Submission Template
2016 National Research Infrastructure Roadmap
Capability Issues Paper

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Introduction to ACAP

The Australian Centre for Advanced Photovoltaics (ACAP), comprising the Australian partners of the Australia-US Institute for Advanced Photovoltaics (AUSIAPV), is developing the next generations of photovoltaic technology, providing a pipeline of opportunities for performance increase and cost reduction. Headquartered at UNSW's School of Photovoltaic and Renewable Energy Engineering, the Centre includes research groups at CSIRO, Australian National University, University of Melbourne, University of Queensland and Monash University. AUSIAPV links ACAP with NSF/DOE Energy Research Center for Quantum Energy and Sustainable Technologies (QESST), based at Arizona State University, the National Renewable Energy Laboratory, Sandia National Laboratories, The Molecular Foundry at Lawrence Berkeley National Laboratories, Stanford University, Georgia Institute of Technology and University of California – Santa Barbara.

These national and international research collaborations provide a pathway for highly visible, structured photovoltaic research collaboration between Australian and American researchers, research institutes and agencies, with significant joint programs based on the clear synergies between participating bodies.

The Centre is significantly accelerating photovoltaic development beyond that achievable by the institutions acting individually, leveraging past and current funding.

This Program is supported by the Australian Government through the Australian Renewable Energy Agency (ARENA). The Australian Government, through ARENA, is supporting Australian research and development in solar photovoltaic and solar thermal technologies to help solar power become cost competitive with other energy sources. The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Question 1: Are there other capability areas that should be considered?

Australian-based photovoltaic (PV) research has, and can continue to have, a disproportional impact on the development of the PV industry with significant flow-on benefits to Australia -estimated at well above U$8 billion to date, arising from reduced cost of PV systems, PV business revenues in Australia, equity and royalty shares of Australians, student fees, and reduced impact of climate change due to rapidly increasing PV deployment. Renewable enegy is of urgently and rapidly

growing importance to slow and limit climate change. Solar photovoltaics (PV) and wind are the most affordable and easily deployable generation technologies and, arguably, well-understood pumped-hydroelectric storage will be substantially sufficient for Australia. In terms of generation technologies, Australia is at the global forefront of PV R&D and education/training but is mostly an importer of technology and knowledge about wind energy and pumped hydro storage.

PV R&D infrastructural capability requires constant upgrade to remain relevant and competitive. A recent report (discussed later) was commissioned to examine in detail the current infrastructural capabilities in the area of photovoltaic research in Australia and national governance arrangements needed for optimal reciprocal access. The national photovoltaic community, including universities, CSIRO and business, was surveyed for the report.[1] This report constitutes a framework for a modern PV research infrastructure capability.

Excellent R&D and education in Australia has combined with China-dominated high-volume low-cost manufacturing, resulting in grid parity (i.e. solar electricity is cost-competitive with electricity from the grid) for most of the world.

Price discovery from the Qld Solar120 program, the ACT Government PV and wind reverse auctions, and the ARENA Large Scale Solar program shows that PV electricity costs $70-80 per MWh in Australia, which is fully competitive with new coal and gas generation. Together, photovoltaics and wind energy now constitute half of new generation technology installed worldwide each year, and constitute virtually all new generation capacity in Australia.

Importantly, PV will soon compete directly with the price of bulk electricity from old “sunk cost” gas and coal generators.

Renewable energy, primarily photovoltaics and wind, is the easiest and cheapest way to meet the commitments of the Paris Climate Change Agreement. In addition, renewable energy also mitigates energy-related security risks. [2,3] Photovoltaics is a vast new industry, worth $120B/year in 2015, doubling every 3-4 years.

Some argue that this implies that the job is done, since the major milestones have been met, and economies-of-scale will do the rest. However, even more rapid uptake of PV is required to mitigate climate change, and this will be facilitated by further R&D to increase efficiency and reduce costs. Further, PV has the potential to displace oil used in transport and gas used in domestic and commercial heating provided that continual further development occurs. Additionally, the decreasing costs of solar electricity will reach various new ‘milestones’ (which might not be obvious at this time) that will enable applications which are not even imaginable at present. This will result in a spur of economic activities which will be capitalised upon by whoever is best prepared at that point in time.

In the last four decades, Australia has developed a globally unique infrastructure and PV community (fuelled by the world-leading PV R&D and education at our universities) which will enable Australia to lead in this solar revolution. The possible economic benefits to Australia are immense. This

[1] www.acap.net.au/sites/default/files/u12/ACAP_MS4A_Report.pdf
[2] http://www.defense.gov/News/Article/Article/612710
[3] https://cpd.org.au/wp-content/uploads/2015/06/Climate-Change-and-Security-Paper-FINAL.pdf

includes metal refinement in Australia, driven by low cost PV electricity, excellent sunshine and abundant minerals, to create "congealed sunshine".

Australia has recently taken a major new step in an exciting new phase by establishing the first Torch technology precinct outside China.[4]

It is well established that increasing solar cell efficiency is the best way to decrease the cost of solar electricity. This is because the vast majority of the solar system costs are area related, and when levelised costs of electricity are considered, they scale *inversely* with the solar device efficiency. Australia has been leading the world in solar cell device efficiency for most of the last four decades. It is important that we continue and further strengthen this lead, in order to exploit the full benefits of the next phases of the solar revolution.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

The Australian Centre for Advanced Photovoltaics (ACAP) has recently considered in depth the governance of sharing of infrastructure.[5] The whole national photovoltaic community, including universities, CSIRO and business, was surveyed for the report. Each of the participating institutions has robust internal governance arrangements, but sharing introduces additional challenges.

It was proposed that, similar to other cooperative consortia operating in Australia, such as the Australian Nanofabrication Facility (ANFF), a consortium of contributing Australian PV research institutions could be formed to facilitate infrastructure sharing further. Denoted as the 'Australian PV Research Consortium (APVRC)' such a group could manage functions including ongoing maintenance and update of the research capability register website, offer advisory assistance to funding agencies on application calls and responses, and to acquire capital funding sources.

Such a consortium would sit within ACAP and may look to the National Collaborative Research Infrastructure Strategy for funding.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Yes. In ACAP's case, interaction with long-term and internationally accepted, accredited photovoltaics testing services (NREL in USA, ISE in Germany) is required for confirmation of world records, as are regularly reported in the international literature.[6] Additionally, a robust Australian PV infrastructural entity will facilitate access to major international facilities on a reciprocal basis.

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

Overseas services should be supported if demand in Australia is insufficient to justify the CAPEX and OPEX high. An example in the PV field is high flux ion implantation.

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[4] http://www.torch.unsw.edu.au/

[5] www.acap.net.au/sites/default/files/u12/ACAP_MS4A_Report.pdf; Sec. 5 and 6, Appx. A and B

[6] Green et al., "Solar cell efficiency tables (version 48)", Prog. Photovolt: Res. Appl. 2016; 24:905–913

Question 5: Should research workforce skills be considered a research infrastructure issue?

Yes. UNSW was supported by the ARC Key Centres program in 1999 specifically to support the development of workforce skills. "Recognizing the rapid growth of the photovoltaics industry and its need for trained staff, a Key Centre for Teaching and Research in Photovoltaic Engineering was awarded to the University, commencing in early 1999. This Key Centre will offer the world's first undergraduate program in Photovoltaics and Solar Energy, beginning in the year 2000. … the Key Centre will initiate strong new programs, particularly in the undergraduate and postgraduate teaching areas and in industry initiated research."[7] This support did lead to advances in the technology that Australia has benefitted from and placed Australia at the leading edge of the industry.

ANU also developed a "major" education stream within its Engineering program.[8] These programs have been vital to the supply of leadership and staff for the rapidly expanding Australian and global renewable energy industries.

Benefits to Australia from past support of photovoltaics R&D and associated education and training have been estimated at over $8 billion.[9]

The global network of Australian photovoltaics alumni connections and their ongoing impact has been outlined by Green.[10]

Question 6: How can national research infrastructure assist in training and skills development?

Availability of cutting-edge infrastructure retains and attracts excellent researchers and students. It also exposes students in Australia to industry-relevant equipment, which is extremely important in an exponentially expanding industry.

[7] www.engineering.unsw.edu.au/energy-engineering/sites/photo/files/u12/lvl3-research/unsw_arc_pv_anrep_1998.pdf, p. 32

[8] http://programsandcourses.anu.edu.au/major/RENE-MAJ

[9] www.acap.net.au/sites/default/files/u3/Info_Sheet_ACAP_1603_estimate%20of%20economic%20impact_Final-Release_2.pdf

[10] Green, MA, "Revisiting the history books", PV Magazine, 06/2016, pp. 94-101 (http://www.pv-magazine.com/archive/articles/beitrag/revisiting-the-history-books-_100024938/655/#axzz4Go4a5tdR)

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

PV research and education in Australia has been historically strong in "punching well above its weight" in training of infrastructure ready researchers and technical specialists. Indeed, Australian-trained entrepreneurs have set the benchmark by spearheading the development of the infrastructure and technology for the global manufacturing of photovoltaics.[11] The local training of the future global workforce builds a strong and friendly international collaboration network.

Further, these alumni connections have encouraged and facilitated a substantial local connection between the global leaders in research and the global leaders in manufacturing in the exciting sunrise industry of photovoltaics,[12] leveraging the Australian Government's investment in research infrastructure to generate additional infrastructure investment and meaningful jobs.

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Please see our response, above, to Question 2.

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

Both CAPEX and OPEX are required, with sufficient longevity (period will vary with topic) to ensure stability and maintenance and effective support for users.

Question 11: When should capabilities be expected to address standard and accreditation requirements?

It is reasonable to expect that the research community in Australia will lead or, at least, contribute to the development of standards and accreditation processes for the industries they are generating and for which they are training the workforce. Australian PV researchers and educators, based at ACAP institutions, led the development of the globally-leading Australian Standards AS4509, AS4777 and AS/NZS5033 and accreditation system for designers and installers that are currently managed by the industry.[13]

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

- Australian Nano Fabrication Facility (ANNF)

[11] www.pv-magazine.com/archive/articles/beitrag/revisiting-the-history-books-100024938/655/#axzz4F6M3DlzI

[12] www.businessinsider.com.au/the-chinese-government-is-building-an-innovation-campus-at-the-university-of-new-south-wales-2016-4

[13] www.solaraccreditation.com.au/

- Quantum Energy and Sustainable Solar Technologies (QESST), an Engineering Research Center (ERC) sponsored by the US National Science Foundation (NSF) and the U.S. Department of Energy (DOE) https://qesst.asu.edu/
- US User Facilities: such as
    - Center for Integrated Nanotechnologies (CINT) http://cint.lanl.gov/;
    - Molecular Foundry http://foundry.lbl.gov/
- Bay Area Photovoltaic Consortium https://bapvc.stanford.edu/
- SOLIANCE http://www.solliance.eu/
- IMEC: http://www2.imec.be/be_en/home.html
- European Framework Programs: https://ec.europa.eu/research/fp7/index_en.cfm

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples domestic or international that should be examined?

Question 14: Are there alternative financing options, including international models that the Government could consider to support investment in national research infrastructure?

The status of the Australian Renewable Energy Agency is unclear. The Government proposes to end ARENA grant funding. If grant funding were to continue then engagement with ARENA would be productive.

Health and Medical Sciences

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

Question 16: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

Solar photovoltaics, a topic in which Australia retains a global leadership position, is an exponentially growing industry in which Australia can play a major role, based on our research, education and training leadership and on the cheap and abundant electrical energy that will be available in this large and sunny island. Our infrastructure needs have been laid out in a report available online.[14]

[14] www.acap.net.au/sites/default/files/u12/ACAP_MS4A_Report.pdf

Equipment would be based at the sites of the currently leading photovoltaics research institutions but deliberately and credibly be made available to the whole research community, as outlined in Sec. 5 and 6 and Appx. A and B of that report,[5] via processes based on those of the Australian Nano Fabrication Facility.

In addition, "incubator" facilities, with access to technical resources, need to be created to take advantage of the young innovators who have and are trained through the ACAP and other research and education institutions. Some past entrepreneurial outcomes from ACAP institutions include:

- **2015: Sundrive,** PV Manufacturing, Vince Allen, (current PhD student, BE PV&SE 2013)
- **2015: Tianjin Huake Tech Pty. Ltd**, Patterning**,** Zhongtian Li (current PhD student, BE PV&SE 2012)
- **2015: Omegachi Pty Ltd**, Adhesion Tester, Xi Wang, PhD2012 (current student)
- **2014: Open Instruments.** PV measurement equipment, Henner Kampwerth (current staff)
- **2014: Solinno,** Consultants. Rhett Evans, Nathan Chang (current PhD students)
- **2014**: **5B Australia Pty Ltd,** Portable PV systems, Chris McGrath, Eden Tehan, Jade Fennell (BE RE 2010, 2011)
- 2014: **Epho Pty Ltd**, commercial solar systems, Oliver Hartley (PhD PV)
- **2013: Sharesun,** PV technology development, Jingjia Ji (current staff, former Pacific Solar)
- **2013: Nanjing Sunport (China),** PV technology, Fengming Zhang **(**former Pacific Solar**)**
- **2012: PVLab Australia,** Specialized test lab, Michelle McCann, (PhD PV 2002)
- **2012: Buildings Alive,** Energy Efficiency, Jesse Steinfield, (BE RE 2010)
- **2012: SolarShare,** Solar farms, Lawrence McIntosh (BE(hons), Sustainable Energy Systems 2008)
- **2011: Sunpulse (Japan),** Solar Projects design and monitoring, Luke Johnson (BE PV 2004)
- **2011: PV Lighthouse**, Consulting and Modelling, Keith McIntosh, Malcolm Abbott (PhD PV 2001)
- **2011: Solar Analytics,** Residential PV monitoring, R Egan, S Jarnason (current staff , former Suntech)
- 2009: **Transform Solar,** elongated solar cell manufacture, Andrew Blakers, Klaus Weber and Andrew Stock (current staff)
- **2008: Sunrise Global,** Solar Cell manufacturing (Taiwan), Ted Szpitalak, Bruce Beilby (former PV staff)
- **2007: Sungevity,** PV systems, Andrew Birch**,** (ME PV&SE 2005)
- **2007: Spark Solar,** Angled Buried Contact Cells, Michelle McCann, Evan Franklin (PhD PV 2002)
- **2006: Btimaging,** PL inspection, Thorsten Trupke (current staff)

- **2006: Pollinate Energy (India)**, No profit -energy access, Monique Alfris (BE PV 2006)
- **2006: China Sunergy (China)**, Solar Cell/ Module manufacturing, Jianhua Zhao (PhD PV1990)
- **2006: JA Solar (China),** Solar Cell/Module manufacturing, Ted Szpitalak (former PV staff)
- **2003: Autonomous Energy,** EPC solar systems, Matthew Linney, (BE PV&SE 2006)
- **2001**: **Suntech Power (China)**, Solar Cell/Module manufacturing, Zhengrong Shi (PhD PV 1992)
- **1995: Pacific Solar**, PV Technology, Martin Green, Stuart Wenham (current staff)

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

- TORCH innovation precinct partnership with Chinese Ministry of Science and Technology[12]
- Global Alliance of Solar Research Institutes[15]
- Green Climate Fund[16]
- International Energy Agency, Photovoltaic Power Systems Programme.[17] Australia already participates in
    - Task 1: Strategy and Outreach;
    - Task 13: Climate-based PV Performance and Reliability;
    - High Penetration of Photovoltaic systems in electricity grids; and supports
    - Solar Resource Assessment (a recent transfer from IEA Solar Heating and Cooling)

  Australia could participate in additional Tasks, if funded, such as Task 15: Building Integrated Photovoltaics.
- International Technology Roadmap for Photovoltaic (ITRPV)[18]
- An Australia-India solar energy research partnership, similar to SERIIUS[19] , but better funded.
- Photovoltaic solar energy partnership with other countries, similar to the U.S.-India Energy Cooperation.[20]
- A substantial Australia – China solar energy research partnership.

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Water security is seriously threatened by excessive use of water by fossil fuel production and thermal electricity generation. It has been documented by the International Energy Agency that fossil fuel sourced energy is a major user of scarce fresh water but "Energy efficiency, wind and solar PV contribute to a low-carbon energy future without intensifying water demands significantly."[21]

[15] www.nrel.gov/news/press/2012/1940
[16] www.greenclimate.fund/home
[17] www.iea-pvps.org/
[18] www.itrpv.net
[19] www.seriius.org
[20] http://energy.gov/ia/initiatives/us-india-energy-cooperation;
[21] www.worldenergyoutlook.org/media/weowebsite/2012/WEO_2012_Water_Excerpt.pdf

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Discovery of new materials for energy production and storage (http://www.cngmd-efrc.org).

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

Understanding Cultures and Communities

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Australia previously made dramatic advances on alleviating the energy poverty of remote indigenous communities in Australia and India through the Bushlight[22] program, implemented through the Centre for Appropriate Technology.[23] This outstanding program boosted quality of life and encouraged young people to remain in communities.

Question 25: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Australia could partner with "Teach 1000 teachers training program on Solar PV" to support the efforts in India and transfer the approaches to remote Australia.[24]

Question 26: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Understanding Cultures and Communities capability area?

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

The US Department of Defense has publicly recognised that the impact of climate change, such as sea level rise, shifting climate zones and more frequent and intense severe weather events, is a national security issue for that country[2] and this is true for Australia too. It is surprising that, apart from impact on water resources, this issue is not mentioned in the issues paper. PV research will lead to a reduction in the use of water for electricity production that will underpin national water security (see response to Question 20).

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[22] www.bushlight.org.au
[23] www.cat.org.au
[24] www.ncpre.iitb.ac.in/pages/education_training_2011.html

Question 28: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 29: Is there anything else that needs to be included or considered in the 2016 Roadmap for the National Security capability area?

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

There are several necessary renewable energy applications for big data/computing:

- Solar and wind potential mapping.[25] This tool needs to be extended to the whole of Australia, starting with the more heavily populated areas
- Electricity grid management (grid + PV + wind + storage + load/weather forecasting)
- Identify best opportunities to include renewable energy generation into Australian electricity grids to avoid or postpone investments in grid upgrade or to use stand-alone systems to reduce grid extent[26]
- GIS location selection for large-scale solar farms and pumped-hydro storage,[27] and
- Wind/solar resource forecasting for obviating renewable energy supply intermittency.

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

Data for Research and Discoverability

Question 33 Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?

Question 34: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 35: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Data for Research and Discoverability capability area?

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[25] http://pv-map.apvi.org.au/potential/

[26] http://www.uts.edu.au/research-and-teaching/our-research/institute-sustainable-futures/our-research/energy-and-climate-1

[27] H.T. Nguyen, J.M. Pearce, Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System, Solar Energy 84 (2010) 831–843

Other comments

If you believe that there are issues not addressed in this Issues Paper or the associated questions, please provide your comments under this heading noting the overall 20 page limit of submissions.