UKERC ENERGY RESEARCH ROADMAP SYNTHESIS: SOLAR ENERGY

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1. OVERVIEW

This document reviews and highlights the most important aspects presented in six solar energy roadmap and strategy documents, including:

- Technology Roadmap: Solar Photovoltaic Energy- International Energy Agency
- UK Solar PV Strategy Part 1: Roadmap to a Brighter Future- Department of Energy & Climate Change
- UK Solar PV Strategy Part 2: Delivering a Brighter Future- Department of Energy & Climate Change
- Connecting the Sun: Solar Photovoltaics on the Road to Large-scale Grid Integration- European Photovoltaic Industry Association
- Realising the Potential of Concentrating Solar Power in Australia- IT Power (Australia) PTY LTD for the Australian Solar Institute
- SunShot Vision Study- Concentrating Solar Power: Technologies, Cost and Performance- US Department of Energy

This document provides the latest information on concerning PV solar photovoltaics on a global and European/UK basis, as well as a focus on concentrating solar power in the US and Australia. Several roadmaps, strategy documents and vision studies have been completed to provide the most up-to-date information.

The roadmaps within this document do not only cover the technologies, as was the main focus of earlier versions, but examine the whole industry on a national or global scale. As mentioned, the information within the roadmaps and this document cover both PV and CSP, this is due to different focuses of countries combined with using the information currently available.

Despite differences in the scope and methodologies of the roadmaps, they share many similar themes. These include reducing the LCOE, continuing innovation, job growth/job creation and integrating in different market segments.

The roadmaps reviewed in this document provide a high-level understanding of the current state of the PV and CSP industries, and the challenges to overcome in order to increase deployment. Whilst each country may have their own initiatives, the analysis of these roadmaps identifies key research areas that can lead to a successful industry.

2. TECHNOLOGY ROADMAP: SOLAR PHOTOVOLTAIC ENERGY

International Energy Agency

https://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf

The roadmap was developed from the result of discussions held during two workshops which were held to identify technological and deployment issues. The roadmap commences by describing the purpose of the document as being a 'basis for greater international collaboration' and identifies technology, economic and policy goals and milestones that will allow solar PV to deliver on its promise and contribute significantly to the world power supply.

The document continues, presenting the current status of both the technology and industry highlighting that the large variety of PV applications allows for a range of technologies to be present in the market. Also noted is the 40% average annual growth rate over the last decade, with cumulative power capacity growing from .1GW-14GW between 1992 and 2008.

Moving forward, the document presents the vision for PV deployment and the subsequent CO_2 abatement potential. Solar is expected to provide 11% of annual global electricity production by 2050 of which 6% will come from PV. 3000GW of installed capacity worldwide could generate up to 4500TWh annually by 2050 if incentive schemes and policies continue to build momentum. This could save 3.2Gt of CO_2 emissions.

The next section focuses on emerging economies including Brazil, China and India. This is followed by a discussion on cost reduction goals of which it is suggested that overall cost targets should be set by application rather than by specific technology. Further, the document suggests that cost reductions for future PV systems will continue along the historic PV experience curve. The roadmap proposes that the primary PV economic goal is to reduce turn-key system prices and electricity generation costs by more than two-thirds by 2030 with the aim of prices dropping by 70%.

The roadmap then presents PV market deployment and competitiveness levels looking at the expectations of the next three decades, highlighting goals for each 10-year segment. It then states that achieving these milestones will require a total investment of approximately $5 trillion.

Continuing, the roadmap presents the technology development goals and milestones for the next 30 years, discussing the advantages and challenges of crystalline silicon, thin films and concentrator technologies.

Finally, the last several sections of the document focus on policy frameworks, recognising action items and milestones identifying four main areas of policy intervention, which include:

- Regulatory framework and support incentives;
- Market facilitation and transformation;
- Technology development and RD&D; and
- International collaboration.

An overview of each area is then provided along with recommendations of action items and timelines. Starting with regulatory framework and support incentives, the action items are as follows:

- Set long-term targets, supported by transparent and predictable regulatory framework to build confidence for PV investments. These should include financial incentive schemes to bridge the transition phase and ensure priority access to girds over the longer term.
- Design and implement a regulatory framework to facilitate large-scale PV grid integration.

Market facilitation and transformation action items include:

- Establish international standards and codes for PV products.
- Identify new financing and business models.
- Enhance training, education and awareness for skill workforce along the PV value chain.

Technology development and RD&D action items include:

- Increase public RD&D funding.
- Ensure sustained RD&D funding in the long-term.
- Develop and implement smart grids and grid management tools.
- Develop and implement enhance storage technologies.

Finally, the international collaboration action items are:

- Expand international R&D collaboration, making best use of national competencies.
- Develop new mechanisms to support exchange of technology and deployment of best practices with developing economies.
- Assess and express the value of PV energy in economic development, particularly focusing on rural electrification.
- Encourage multilateral development banks to target clean energy deployment.

The document concludes by identifying actions for various stakeholder groups. The roadmap identifies priority actions for the next ten years which include:

- Provide long-term targets and support policies to work towards building investor confidence in manufacturing capacity and deployment of PV systems.
- Implement effective and cost-efficient PV incentive schemes in order to foster innovation and technology development.
- Develop and implement appropriate funding schemes.
- Increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, whilst supporting longer-term innovations.

3. UK SOLAR PV STRATEGY PART 1: ROADMAP TO A BRIGHTER FUTURE

Department of Energy & Climate Change

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249277/UK_Solar_PV_Strategy_Part_1_Roadmap_to_a_Brighter_Future_08.10.pdf

The roadmap is the first part of a two part Strategy process set out by the UK Government that primarily focuses on the policy aspects of the UK Solar PV industry.

The document starts by noting that solar is one of eight key technologies working to achieve the 15% renewable energy from final consumption to 2020. Solar PV is an attractive option for many as it can be deployed in a variety of locations, scales and users. In addition, the roadmap suggests that the use of PV boosts competition within the market, increases consumer choice and is an attractive option for homeowners.

The roadmap continues by highlighting the potential economic contribution as well as the contribution to the overall European deployment capacity. The industry has the potential to create tens of thousands of jobs and currently contributes 6% share of deployed capacity across Europe, despite its lack of sunshine in comparison to other European countries.

The document notes the efforts being made to reduce LCOE by 20% by 2020, to ensure competitiveness with other large-scale generation technologies. Further, the document presents the current status of the UK solar PV industry as accounting for 12% of renewable electricity capacity and 2.9% of renewable electricity generation in the UK. Looking forward, expected potential deployment ranges from 7-20GW, although mid-range estimates show it is more likely in the range of 9.3-10.7GW by 2020. In order to reach the higher 10-20GW ranges, cost increases for development tools for balancing supply and demand for electricity would have to be implemented.

Next, the document examines some of the challenges of the solar PV industry which include:

- Appropriate use of land and buildings;
- Continued interaction with local communities;
- Uncertainties associated with effects of significant deployment, particularly large volumes of solar PV embedded generation and the challenges that can occur for grid system balancing;
- Local grid issues; and
- Financial incentives to encourage deployment and cost effectiveness.

Continuing, the document considers the three main solar markets, and the one growing market:

- Domestic
- Building mounted
- Ground mounted
- Building integrated

The following couple of sections cover the current financial support mechanisms as well as identify the areas of geographical importance within the UK. Currently, the financial support mechanisms available to solar PV within the UK are:

- Renewable Obligations
- Contracts for Difference
- Feed-in-Tariff

South-west England has the highest deployment of solar PV in the UK; 44% of the large-scaled deployments under the Renewable Obligations are located in SW England. Noted is the idea that clustering could create difficulties in local grid management.

There is increasing engagement within the solar industry including the inaugural meeting of the Solar PV Strategy Working Group, which focuses on identifying solutions to barriers, and will help develop a set of actions for the future of solar PV in the UK. Additionally, the roadmap identifies the Government's four main principles for solar PV, of which are described in detail. These include:

- Ensuring support for solar PV should allow cost-effective projects to proceed and to make a cost-effective contribution to UK carbon emission objectives in the context of overall energy goals;
- Support for solar PV should deliver genuine carbon reductions which help meet the UK's target of 15% renewable energy from final consumption by 2020;
- Support for solar PV should ensure proposals are appropriately sited, give proper weight to environmental considerations and provide opportunities to influence decisions;
- Support for solar PV should assess and respond to the impacts of deployment on: grid systems balancing; grid connectivity; and financial incentives.

The final section provides an overview of the key aspects of the forthcoming DECC Strategy Document, which include:

- DECC will complete further analysis on cost reduction levels necessary to deliver different levels of solar PV deployment over the next decade;
- Continue work to determine reliable methodologies to access data on jobs and investment in the UK solar PV sector;
- Consideration of the distribution of potential deployment sites across the domestic, commercial and industrial roof and large-scale ground mounted sites;
- Perform a detailed analysis of current findings to help shape solar PV policy in order to deliver carbon reductions to help me the 2020 target.
- Explore measure and technological advances to manage grid systems balancing with increasing levels of solar PV.

4. UK SOLAR PV STRATEGY PART 2: DELIVERING A BRIGHTER FUTURE

Department of Energy & Climate Change

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/302049/uk_solar_pv_strategy_part_2.pdf

The document starts by examining the important solar PV markets in the UK highlighting that 2013 was a record year for solar PV in the UK with the total capacity growing by almost 1000 MWp after the realignment of financial incentives with market prices. By the end of December 2013, total installed capacity was 2.7GW, with deployment at all scales, with a large amount of future development plans underway.

The document also discusses that with the continued increase in deployments, DECC and others are looking for innovative designs in the appearance of solar PV installations in order to keep away critics. The document then states that the future of the industry in the UK is centred primarily in two key markets:

- Growing the momentum on deploying PV at smaller scale on, and in, housing, small commercial premises and community buildings.
- Increasing significantly mid-size deployment particularly on commercial and industrial buildings but also on larger public and community buildings.

Moving forward, the document discusses the UK/DECC's ambition for the main solar PV market sectors, which include:

- Small-scale rooftop installations on housing
- Mid-size commercial and industrial rooftops
- Public buildings
- Building-integrated solar
- Large-scale ground-mounted

In addition, DECC will examine opportunities to reduce the overall costs of installation and deployment by addressing UK specific barriers. The document examines in depth each of the market segments which include:

- Grid-connection
- Planning and financing costs
- Supply chain cost reduction
- Reduce installed costs for solar PV to domestic, commercial and industrial consumers
- Provide a levelised cost comparison of mid-sized solar PV with domestic and large-scale PV
- Understand and monitor how soon different markets might achieve grid parity

The document then states that realising the ambition of these projects will also require for the projects to be connected to the electricity grid in a timely and affordable manner. In response to concerns, Ofgem will take steps to help drive a more efficient, customer-focused connections service.

The next section emphasises the importance of innovation as a key to cost reduction and deploying significantly greater levels of solar PV, whilst minimising costs for customers. This is in addition to delivering carbon reductions and helping achieve the UK's target of 15% of final consumption from renewable energy by 2020. The document highlights four key areas in which innovation is vital in order to reach these goals. These include:

- Cost reduction through innovation
- Innovative financing solutions
- Balancing the system through innovation
- Carbon emissions reduction through innovation

Finally, the last section of the document focuses on jobs and growth of the solar PV sector, noting that growth in the sector means that long-term jobs and investment potential is difficult to predict with certainty but there is an estimate of the potential of tens of thousands of jobs from solar PV. This is shown by the estimate of between 11,700 and 14,000 direct and indirect jobs calculated as of the end of 2013. Further, DECC is also encouraging the industry to open employment in the sector to a greater number of women.

5. CONNECTING THE SUN: SOLAR PHOTOVOLTAICS ON THE ROAD TO LARGE-SCALE GRID INTEGRATION

European Photovoltaic Industry Association

http://www.epia.org/fileadmin/user_upload/Publications/Connecting_the_Sun_Full_Report_converted.pdf

The document commences by stating that by 2030, solar photovoltaic (PV) could cover up to 25% of the electricity demand in Europe. This is due in part by falling prices of which residential PV systems are expected to fall from approximately 2.31€/W in 2012 to approximately 1.30€/W in 2022.

The aims of the roadmap are then highlighted, stating that this document aims to provide a holistic vision of how solar electricity will be integrated into the electricity system. The document provides three different scenarios for the penetration of PV electricity in 2030:

- Baseline scenario: envisages a business-as-usual case with 4% of European electricity demand provided by PV in 2020, and 10% in 2030.
- Accelerated scenario: PV meeting 8% of the demand in 2020 with a target of 15% of the demand in 2030.
- Paradigm shift scenario: Based on assumption that all barriers are lifted and specific boundary conditions are met, foresees PV supplying up to 12% of European electricity demand by 2020 and 25% in 2030.

In addition to these scenarios, current forecasts show that PV continues to out-perform growth forecasts due to its decentralised nature and ability to lower prices due to its modularity. The SET Study estimated that PV could reach up to 12% of Europe's electricity demand by 2020. Further, it is suggested that by deploying grid integration solutions, reaching the 25% penetration scenario could be a realistic target.

Moving forward, the roadmap examines the electricity system's behaviour under normal as well as extreme conditions, acknowledging that large-scale PV integration into the European grid is technically feasible with a high level of security of supply. The main challenges of the increased integration of PV include:

- Variability: the larger the number of systems and the area considered, the smaller the variability of the power generated by PV systems in that area.
- Dispactchability: PV peak production takes place around midday which is the time when demand also reaches one of its daily peaks. In order to increase PV's contribution to meeting the evening consumption, two solutions exist:
    - Shift part of the electricity in-feed from the day to the evening with the help of storage facilities.
    - Shift part of the evening consumption to earlier hours of the day with Demand Side Management.

  Also falling under the dispatchability heading, there is a seasonal basis for which complementary output of PV and wind can reduce the need for back-up generation. Further, PV's ability to produce electricity close to where it is consumed alleviates the need for additional, significant investment in new transmission lines. The roadmap states that focusing on dense consumption areas would require only 10% more installed PV capacity but would reduce by almost 75% the need to transfer the excess generation.

- Flexibility: To achieve the Variable Renewable Energies (VRE) penetration foreseen in 2030, additional flexibility will be required to respond to balancing needs.

The roadmap then examines the financial support schemes which are available to PV. Currently, support schemes such as feed-in-tariffs are available however, these will be slowly phased out as PV becomes more competitive. With prices decreasing faster than expected, PV competitiveness is approaching in many European markets.

Further, the question of how grid integration will affect PV competitiveness in the market is examined. Conclusions include:

- Costs associated with increased PV integration in the system operation will have an impact on PV competitiveness.
- Cost of widespread deployment of state-of-the art capabilities in PV inverters will be negligible.
- Curtailment would have a significant negative impact on the revenue stream of PV system owners even when cuts are limited and should only be used in extreme grid situations and after all other technically more efficient options have been executed.
- If PV system owners are required to pay grid costs and taxes even when self-consuming electricity, PV competitiveness will be delayed by a certain number of years depending on the market segment and the country.

The roadmap then provides policy recommendations. The document notes that while there are no technical limits to PV integration into the electricity system, integrating large shares of distributed generation into the electricity system requires a series of complementary measures, which include:

- Create a continuum among TSOs, DSOs and distributed generation.
- Increase overall system flexibility.
- Implement a new approach to overcome bottlenecks in the distribution grid.
- Ensure a fair financing of all parties.

The roadmap concludes by looking to future large-scale grid integration mentioning that grid operators may see challenges ahead from the increase of variable RES, however, PV is already providing solutions to many of these. Finally, as many European policymakers consider new investments for more efficient grid infrastructure, they should take notice of the benefits that PV is producing, and plan for greater benefits that will come in the future.

6. REALISING THE POTENTIAL OF CONCENTRATING SOLAR POWER IN AUSTRALIA

IT Power (Australia) PTY LTD for the Australian Solar Institute

http://www.itpau.com.au/wp-content/uploads/2012/07/CSP_AUST_Final_May2012.pdf

The document starts by stating that most of the electricity used in Australia in 2050 will be generated from plants that have yet to exist, with a projected $200 billion in new generation investment projected. Concentrated Solar Power (CSP) has the potential to make a significant contribution to Australia's energy future. The document aims to address the current challenges, realities and potential for the CSP industry in Australia.

Next, the document highlights the CSP technologies currently in use:

- Trough
- Linear Fresnel
- Dish
- Tower
- Fresnel Lens

Moving forward, the next section examines the CSP markets in Australia, noting that despite being limited to areas of both high solar resource and grid connectivity, CSP could provide up to 15 GW in the near-to-mid-term, which accounts for approximately 30% of Australia's total current electricity generation capacity. Furthermore, the section discusses the idea that the existing transmission and distribution networks are not ideally configured for CSP. Currently, in areas where the solar resource is the best, there is either no access or the suitable grid capacity is limited.

The document further discusses areas for which CSP would be sufficient, identifying three location-based market segments to be considered:

- Large-scale plants connected to the high capacity transmission network.
- Medium-scale plants connected to lower capacity distribution network.
- Off-grid systems.

In each of these segments, CSP plants could be configured with or without thermal storage, with an energy potential ranging between 25,000 and 60,000GWh/year.

Next, the document discusses the potential advantages of CSP to Australia's energy sector:

- Dispatchable energy supply
- Lower emission conventional power plants
- Emission reduction
- Clean energy sector growth
- Community-supported generation
- Potential for future solar fuels

Much of the document provides discussion concerning the costs and revenue of CSP in Australia. Given the early stage of the industry, reliable data concerning the cost of delivering energy to grid or off-grid customers, as well as capital cost information is difficult to come by. The current conservative estimate involving the least technical risky CSP technology, built as a 'most favourable' site, is approximately $252/MWh. Currently, CSP projects are not commercially attractive without subsidy, but private investors cannot monetise the broader public and sector-wide benefits that CSP generation may offer, so the NPV does not meet their risk-reward benchmarks. However, the document does state that with rising energy prices and falling CSP capital costs, the cost-revenue gap should close between 2018 and 2030.The document also highlights a recent study which predicts that the LCOE of CSP with storage will match that of wind by 2025.

The document then offers a table of challenges facing the CSP market segments:

Market	CSP Value Proposition	Specific issues
Off-grid/mini grid	• Reliable power at price competitive with diesel. • Hedge against future fuel price fluctuations and supply chain risks.	• Customer expectations of very high overall system availability and capacity factor. • Short time horizons on investment decisions. • Split/perverse incentives around diesel fuel excise rebates. • Requires demonstration at 1 to 10 MW scale in grid connected areas to build confidence.
Stand-alone, grid connected plants	• Grid-stabilising, load-firming, zero-carbon generation. • Enables penetration of renewable energy sources to > 20%. • High correlation with daytime peak loads. • Load-following using thermal energy storage. • Co-fire with gas, biomass etc to maximise reliability of supply.	• Very large capital costs of individual projects. • Lack of transmission infrastructure to optimal solar locations. • Benefits of avoided line loss and grid extension not adequately rewarded. • Building confidence with network service providers. • Hard to get long term PPAs.
CSP add-ons to fossil-fired systems	• Lower emissions intensity for existing power plants. • Leverage existing infrastructure. • Prolong existing fleet lifetime. • High performance systems with lower project risk and capital cost.	• Building confidence of existing generators re CSP integration with core (traditional/fossil) operations. • Split/perverse incentives, e.g. free carbon permits reducing pressure to lower emissions.

Projects are currently considered high risk and must build confidence in its capability among key stakeholders.

Finally, the document concludes by highlighting the idea that whilst challenges exist, there are several large benefits that can outweigh the cons once CSP is implemented. These include:

- Emission reduction
- Clean energy sector development and R&D
- Energy security
- Regional employment and education.

7. SUNSHOT VISION STUDY-CONCENTRATING SOLAR POWER: TECHNOLOGIES, COST AND PERFORMANCE
U.S. Department of Energy
http://www1.eere.energy.gov/solar/pdfs/47927_chapter5.pdf

This document aims to provide a detailed discussion of the opportunities for potential cost reductions to existing and emerging concentrating solar power (CSP) technologies. The document commences by stating that at the end of 2010, the United States was operating approximately 512 MW of CSP. Then, the four main current CSP technologies are presented in some detail. The CSP technologies examined in the document are: Parabolic trough; Linear fresnel; Power tower; and Dish/Engine.

The document continues and examines the cost and performance of CSP plants levelised cost of energy. LCOE is determined to be the best way to evaluate all four types of CSP technologies, using only one index. Whilst LCOE varies depending on the location, ownership, values of key financing terms and available incentives, among other factors, the document gives an example of the southwestern US, which has a current LCOE of 12-18 cents/kWh with a 30% investment tax credit.

Next, the document covers technology and cost improvements to existing and emerging CSP technologies. The document states that reductions in the delivered cost of electricity from CSP plants are anticipated to occur primarily from decreasing the upfront investment cost, and improving performance. Reduced capital cost will be a consequence of manufacturing and installation scale-up as well as technology advancements through R&D aimed at cost reduction and performance improvements. Furthermore, the document highlights other component and system level advancements that are currently undergoing research. These include:

- Solar field
- HTF
- TES
- Cooling technology
- Power block

In 2009, DOE CSP sub-programme set a goal to reduce the LCOE of CSP technology to 9 cents/kWh or less by 2020. In 2011, the DOE unveiled the SunShot initiative, an aggressive R&D plan to make large-scale solar energy systems cost competitive without subsidies by the end of the decade. The overarching goal of SunShot is reaching cost parity with baseloads energy rates estimated to be 6 cents/kWh without subsidies. The document notes that whilst the industry is on the right trajectory, an extra step is necessary to reach the SunShot goal.

The final section of the document examines the material and manufacturing requirement necessary for the increased CSP deployment. Majority of the supply chain is ‘overwhelmingly domestic,’ and most of the materials to build a CSP plant can be found domestically. Furthermore, many of the manufacturing processes can be transferred from traditional fossil fuel system manufacturing and the automotive industry.