When I was working on novel recycling approaches at UNSW, our team was always thinking about and testing processes that would be viable to implement outside university walls. Now, at SOLARCYCLE, we have taken recycling to another level of development as we create scalable, industrial level solutions for recycling solar."

SNAPSHOT

CAPACITY BUILDING

182
EARLY CAREER RESEARCHERS

349
HONOURS STUDENTS

171
MASTERS STUDENTS

392
PHD STUDENTS

62
ACAP POSTDOCTORAL FELLOWS

72
SEED FUNDED PROJECTS

4

EMERGING OPPORTUNITIES

Developing a pipeline of prospects

We are only at the beginning of solar's rise. It's now recognised as the lowest cost form of new electricity generation and is expected to dominate the energy market over the next decades, but, with less than 5% of the world's electricity delivered by solar, there's a long way to go. New challenges are expected, and new solutions imagined.

The team at ACAP are charged with looking ahead to identify opportunities and new markets for solar technologies.

Industry often looks to the deep expertise accessible through a research partnership with ACAP to explore challenges and accelerate learning. Often, an unexpected opportunity emerges from existing research, at other times an industry partner presents with a technology challenge or industry opportunity ahead.

Industry often looks to the deep expertise accessible through a research partnership with ACAP to explore challenges and accelerate learning.

Industry looks to the deep expertise within ACAP to explore challenges and accelerate learning. Seed funding of early-stage research often results in support for the partnership in larger programs of work.

In support of discovery, ACAP runs competitive rounds to seed new research activities and to develop new partnerships.

Since 2013, ACAP has completed 72 small project activities out of six competitive rounds.

Seed funding supports a diversity of projects including: new concepts that require a small amount of support to gain traction; new partnerships where a commitment from ACAP establishes a collaboration opportunity; and also bridging activity, to maintain a well-developed idea or talent as a larger program or spin-out is being negotiated.

EFFICIENT DIAGNOSIS OF DEFECTS IN SOLAR PLANTS USING PHOTOLUMINESCENCE IMAGING

Dr Oliver Kunz
Research Fellow on outdoor photoluminescence imaging, UNSW

UNSW Research Fellow and ACAP grant recipient Dr Oliver Kunz has a vision. He wants to see solar panels reliably generating electricity for 30-50 years or more after installation. And, he says, crucial to this endeavour is effective and efficient quality control in the field.

To this end, Kunz and his team have developed a way to use photoluminescence (PL) imaging technology for solar plant surveillance in full sunlight without any contact or interfering with the plant's operation – something that's never been possible before.

PL imaging uses the emission of infrared light from a semi-conductor material to create a rich and detailed view of features in the material. The emitted light is the photoluminescence. It is produced when electrons in the material become excited by a light source and then relax back to their lower energy state. This light is not visible to the human eye.

The brightness of the emitted light is directly related to the quality of the material. Defects and degradation show up as darker spots in the images and expert analysis can determine the root cause of the problem.

PL imaging is considered the gold standard for assessing defects and degradation of solar panels.

The problem

Surveillance of solar farms for early detection and diagnosis of faults or degradation is crucial to speeding up the feedback loop and ensuring reliable, least-cost system power output, and the supply of panels that will go the distance.

The largest solar farms are now at gigawatt scale and, thus, have several million modules installed. Global demand for panels is huge, and the pace of technological development is rapid.

But this breathtaking pace of development and exponential scaling of production comes with risk.

"The current high efficiency PERC silicon technology will soon be replaced by even higher efficiency solar cell technologies that have been developed: TOPCon and heterojunction (HJT) solar modules.

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Dr Oliver Kunz with a custom drone taking daylight photoluminescence images on a utility scale solar farm with this system for the first time. The first stage of development of the drone-based imaging was made possible by small project funding under ACAP.

“If there are any problems with solar modules in the field, we need to detect them as early as possible and then inform the industry that something needs to be changed.”

“They’ll be rapidly rolled out at an industrial scale and the transition will happen in the next two to three years,” explains Kunz.

“With such a pace, you don’t have time to thoroughly test large quantities of all these new module types for years in the field.”

Modules are put through accelerated stress testing over a few months, but some things only go wrong with time or under broader environmental conditions. Logistics, manufacturing methods and supply chain pressures can also impact the quality of the modules. Solar manufacturers are contracted to supply high volumes of solar modules and may be forced to compromise on their choice of suppliers and the quality of production materials.

Kunz says, “We have seen panels failing after a short time.”

“If there are any problems with solar modules in the field, we need to detect them as early as possible and then inform the industry that something needs to be changed.”

PL imaging can identify: microcracks that are not visible to the naked eye; defects or impurities in the crystal structure of the solar cell; series resistance effects; and the presence of various degradation mechanisms.

PL imaging can also be used to monitor degradation of the solar cells over time – helping the identification of modules that are degrading prematurely.

It’s worth noting that it was only in 2005 at UNSW when PL imaging was first successfully used on large area silicon wafers. Since then, it’s become a core enabling technology in solar PV R&D and is used at most PV research institutes and leading solar cell manufacturers.

Until now, though, PL imaging of solar cells has only been possible under laboratory conditions, usually using lasers and specialised filters in a darkroom. But sunlight is thousands of times brighter than the photoluminescence from the solar panel so it's not possible to use the same technologies in the field in daylight.

The technological breakthrough

To achieve outdoor PL imaging of installed PV modules during the day, Kunz and his team have developed a method that uses specific optical filtering and lock-in imaging techniques to tease out the tiny PL signal from the modules under bright daylight conditions.

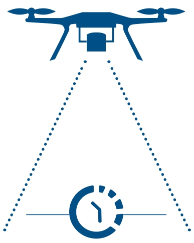
Another breakthrough has been to do this without the need for touching any of the electrical connections. The use of an optical modulation technique on single modules or strings of modules was paramount to this.

Another method the team developed uses ultranarrow bandpass filters that image solar panels in a sub-nm wavelength bandpass channel where virtually no light from the sun reaches the earth's surface, but where PL emission from solar panels is high.

Using these techniques from elevated platforms or drones significantly speeds up inspection times and allows surveillance of large sections of solar farms in a very short amount of time. If something interesting is picked up, then more detailed inspection can be carried out from the ground or via near-field drone-based inspection.

The inspection only minimally affects the power output of a solar farm.

Large scale module inspection of solar farms typically involves drone-based



Using these techniques from elevated platforms or drones significantly speeds up inspection times and allows surveillance of large sections of solar farms in a very short amount of time.

Until now, surveillance and testing of solar modules in the field has been more cumbersome and expensive.

infrared thermography which detects infrared heat emissions, but it has limitations. Infrared imaging cannot detect many electronic defects in solar panels and, in many cases, it does not have the image quality required to carry out root cause failure analysis. Detailed testing of installed solar modules has previously involved removal and transport for testing offsite, or costly in-the-field electroluminescence imaging techniques performed at night-time.

Kunz says, "[In electro-luminescence testing] operators typically unplug strings of solar panels at night and then plug in generators and push current into the strings, which requires quite a bit of equipment, and personnel with very specific training."

"In contrast, our outdoor technology is simpler to use and does not require changes in system wiring or working at night."

Applications in industry

The technology is not yet commercialised but future applications in the industry include assessments of the health of solar plants at commissioning stage, for insurance purposes, and when there's a change of ownership. The technology can also be used for damage assessment after severe weather events such as hailstorms.

Other commercial opportunities arising from the technology include the provision of the monitoring service, analysis of the data, and selling or leasing the hardware to take the measurements.

The team is assessing all of these options in a follow-on ARENA grant.

There's also potential for the technology to be used with commercial and residential

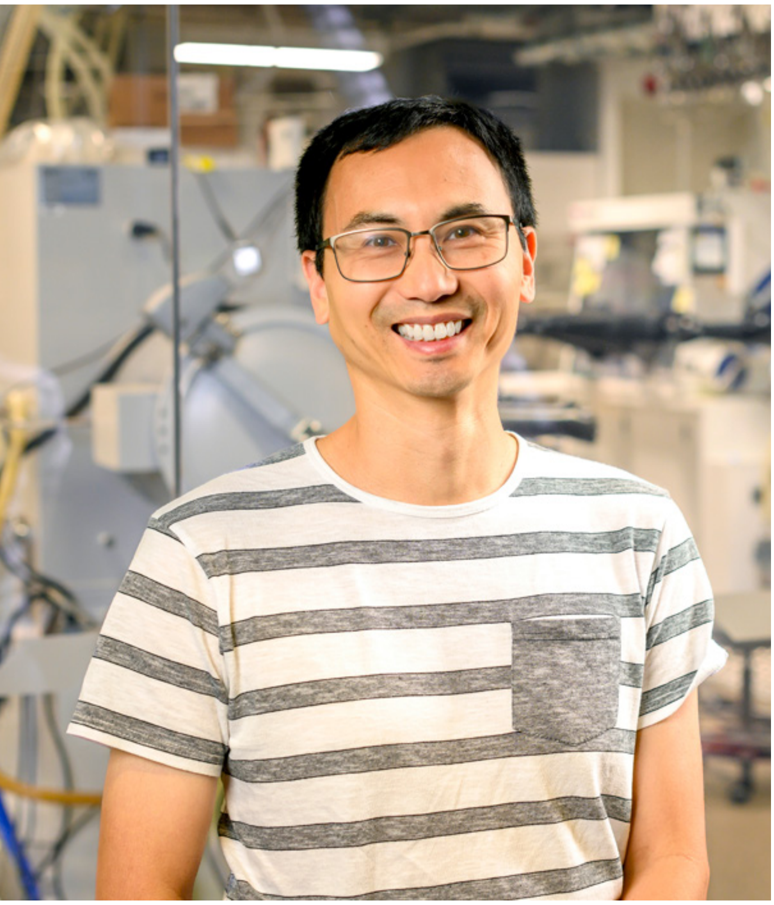
> "In contrast, our outdoor technology is simpler to use and does not require changes in system wiring or working at night."

rooftop systems, although there are tight regulations around the flying of heavy drones capable of carrying the required equipment in built up areas.

In the future, there is potential to scale the application of the technology by combining it with automated piloting of the drones, and machine learning for automated processing and analysis of the data gathered.

"The longer solar panels last, the more energy you get back from them and the less costly the energy is for everyone. But we also need to rapidly work towards a truly circular economy with as little waste streams as possible," says Kunz.

"The longevity of solar panels is an absolute core requirement of that and we hope our work can contribute to this goal."



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Dr Nathan Chang used industry experience in setting up manufacturing lines to develop new models and methods for assessing the cost of new technologies, and to project where future prices were going.

WHEN EVERY CENT COUNTS - BUILDING THE CASE FOR PV MANUFACTURING IN AUSTRALIA

Dr Nathan Chang
Postdoctoral Research Fellow and Manufacturing Program Lead (ACAP), UNSW

Dr Nathan Chang joined ACAP in 2015 to do his PhD after working for over a decade in the solar panel manufacturing industry.

Dr Chang reflects, "When I started in solar in 1998, solar panels were selling for over $10/W. When we took an Australian technology into manufacturing in 2005, our target was $3/W. By 2010, we were chasing $1/W and now solar is less than 20c/W."

"The rate of change is phenomenal, driven by research and technology development, and by scale."

Nathan used his industry experience in setting up manufacturing lines in his PhD research to develop new models and methods for assessing the cost of new technologies, and to project where future prices were going.

Nathan completed his PhD in 2018 and the skills he developed have since been sought after by research and industry, in Australia and internationally, as solar becomes increasingly competitive.

Based on his work, and through seed project funding, ACAP has developed collaborations with SunCable on optimising technologies for large scale solar deployment, and with the Australian PV Institute (APVI) on the supply chain for solar manufacturing. In both cases, the work was started with seed funding under ACAP and has grown to more substantial research programs, attracting new partners and independent funding.

Nathan now leads the ACAP's Program of work on Manufacturing Issues, along with colleagues at CSIRO. This program is looking at manufacturing issues and opportunities; at sustainability for solar as deployments grow from hundreds of gigawatts to terawatts; and at end-of-life management for solar technologies, including redeployment and recycling.

"We are optimistic that we can bring elements of the solar manufacturing process back to Australia."

"We are at an exciting stage of solar development where, through confident investment in large-scale manufacturing in China, we have been able to achieve an incredibly low cost of solar," says Dr Chang.

"As a result, we have a viable solution for a net-zero emissions economy and there are commitments worldwide to deploying solar at large scale over the next decade. This creates a whole new industry opportunity."

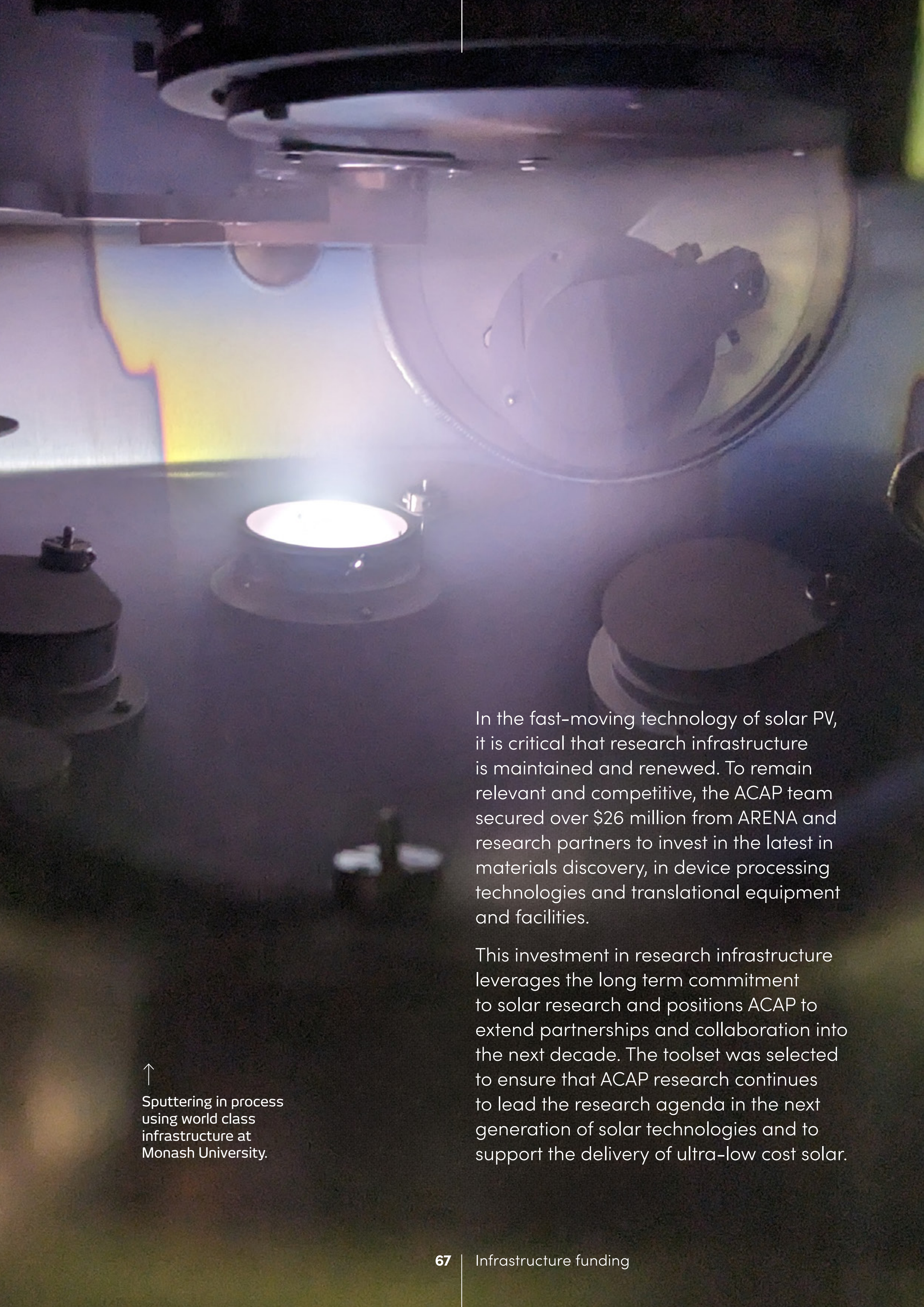
"In our work on supply chains, we are asking how and where Australia could play a role in manufacturing the solar modules needed in Australia, and around the world? We want to leverage Australia's role in technology development and make the most of our vast solar resource."

"By working closely with industry, government and investors, we are optimistic that we can bring elements of the solar manufacturing process back to Australia and make a significant contribution to the world's needs for solar modules."

5

INFRASTRUCTURE FUNDING

Investing in tools and facilities to fast-track discovery



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Sputtering in process using world class infrastructure at Monash University.

In the fast-moving technology of solar PV, it is critical that research infrastructure is maintained and renewed. To remain relevant and competitive, the ACAP team secured over $26 million from ARENA and research partners to invest in the latest in materials discovery, in device processing technologies and translational equipment and facilities.

This investment in research infrastructure leverages the long term commitment to solar research and positions ACAP to extend partnerships and collaboration into the next decade. The toolset was selected to ensure that ACAP research continues to lead the research agenda in the next generation of solar technologies and to support the delivery of ultra-low cost solar.

SPUTTERING INTO TOP GEAR DEVELOPING A LIBRARY OF SOLAR CELL MATERIAL COMBINATIONS

Professor Jacek Jasieniak

Professor of Materials Science and Engineering at Monash University, Pro Vice-Chancellor (Research Infrastructure)

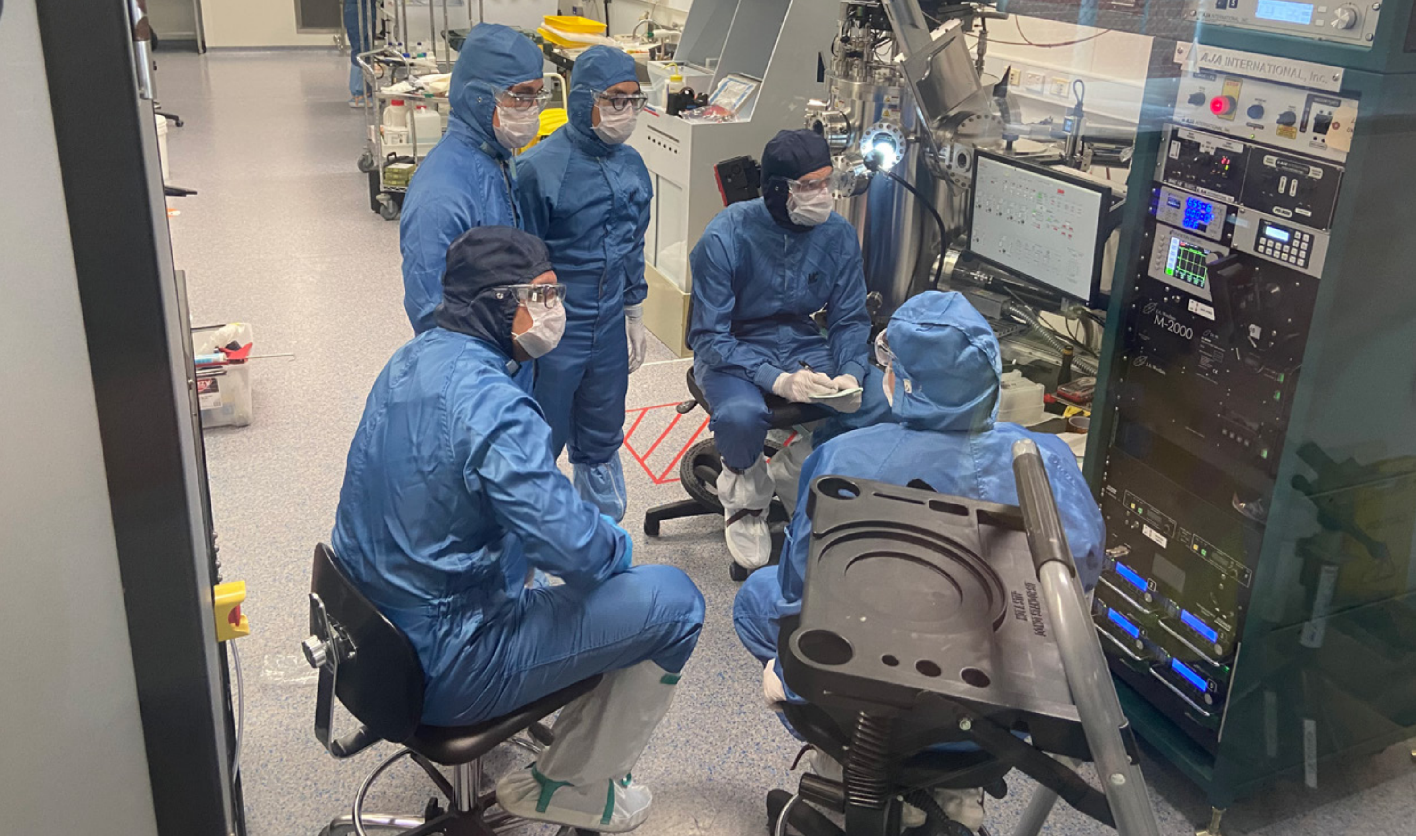
Until now, the discovery of new solar cell materials has been a manual, step by step process that is inherently slow, unproductive, and expensive. Speeding up the rate of discovery of new solar cell materials and compositions is critical to meeting the challenge of climate change. To this end, ACAP, Monash University and the Australian National Fabrication Facility (ANFF) have invested in a new combinatorial sputtering facility which will do exactly that.

Professor of Materials Science and Engineering at Monash University Jacek Jasieniak says, “The truth is, silicon solar cell technology continues to accelerate in its deployment, but its level of material innovations has been relatively constant for some time.”

“The globe has about 1 terawatt (peak) of installed photovoltaic capacity, and it’s been a hard slog to get to that point. The challenge is that we need to increase that by a factor of 50 to 70 as quickly as possible to mitigate climate change effects arising from incumbents.”

On order since 2019, the recently commissioned, advanced combinatorial sputtering tool is one of only a handful in the world, and Professor Jasieniak’s team are still learning how to operate it.

The tool will accelerate discovery and development of materials such as new earth-abundant inorganic absorbers, interfacing transport layers, electrodes, anti-reflective coatings and protecting layers.



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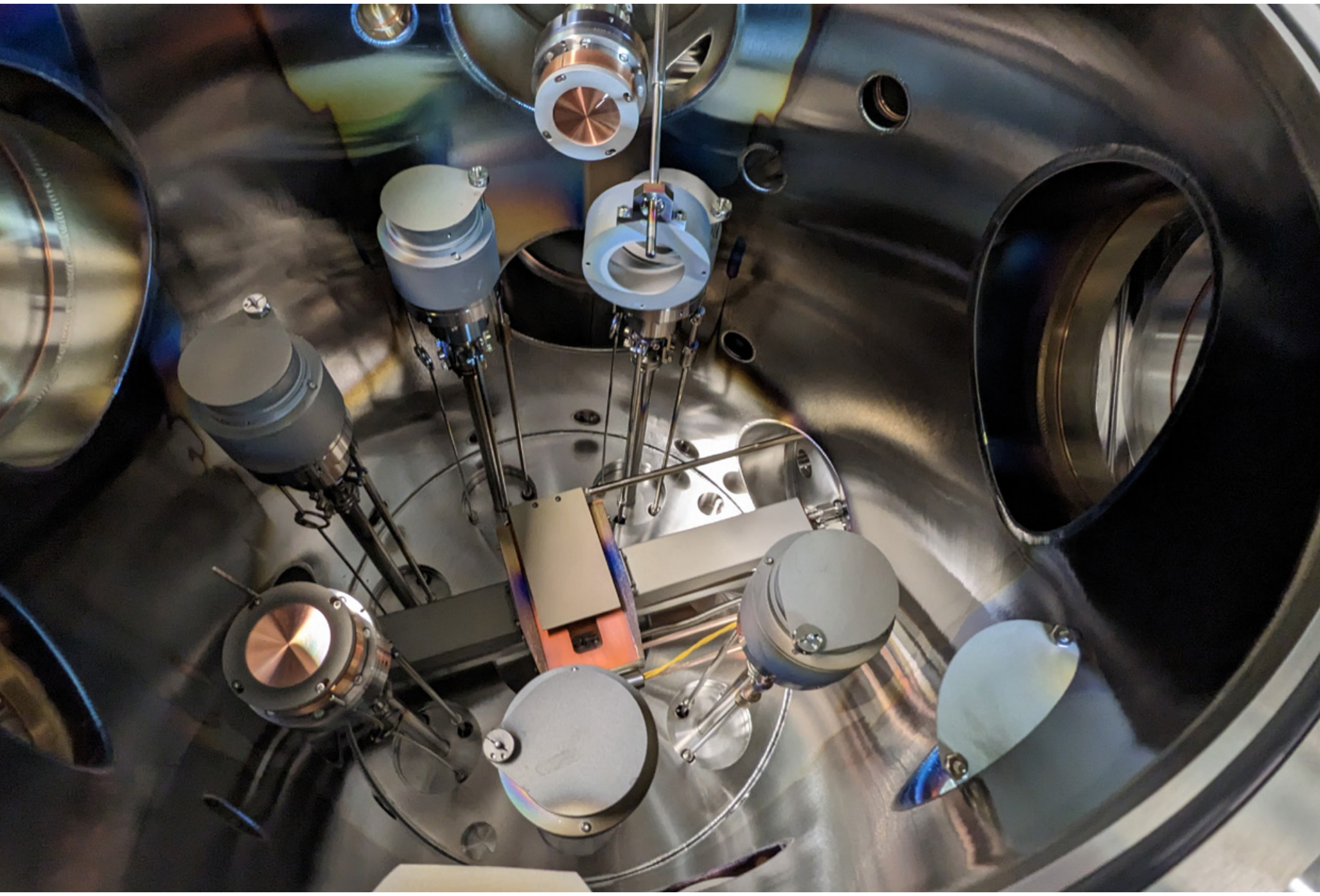
Commissioning of the sputtering system at the Melbourne Centre for Nanofabrication with engineers from the manufacturer, AJA.

The sputtering facility speeds up development by allowing researchers to quickly create a library of materials with different compositions that can be tested.

It will speed up the development by allowing researchers to quickly and easily create and test a wide range of inorganic material combinations. This is done by simultaneously depositing multiple materials onto a substrate using a process called sputtering.

Sputtering is a physical vapour deposition (PVD) technique in which a plasma is used to bombard a target material, ejecting material fragments that are deposited on a nearby substrate. The sputtering facility is described as combinatorial because allows researchers to deposit multiple target materials simultaneously, creating a library of materials with different compositions.

The library of materials can then be tested using a variety of techniques to identify materials with the desired properties for solar cells. This process is much faster than traditional methods of materials development, which typically involve developing and testing materials one at a time.



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New sputtering system with chamber open, exposing the targets.

"In a solar cell, there's typically five layers or so that need to be optimised. In any one of those layers, if we want to develop new material configurations or optimise and improve on the current solar cells, really understanding and tweaking the type of material and its conditions are critical," says Jasieniak.

"So, by having a combinatorial system like this, instead of depositing one material within one parameter space at one time, which is very slow, we can explore large composition spaces through this deposition technique at once."

"The material discovery component is accelerated by at least two orders of magnitude by having an in-situ system

“The material discovery component is accelerated by at least two orders of magnitude,” says Professor Jasieniak.

that allows the combinatorial sputtering approach.”

Specifically, the customised system has been scoped to enable combinatorial discovery of materials using vacuum-based sputtering of different metals: metal oxide, metal sulphide, metal selenides, metal nitride, metal carbide thin films and mixtures thereof with thicknesses of ~5–1000’s of nanometres – a human hair is about 100,000 nanometres thick.

The combinatorial discovery is enabled through simultaneous operation of up to four sputtering heads and an automated sample x-y translation stage.

In-situ reflection high energy electron diffraction allows structural properties of the evolving interface to be studied during the deposition process. Moreover, the integrated in-situ spectroscopic ellipsometer enables full optical and thickness analysis of sputtered coatings during combinatorial or standard coating processes.

Given the challenges to measure thickness during deposition of films in confocal sputtering, this is a critical component towards ensuring reliable and productive use of the system and a better correlation between the evolution of sputtered films, their deposition parameters and composition. The system has been integrated directly into the sputtering system to provide single focal point measurements that can be rastered using the substrate translation stage for mapping.

Open access to the facilities for greater impact

The facility has been located at the Melbourne Centre for Nanofabrication, an ANFF facility, to enable open-access use.

“We can use it, industry can use it, our ACAP partners can use it and in doing so I think we can accelerate that innovation pathway.”

Jasieniak says, “We’ve intentionally put it into an ISO 9001 certified facility that is appropriately staffed to support use, so that we are not the bottlenecks.”

“We can use it, industry can use it, our ACAP partners can use it and in doing so I think we can accelerate that innovation pathway. That is the vision.”

Joining the dots

In addition to the combinatorial sputtering system, ACAP has provided funding for Monash University to establish another facility at the Melbourne Centre for Nanofabrication: a dedicated High Throughput Solution-Processable Photovoltaic Materials Discovery Facility.

Developed by Professor of Chemical Engineering at Monash University Udo Bach, and not yet commissioned, the world-first toolbox will use automation, AI and advanced robotics to rapidly synthesise, test characterise and optimise new materials for PV cells.

The main purpose of the materials discovery toolbox is to accelerate the development of novel, printable, photovoltaic materials such as lead halide perovskites and their lead-free analogues.

Jasieniak says “As these types of combinatorial high throughput material discovery approaches get developed, there needs to be a complementary suite of characterisation techniques, so that you’re not creating discovery bottlenecks.”

“There’s a real opportunity to think about how to collaborate and build systems that enable researchers to really take advantage of this type of accelerated deposition to get to materials discovery outcomes. That’s what we’re seeing. And we’re connecting those dots.”

STREAMLINING THE REALISATION OF INDUSTRIAL SCALE SI-TANDEM PV TECHNOLOGIES

Dr Kean Chern Fong
Senior Research Fellow, ANU Centre for Sustainable Energy Systems

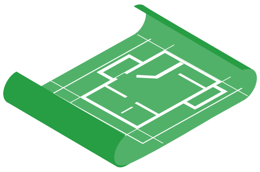
Dr Kean Chern Fong calls the newly commissioned Si and Tandem Hetero Contact Laboratory "a game changer" for developing novel contact and interface technologies.

The ACAP funded new Angstrom cluster enables a streamlined process for device fabrication, from film deposition to direct metallisation. Four different deposition tools are integrated into a single system, and samples can be transferred between them without being exposed to atmospheric air, avoiding the detrimental effects of oxidation or moisture-related degradation.

"The set of tools creates a sandbox environment that opens up a virtually limitless number of possibilities for exploring advanced heterostructure architectures," says Dr Fong.

"Even at this early stage, we are already seeing development of materials and processes towards solving key challenges in the PV industry," he says. "In the medium term, I expect a number of these technologies to provide strong publication outcomes, and to attract interest and future investments from PV manufacturers globally."

"In the long run, development and the learning from these technologies will have the potential to solve key technical challenges that will enable reduction in the cost of PV, and realisation of industrial scale Si-Tandem PV technologies."



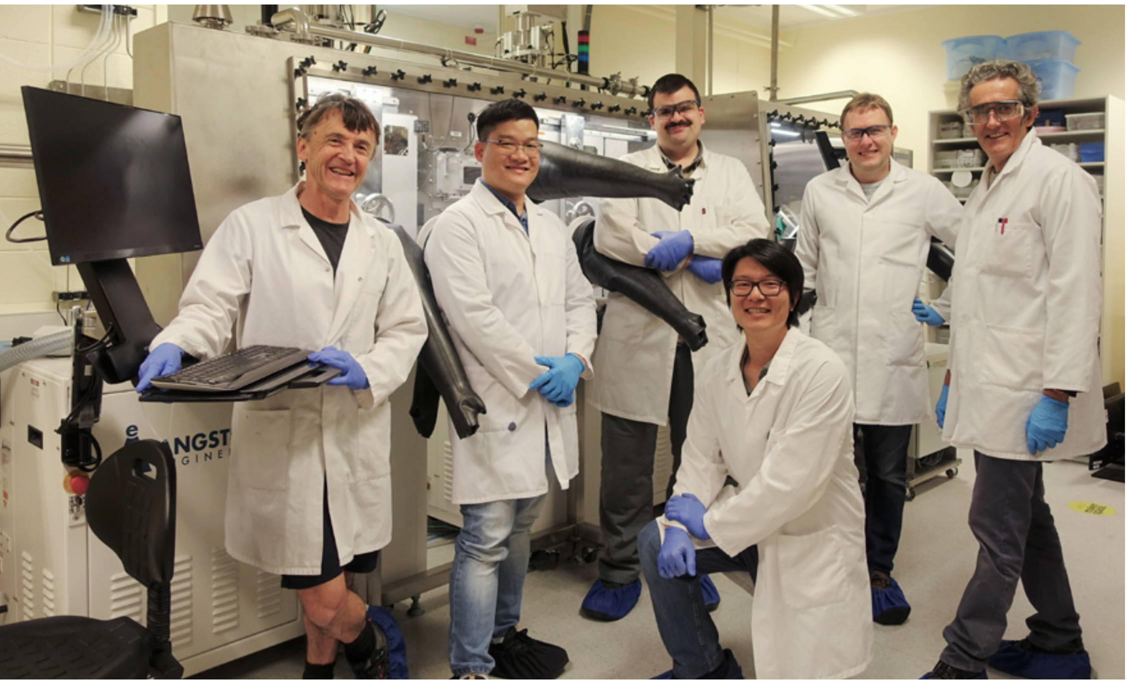
The design of the laboratory was informed by coordination of ideas between the various PV groups not only within ANU, but also other ACAP members such as UNSW and University of Melbourne.

The one-of-a-kind laboratory combines four techniques to deposit thin film solar PV materials onto a substrate layer within a virtual cluster that is interfaced via a nitrogen glovebox network.

The deposition techniques are atomic layer deposition (ALD), plasma-enhanced chemical vapor deposition (PECVD), evaporation, and sputtering. The best deposition technique for a particular application will depend on the specific requirements, such as the material to be deposited, the desired film thickness and uniformity, and the budget.

Because samples can be transferred between the different deposition tools without being exposed to atmospheric air, researchers can create novel complex film stacks that combine materials deposited by different methods.

Dr Fong explains, "For example, a hetero-contact stack might consist of an amorphous-Si layer for passivation, transition metal oxide for carrier selectivity,



TCO for lateral conduction, and metal for contacting, where the ideal deposition method is different for each layer."

Prior to the installation of this new equipment, there were no such capabilities available to researchers in Australia.

Dr Fong says, "The innovations to be realised through this facility target specific engineering needs: substitution of furnace diffusions in next-generation Si cells; enhancing performance and stability of perovskite cells; and innovation of novel, stable and efficient tandem-cell interconnections."

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The ANU team with the new evaporator and sputter coater. The cluster is available for use by all ACAP research partners.

"Each are likely to revolutionise the PV technology roadmap for PERC, IBC, and tandem categories, and are therefore of immense commercial impact in the coming 10 years."

"Even at this early stage, we are already seeing development of materials and processes towards solving key challenges in the PV industry," he says.

Working with other ACAP nodes

Dr Fong says the design of the laboratory was informed by coordination of ideas between the various PV groups not only within ANU, but also with other ACAP members such as UNSW and University of Melbourne.

"We identified gaps in our collective infrastructure capabilities to ensure that the tools support all current and future research and collaboration activities."

The cluster is available for use by all ACAP research partners.

PAVING THE WAY TO A TRULY SUSTAINABLE SOLAR RECYCLING INDUSTRY

Dr Rong Deng
Postdoctoral Research Fellow at the School of Photovoltaic and Renewable Energy Engineering, University of New South Wales

UNSW Research Fellow Dr Rong Deng doesn't like the term 'waste bomb' when referring to the one million tonnes of household solar panels that'll reach their end of life by 2030. She prefers to characterise them as a rich and growing source of re-usable materials for making new panels, or other high value products.

With the support of ACAP, Deng delivered a ground-breaking white paper that will guide the Australian PV industry towards circular, cost-effective solar panel end-of-life management.

Deng, who was recognised in Forbes Asia's 30 under 30 Healthcare and Science list, is on a mission to revolutionise the sustainability of the solar industry in time for the coming tsunami of retiring solar panels. In early 2024, with the support of ACAP, Deng will deliver a ground-breaking white paper that will guide the Australian PV industry towards circular, cost-effective solar panel end-of-life management in the next 10 years.

To date, solar panel recycling processes have been expensive and ineffective. There's a lack of specialist infrastructure, and aside from the aluminium frames, the materials are often contaminated and have limited second life uses.

And unlike in the EU, in Australia there's currently no requirement on the industry to take responsibility for old panels. As a result, commercial-scale recycling is largely non-existent.

The challenges of recycling solar panels

By design, solar panels are a fused, watertight, weatherproof sandwich of glass, metals, semiconductors and plastics. This is critical for generating electricity for up to 25 years, but it means they're difficult to separate.

Removing the aluminium frame and the electrical junction box is as far as most current recycling goes. The glass is hard to separate from the solar cells and is sometimes shredded to be sold as low-grade contaminated granules.

The remaining valuable materials – the silicon wafer, silver and copper – are more difficult to extract, particularly in a pure re-usable form. No current commercial recycling process deals with these, so they

“If annual PV installation expands 5-10 times, then we’re using all of the world’s silver and we’ll run out of the world’s silver reserves in two decades.”

are either sent to landfill or used as a filler in concrete or bricks.

Solar’s silver problem

Silver, the most conductive metal on earth, is an integral and expensive part of a solar panel. It collects and conducts the electricity produced by the excited electrons in the silicon wafer.

Deng says, “Silver consumption in the photovoltaic industry is currently about 10% of the world’s supply of silver. But if annual PV installation expands 5-10 times, then we’re using all of the world’s silver and we’ll run out of the world’s reserves in just two decades.”

In the EU, PV manufacturers are required to recycle used panels and recover at least 80% of their mass. As such they recover the bulk materials – glass, aluminium and low grade, contaminated silicon. Not all of the silver (the most valuable of the materials) and copper are recovered.

Solar panels contain 5-10 times less silver than when they were made 20 years ago, but the massive scaling of the industry in the next decades means silver supply is a serious problem.

The imperative to recycle

In 2022, the world reached 1 terawatt of installed solar, but leading solar power experts have predicted that if the world is to meet its decarbonisation goals, about 75 terawatts or more of globally deployed PV will be needed by 2050.

Here in Australia, by 2050, it’s estimated we’ll be grappling with 2 to 3 million tonnes of solar panels at the end of their working life.

> “These waste panels should be viewed as a big reservoir of materials ... to be supplied back into manufacturing.”

There are compelling benefits from recycling solar panels, including:

- preventing depletion of silver reserves
- avoiding landfill and toxic emissions from the lead and fluorine
- creating revenue and circular business models through the re-sale of valuable aluminium, copper, silver and silicon
- avoiding the energy and other environmental impacts of producing raw materials for new panels.

The imperative to innovate and improve material sustainability is on the industry right now. And, Deng says, with the massive scaling of the industry, the economic feasibility of full materials recovery also improves.

The research

With the aim of achieving the highest level of materials recovery, circularity and cutting current recycling costs by 50%, Deng and her team comprehensively reviewed the technologies, opportunities and challenges of recycling silicon solar panels (80% of the PV market).

This included projecting the volumes and flow of retiring panels; the complex logistics of recovering small numbers of panels on the rooftops of millions of houses all over the country; and identifying optimal locations for large scale recycling.

They looked at the composition of the panels and how these have changed over time. They searched for next-use markets and secondary applications for the extracted plastics and glass to build circular business models (recovered silver and aluminium have a large market demand).

Critically, Deng's team comprehensively reviewed all emerging silicon solar PV recycling processes and technologies currently in the lab or in pilot phase around the world. They compared the equipment, the costs, the quality of materials extracted, the advantages and disadvantages and the potential for improvement for large scale application. Gaps, trends and opportunities for further research and development were identified.

Excitingly, Deng and her team have identified two promising breakthrough recycling technologies that have the potential to improve the efficiency and lower the costs of separating and sorting the materials.

Excitingly, Deng and her team have identified two promising breakthrough recycling technologies.

The importance for the industry

Deng's white paper will help the industry develop recycling standards and regulations, including a Product Stewardship Scheme for Photovoltaic Systems that will involve the whole supply chain in taking responsibility for PV systems through to their end of life and developing an efficient and innovative domestic PV recycling industry.

Deng says, "These waste panels should be viewed as big reservoir of materials, if we recycle them properly from now on, we can supply materials back into manufacturing, stopping and reducing digging into the earth, and achieving a circular economy for the PV industry, making PV truly sustainable."

"The industry is active, we are keen to leverage our expertise and skills to collaborate with industry partners to develop better tools, technologies, and standards."

SNAPSHOT

$28.7 MILLION INVESTMENT IN RESEARCH INFRASTRUCTURE

$19m
IN ARENA FUNDING

$9.7m
IN PARTNER FUNDING

19
INVESTMENTS IN RESEARCH EQUIPMENT

5
UNIVERSITIES AND RESEARCH INSTITUTES

6

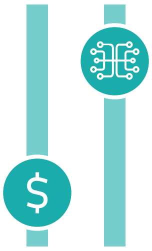
ULTRA-LOW-COST SOLAR

Breakthrough research needed for Australia to be a renewable energy superpower

Professor Renate Egan

University of New South Wales

Director of the Australian Centre for Advanced Photovoltaics 2023–

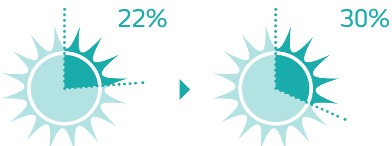


To drive the zero-emissions economy of the future, that sees Australia as a renewable energy superpower, we need to push solar technologies even further and the costs even lower.

Solar has the potential to transform our industries, transport and the way we live. Today, solar is competitive with residential and commercial electricity pricing at the point of use – on rooftops, where it is widely deployed in Australia today. To drive the zero-emissions economy of the future, that will see Australia as a renewable energy superpower, we need to push solar technologies even further and the costs even lower.

In 2022, the Australian Renewable Energy Agency (ARENA) laid out its vision for Ultra Low Cost Solar[1] in a white paper. By 2030, ARENA wants commercial solar cells to hit 30% efficiency, up from 22% today. Additionally, it wants large scale full system costs (panels, inverters and transmission) to fall by 50% to 30 cents per watt.

In achieving these ambitious goals, the cost of electricity would be as low as $15/MWhr, opening vast opportunities in green industrial processing, such as green-steel and green-ammonia.



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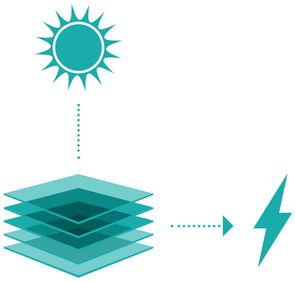
1. The Incredible ULCS - Ultra Low Cost Solar White Paper - Australian Renewable Energy Agency (ARENA) https://arena.gov.au/knowledge-bank/the-incredible-ulcs/.



Tandem Solar Cells offer the promise of an efficiency boost, by stacking two solar cells, one on top of the other, to make the most of the available sunlight and deliver more power per unit area.

The goal is ambitious but achievable

To achieve these targets, the research program at the Australian Centre for Advanced Photovoltaics (ACAP) has been extended out to 2030, with more than 250 Australian researchers already working to achieve the 30:30:30 goals.

The program of work has been revised to reflect the industry, the market and Australia's ambition to be a renewable energy superpower.

- To deliver an improvement in efficiency to over 30%, we need to build on the silicon solar cell, to add a second material that can make the most of the available energy in sunlight. The two cells, working together, makes a tandem solar cell that is the subject of significant research in the 2030 ACAP research program.
- To deliver high efficiency tandem solar cells, research is focused on finding the best material combination and on developing the best device structures.
- To ensure emerging solar cell technologies are reliable and durable, ACAP is working on module assembly technologies. ACAP is answering research questions on the robust interconnection of the individual cells and encapsulating these cells to deliver long operating lifetimes.
- To drive down the cost, we remain focused on the manufacturability of new technologies and are working with industry on scaling up innovation.
- To ensure we can reach the scales needed to deliver terawatts of solar power, we are looking into the materials used to make sure this can be done sustainably, and what to do with solar module technologies when they reach the end of life.

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Solar cells under testing at UNSW.

“Solar is disruptive, and we are really only just at the beginning. The technology of today works, and we should be deploying it as fast as we can. In doing so, we will continue to learn and improve. At the same time, to decarbonise all aspects of our economy, including industrial processes to deliver green steel and aluminium, we will need research and development to drive further downward pressure on the cost of solar PV.

“Ultra-low-cost solar will create new industries and economies that could make Australia a renewable energy superpower and will enable us to meet both our international commitments to decarbonisation and our obligations to the next generation to limit the impact of climate change.”

“Solar is disruptive, and we are really only just at the beginning.”

SNAPSHOT

PARTNERSHIPS

26 PARTNERS

14 INDUSTRY

6 INTERNATIONAL RESEARCH

6 AUSTRALIAN RESEARCH

- ARENA – Australian Government, Australian Renewable Energy Agency
- ACAP
- UNSW Sydney
- Australian National University
- The University of Melbourne
- The University of Queensland, Australia
- Monash University
- CSIRO
- QESST
- NREL – National Renewable Energy Laboratory
- Green Energy Institute
- Stanford University
- Berkeley Lab
- The University of Sydney
- Suntech
- Trinasolar – Smart Energy Together
- BlueScope
- Tindo Solar
- BT Imaging – Innovate. Control. Yield
- PV Lighthouse
- Raygen
- suncable
- Neoen
- Sundrive
- 5B

For more information on partnership with ACAP contact acap@unsw.edu.au