Low
Carbon
Innovation
Coordination
Group

Technology Innovation Needs Assessment (TINA)

Solar Photovoltaic and Thermal Technologies
Summary Report

March 2016

Background to Technology Innovation Needs Assessments

The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed funding and delivery bodies in the area of 'low carbon innovation'. Its core members (at the time of this document's completion) are the Department of Business, Innovation and Skills (BIS), the Department of Energy and Climate Change (DECC), the Energy Technologies Institute (ETI), the Engineering and Physical Sciences Research Council (EPSRC), Innovate UK, Scottish Enterprise, and the Scottish Government.

The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINAs' conclusions since they are the focus of other Government initiatives. This document summarises the solar energy TINA analysis.

The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.

The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations.

Disclaimer – the TINAs provide an independent analysis of innovation needs and a comparison between technologies. The TINAs' scenarios and associated values provide a framework to inform that analysis and those comparisons. The values are not predictions or targets and are not intended to describe or replace the published policies of any LCICG members. Any statements in the TINA do not necessarily represent the policies of LCICG members (or the UK Government).

Core members of the Low Carbon Innovation Coordination Group (LCICG):

Department for Business Innovation & Skills

Department of Energy & Climate Change

energy technologies institute

EPSRC Engineering and Physical Sciences Research Council

Innovate UK Technology Strategy Board

Scottish Enterprise

The Scottish Government Riaghaltas na h-Alba

This analysis was prepared for the LCICG by:

CARBON TRUST

Acronyms and Units

Acronyms and abbreviations

1G	First generation PV, a category roughly equivalent to c-Si
2G	Second generation PV, a category roughly equivalent to inorganic thin film
3G	Third generation PV, a category that includes all other PV technologies (e.g. organic, perovskite, multi junction and dye-sensitised)
AC	Alternating Current
BIPV	Building Integrated Photovoltaics
BIS	Department for Business, Innovation and Skills
BIST	Building Integrated Solar Thermal
BoS	Balance of System
c-Si	Crystalline Silicon
CfD	Contract for Difference
CPV	Concentrator Photovoltaics
CSP	Concentrated Solar Power
DC	Direct Current
DECC	Department of Energy & Climate Change
EN&S	Electricity Networks & Storage
EPSRC	Engineering and Physical Sciences Research Council
ESME	Energy Systems Modelling Environment
ETI	Energy Technologies Institute
ETS	Emissions Trading System
EU	European Union
FiT	Feed-in Tariff
GVA	Gross Value Added
IEA	International Energy Agency
KTN	Knowledge Transfer Network
LbD	Learning by Doing
LCICG	Low Carbon Innovation Co-ordination Group
LCOE	Levelised Cost of Electricity / Energy
LEC	Levy Exemption Certificates
LED	Light Emitting Diode
LMH	Low, Medium, High
PV	Photovoltaic
PV-T	Photovoltaic – Thermal
R&D	Research and Development
RHI	Renewable Heat Incentive
ST	Solar Thermal
TCO	Transparent Conducting Oxide
TINA	Technology Innovation Needs Assessment
TRL	Technology Readiness Level
UAE	United Arab Emirates
UK	United Kingdom
WACC	Weighted Average Costs of Capital

Units of measure

bn	Billion
GW	Gigawatt
kW	Kilowatt
MWh	Megawatt hour
tn	Trillion
TWh	Terawatt hour
We	Watt of electrical power
Whe	Watt hour of electrical energy
Whth	Watt hour of thermal energy
Wth	Watt of thermal power

Key Findings

Solar technologies have the potential to deliver low carbon energy in a wide range of centralised and decentralised settings. Solar technologies can deliver both power and heat, but power applications dominate the opportunities for the UK. Innovation could significantly reduce the cost of solar technologies, reducing UK deployment costs to 2050[1] by £14.5bn (£9.0 – 24.4bn) for solar power and £0.2bn (£0.04 – 2.40bn[2]) for solar thermal[3] technologies, although the majority of this innovation is likely to occur outside the UK. Similarly the vast majority of the value creation from solar technologies is likely to occur in other countries, but innovation in certain valuable sub-sectors would help create UK-based business opportunities that could contribute £16.7bn (£11.9 – 27.4bn) from solar power and £1.1bn (£0.6 – 4.1bn) from solar thermal technologies to 2050[2]. In some areas market failures impeding innovation mean that public sector support will be required to unlock this value.

Potential role in the UK's energy system	• Solar technologies may be less well suited to the UK climate than to sunnier regions, but solar technologies enjoy the highest level of public support out of all renewables[4] and there are already over 9GW of solar power[5] and upwards of 0.5GW of solar thermal[3] in the UK. • Solar technologies could deliver[6] 6% (2 – 13%) of total UK electricity generation and 0.2% (0.1 – 3%) of UK heat generation by 2050, helping to decarbonise and decentralise the generation of power and heat in the UK. • The different properties of newer solar photovoltaic (PV) technologies (e.g. flexible, transparent, printable) could open up completely new applications, potentially leading to much higher deployment of PV in the UK's energy system than assumed in this report. • However the seasonal, diurnal and intermittent nature of solar energy creates challenges for the energy system which both limit the deployment of solar technologies and create opportunities for other technologies such as smart grids and system flexibility enablers such as storage.
Cutting costs by innovating	• The dominant solar technologies are quite mature relative to other low carbon technologies meaning that most of the cost reduction opportunity can be attributed to 'learning by doing' (e.g. process innovation) rather than 'learning by R&D'. However the R&D component of innovation increases for newer technologies. • Solar PV panels have reduced in cost by ~90%[7] over the last 20 years and further cost reductions of ~50% are possible between 2015 and 2050. Subsequent PV technologies could be cheaper in the long term, and offer other advantages (e.g. transparency, colour, flexibility, weight). • There is a similar, although less certain, cost reduction opportunity in solar thermal technologies; ~35% reduction may be possible between 2015 and 2050. • R&D-driven innovation in solar technologies could reduce the cost of their deployment in the UK by £14.7bn (9.1 – 26.9bn) to 2050, although much of this innovation is likely to occur outside the UK.
Green growth opportunity	• The UK has strengths in some of the core capabilities needed to take a strong position in certain solar technology sub-sectors (e.g. building integrated PV) and component areas (e.g. glass substrates, materials for functional layers, novel PV chemistries, thermal storage and high temperature engineering) which could have significant economic value in aggregate; however, the UK is not positioned to lead technology development across the solar sector. • The global market for solar technologies could be £285bn (£159 – 432bn, undiscounted) in 2050 and the economic value to the UK from selling into this market could be worth £18.7bn (£13.0 – 32.9bn) to 2050 with displacement taken into account.

[1] All sums to 2050 are cumulative (2015-2050) present discounted values for low-high scenarios.
[2] The availability of reliable data on solar thermal deployment and costs is limited compared to solar PV which creates greater uncertainty for all the solar thermal numbers reported here.
[3] This report only considers solar thermal technologies for water heating and not space heating.
[4] DECC, Public Attitudes Tracking survey: Wave 14 (2015)
[5] Solar power is dominated by solar photovoltaics but also includes technologies converting solar heat into electricity such as concentrated solar power (CSP).
[6] Solar energy delivered is based on the analysis in this TINA; total generation estimated from energy system modelling scenarios with 615 TWhe and 500 TWhth in 2050.
[7] Agora Energiewende, Current and Future Cost of Photovoltaics, 2015; Bloomberg, Solar Silicon Price Drop Brings Renewable Power Closer, 2012; Carbon Trust analysis.

The case for UK public sector intervention	•	Current solar PV and solar thermal[3] technologies are essentially globally commoditised and the UK could largely rely on other countries for the innovation required, with the exception of building integrated technologies where optimisation for UK building stock is required.
	•	The market failures and barriers to innovation in solar technologies are generally minor relative to other low carbon technologies, but there are some areas where public sector intervention is justified. – The UK has the potential to take a leading position in future solar technologies but the dominant position of existing technologies makes it difficult for the private sector to invest in the innovation required. – Some of the technologies that the UK could have export strengths in are unlikely to be deployed in large volumes in the UK (e.g. concentrated solar power (CSP) and concentrator PV (CPV)) making private sector investment in the UK more risky. – Multiple barriers in the building sector make it difficult for companies to invest in innovation in building-integrated PV, ST and hybrid PV-T. – Higher relative incentives for solar PV in recent years have made it very hard for solar thermal technologies to compete for consumer investment. – Hybrid PV-T systems can deliver more low carbon energy and are more complex products than simple PV or ST but current incentives do not reflect this (they are currently not eligible for the domestic/ RHI that ST receives and receive the same FiT as simple PV).
Potential priorities to deliver the greatest benefit to the UK	•	Support fundamental and applied R&D in future solar PV technologies.
	•	Support basic and applied R&D and challenges/competitions for components which could be used in multiple types of thin film PV (e.g. coatings, barrier layers, edge seals, etc.).
	•	Provide challenges/competitions with specific cost reduction and performance targets for solar technology balance of system components and supply chain where the UK is strong.
	•	Support demonstration projects, standard setting, testing infrastructure and coordination to remove market barriers (e.g. in building-integrated solar systems, emerging PV technologies, CPV and CSP).
	•	Support international partnering in technologies that are unlikely to be deployed in large volumes in the UK (e.g. CSP and CPV), but may offer significant export opportunities.

Table 1 Solar TINA summary by sub-sector

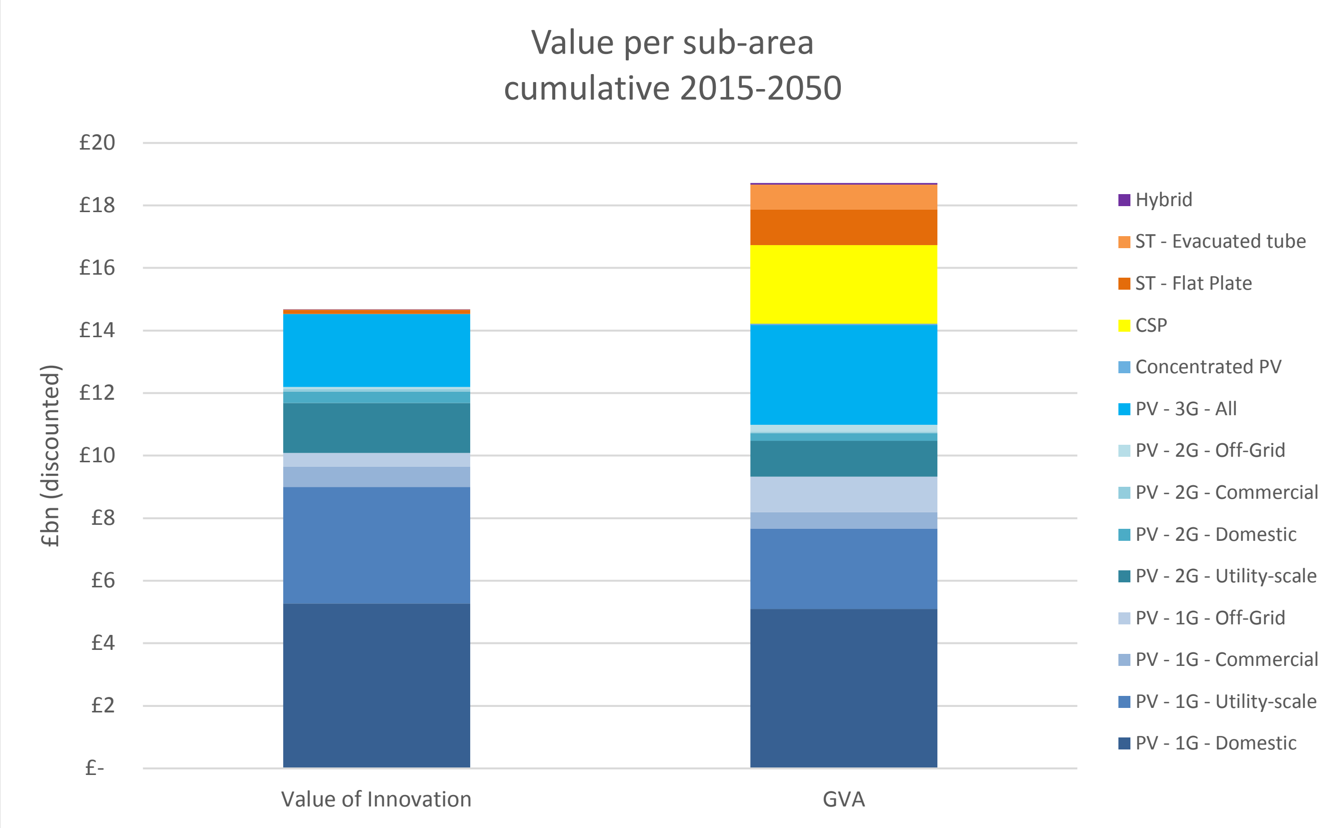
Sub-area	Focus/ technology	Value in meeting UK emissions targets at low cost £bn[8]	Value in UK business creation £bn[8]	Key needs for UK public sector innovation activity/investment
1st Gen PV	Domestic	5.3 (3.8 – 8.3)	5.1 (4.2 – 8.0)	Improved 'Balance of System'
	Commercial	0.6 (0.4 – 1.1)	0.5 (0.4 – 0.8)	
	Utility-scale	3.7 (2.8 – 5.9)	2.6 (2.1 – 3.3)	
	Off-grid	0.4 (0.3 – 0.6)	1.1 (0.8 – 2.0)	
2nd Gen PV	Domestic	0.1 (0.0 – 0.1)	0.0 (0.0 – 0.1)	Improved 'Balance of Module'
	Commercial	0.37 (0.18 – 0.66)	0.25 (0.17 – 0.40)	
	Utility-scale	1.6 (0.9 – 2.7)	1.2 (0.8 – 1.9)	
	Off-grid	0.07 (0.02 – 0.15)	0.2 (0.2 – 0.4)	
3rd Gen PV	All	2.3 (0.6 – 4.8)	3.2 (2.4 – 5.2)	Improved active layer (better power conversion efficiencies), improved lifetimes (better stability and encapsulation techniques), reduced barriers to new product development (standards, testing)
CPV	All	0.00 (0.00 – 0.00)	0.05 (0.04 – 0.10)	International partnering
CSP	All	0.0 (0.0 – 0.0)	2.5 (0.8 – 5.2)	International partnering
Thermal	Flat plate	0.1 (0.0 – 2.0)	1.1 (0.6 – 4.1)	Testing, standard setting, demonstration and R&D for BIST
	Evacuated tube	0.01 (0.00 – 0.16)	0.8 (0.5 – 1.3)	
BIPV/BIST[9]	Building integrated			Testing, standard setting, demonstration and R&D
Hybrid	All	0.02 (0.01 – 0.24)	0.0 (0.0 – 0.1)	Demonstration and R&D
Total		**14.7 (9.1 – 26.9)**	**18.7 (13.0 – 32.9)**	

Source: E4tech and Carbon Trust analysis.

[8] 2015-2050 cumulative, discounted, Medium (Low – High) deployment.

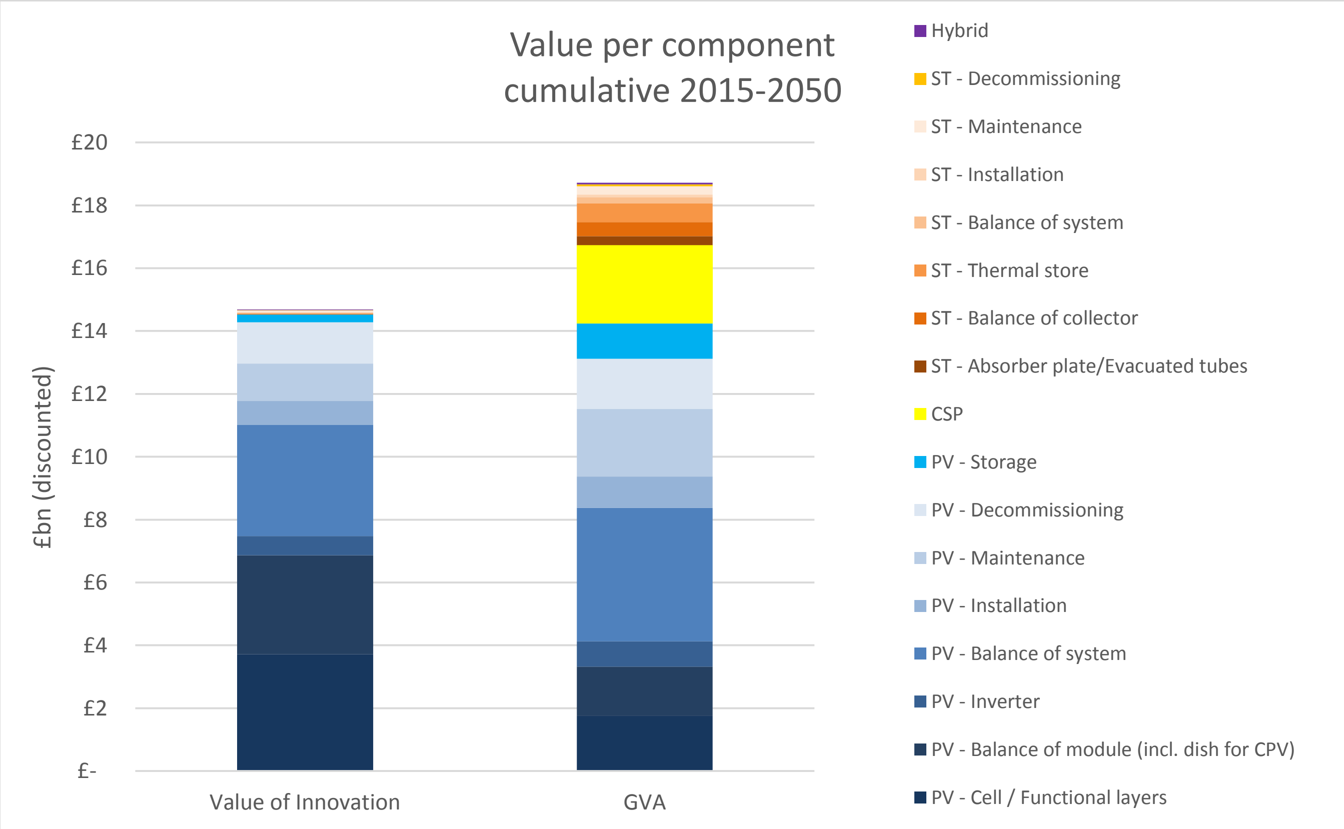
[9] For BIPV and BIST the values for meeting environmental targets at least cost and in business creation are included within other categories, these may be disaggregated in future analysis.

Figure 1 Value to the UK per technology sub-sector for all technology components (cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

Figure 2 Value to the UK per technology component for all technology sub-sectors (cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

The role of solar technologies in the UK energy system

There are many ways in which the sun's energy can be harnessed. Of the available technologies, solar PV, which converts solar radiation directly into electricity, has seen the most impressive global deployment in recent years. The scope of this TINA includes solar PV as well as a range of other solar power and heat technologies. However, the TINA does not consider newer air-based transpired solar or building-fabric integrated carrier systems or other forms of solar heating such as heat pump systems.

In the UK, solar power is expected to make a significant contribution to renewable energy consumption targets. Historically PV in the UK has been a relatively expensive low carbon technology, but its cost reductions in recent years have placed PV in a competitive position. Solar power can be deployed fast, close to loads if necessary, in a variety of different configurations, and often without significant infrastructure requirements.

Solar thermal technologies could contribute to decarbonising heat in the UK without being dependent on the decarbonisation of the power sector. However, deployment to date has been modest compared to other countries.

The deployment of solar technologies will depend on various factors, including the impact that innovation has on cost reduction, and unlocking next generation technologies and applications that are more suited to UK conditions. Other factors, such as the availability and cost of other low-carbon technologies, public acceptability, building regulations[10], government incentives and future energy demand will also affect solar deployment.

There are already over 9GWe[11] of solar power[12] and upwards of 0.5GWth[13] of solar thermal[3] installed in the UK. Most of the PV deployment has occurred in the last five years, supported by subsidies. Despite the fact that solar technologies are less well suited to the UK climate than to sunnier regions, they could deliver 6% (2-13%)[6] of total UK electricity generation and 0.2% (0.1-3%)[6] of UK heat generation by 2050, contributing to decarbonise and decentralise the generation of power and heat in the UK.

We have considered three indicative deployment scenarios, based on energy system modelling, published studies[14] and analysis by LCICG members, which reflect how the aforementioned factors could impact the uptake of solar technologies under different conditions[15]. These scenarios aim to capture an indicative range of feasible deployment, and are neither forecasts for the UK nor targets for policy makers[16]. The medium scenario is used as the central value for all of the following TINA analyses.

- **Low scenario** (power: 10 GW by 2025, 10 GW by 2050; heat[3]: 0.7 GW by 2025, 0.7 GW by 2050). This scenario assumes other low-carbon technologies will achieve lower costs leading to removal or a very significant reduction in deployment support from 2020. Deployment from 2020 to 2050 is just sufficient to match requirements and maintain the installed capacity.
- **Medium scenario** (power: 23 GW by 2025, 33 GW by 2050; heat[3]: 1.1 GW by 2025, 2.0 GW by 2050). This scenario reflects current trends in the UK power sector, where solar PV is a popular[4] technology, with deployment increasing rapidly until ~2030, when significant deployment of CCS is assumed to start. Solar thermal[3] deployment grows at the rate required to maintain the UK's current share of total global deployment.
- **High scenario** (power: 29 GW by 2025, 70 GW by 2050; heat[3]: 9 GW by 2025, 28 GW by 2050). Solar power deployment increases significantly and it becomes one of the main UK power sources. Solar thermal becomes one of the key technologies to decarbonise UK heat and its uptake sees a strong increase.

Due to data availability, this report considers the use of solar thermal technologies for water heating only; use of solar thermal for other applications, such as space heating or process heat, are not included. Deployment of these other solar thermal technologies would be additional to renewable heat delivered in these deployment scenarios.

Currently PV markets are dominated by c-Si and the deployment scenarios used in this report assume that c-Si continues to dominate even in 2050. However newer generations of PV technologies can have very different properties to c-Si, e.g. transparent, flexible, conformable, different wavelength response and thermal characteristics. These could open up completely new applications, potentially leading to much higher deployment of PV than is assumed in these scenarios[17].

[10] Regulations requiring low carbon buildings could drive deployment of solar technologies in new buildings, particularly BIPV/BIST.

[11] DECC, Solar photovoltaics deployment statistics (February 2016).

[12] Solar power is dominated by solar photovoltaics but also includes technologies converting solar heat into electricity such as concentrator solar power (CSP).

[13] ESTIF, Solar Thermal Markets in Europe – Trends and Market Statistics (2014).

[14] Energy Technologies Institute's (ETI) Energy System Modelling Environment (ESME) model, "Options, Choices, Actions; UK scenarios for a low carbon energy system transition" 2015. DECC 2050 calculator. Expert interviews and Carbon Trust/E4tech analysis.

[15] Deployment of solar thermal in the UK is not recorded as well as solar PV, making it more difficult to develop representative scenarios

[16] By trying to capture the full range of uncertainty over the mid to long term to inform innovation policy, these indicative deployment levels are not precisely aligned with UK government short and mid-term targets.

[17] This level of deployment would require a fundamentally different approach to how PV is integrated with the system, e.g. curtailment of excess generation.

Systems perspective

The increasing deployment of intermittent, non-dispatchable power and heat generation will require changes to how the national energy system is managed. The increase of distributed generation could cause considerable congestion in electricity distribution networks which, if unaddressed, could effectively limit deployment of distributed generation (both for solar PV and other technologies).

Overall, solar thermal and solar PV tend to generate very little at times when UK system-wide demand for heat and power are highest (i.e. evenings and early mornings in mid-winter). This means that their contributions to peak capacity requirements are far lower than their contribution to total energy consumption. Conversely, solar thermal and solar PV will tend to generate most energy at times when UK demand for heat and power is lowest (i.e. in the middle of the day in mid-summer), and this excess generation can cause different issues. However, PV output profiles typically have a better correlation to non-domestic property demand, where peak demand typically occurs during daylight. In other countries with hotter climates, where peak winter heating loads are lower and peak electricity demand is driven by cooling requirements (e.g. air conditioning) the temporal matching between national demand and solar output is much better and integration can be easier.

At low penetration levels solar PV is relatively easy to accommodate with very little additional infrastructure changes required, but as deployment increases system integration challenges will occur and in high deployment scenarios the incremental infrastructure cost (e.g. through grid reinforcement, operational changes, or the addition of energy storage/other flexible plant to manage intermittency) could be significant. For example, on a summer weekend in the UK, midday electrical demand is typically about 30 GW, of which about 10 GW is met by ‘must run’ plant which cannot be easily curtailed[18]. This suggests that if solar PV capacity exceeds about 20 GW, as would occur around 2025 and 2020 in the medium and high scenarios respectively, it could present a significant challenge to system balancing.

Due to the uneven, and to an extent uncontrolled, distribution of solar technology deployment, clusters of excess generation are likely to occur, e.g. in more rural areas where there is lower demand, in particularly sunny locations, near utility scale PV ‘farms’ and in regions where domestic deployment has been very popular. This clustering could present challenges for the electricity transmission and distribution systems long before supply exceeds demand at a national level.

The main system issues caused by excess supply are voltage rises (where the voltages across the system rise towards maximum limits) and minimum demand conditions (where embedded generation reduces net daytime demand close to overnight levels and other generation assets have to be constrained).

Improvements in solar PV devices could help mitigate some of the issues caused and help manage other system issues. For example integration of batteries with inverters could smooth output and discharge at times of peak demand and smart inverters could provide a range of network support functions, including power factor control.

There are additional localised electrical issues related to components within PV systems which convert the DC electrical output of the PV cells into AC. Inverters can contribute to harmonic issues in the local distribution network. The issue can be particularly acute when many similar products are on the same network; individually their effects are minor, but in aggregate they can be problematic.

Note however that many electrical products in a typical building use DC, creating this from AC supplies through built in and external power adaptors (which usually contain rectifiers and transformers) Each set of power conversion electronics has a financial, embedded carbon and efficiency cost. In the future there could be opportunities for PV inverters to supply DC directly, saving money and carbon by supplying local DC networks powering electronic devices, LED lighting and charging batteries.

Innovations in other parts of the energy system will also help, mostly related to improving the performance and reducing the costs of system flexibility enablers. These technologies could reduce the stress on transmission and distribution networks, and reduce the need for peak heat and power generation capacity by allowing both demand and supply of energy to be shifted in time, albeit at an additional cost. Examples include electricity and heat storage to shift the supply of solar energy from day to night or from summer to winter, and smart systems to shift flexible demand towards times of highest solar output.

These challenges caused by intermittent energy supply and the opportunities for system flexibility enablers that they create are analysed in more depth in the Electricity Networks and Storage (EN&S) TINA[19].

[18] National Grid, Briefing Note for DECC on Solar PV Deployment (2012)

[19] LCICG, Electricity Networks & Storage (EN&S) TINA (2012).

Cutting costs by innovating

Current costs

Over the past 30 years solar power has experienced a dramatic cost reduction that has made it competitive with fossil fuels in certain markets, in some cases even reaching grid parity. In 2015 the levelised costs of energy (LCOE) from utility-scale solar PV were as low as ~£50/MWh[20] in optimal climates (e.g. UAE, Texas), where the average price of electricity to ultimate customers is in the range £35-78/MWh[21]. However, LCOEs do not fully reflect the system-level cost impacts (e.g. balancing, storage, etc) that would result from significant solar PV deployment.

In the UK, utility-scale costs are in the vicinity of £100/MWh[22] and this could fall to £85/MWh in 2020 and as low as £50/MWh by 2050. However, solar energy costs vary widely depending on various factors, such as technology, solar irradiation, component lifetime and degradation, storage requirements, cost of finance etc. As an example,

Table 2 illustrates the typical cost share by component of a crystalline silicon (c-Si) PV system.

The cost of CSP is currently around £130/MWh[20] in the countries it is deployed in, however conditions make CSP deployment economically unfeasible in the UK. Solar thermal costs for heat generation are currently around £120/MWh and could fall to £80/MWh by 2050, although costs can vary considerably depending on the technology.

[20] IRENA, Renewable Power Generation Costs In 2014, 2015; Carbon Trust analysis.

[21] EIA, Average Price of Electricity to Ultimate Customers by End-Use Sector (June 2015).

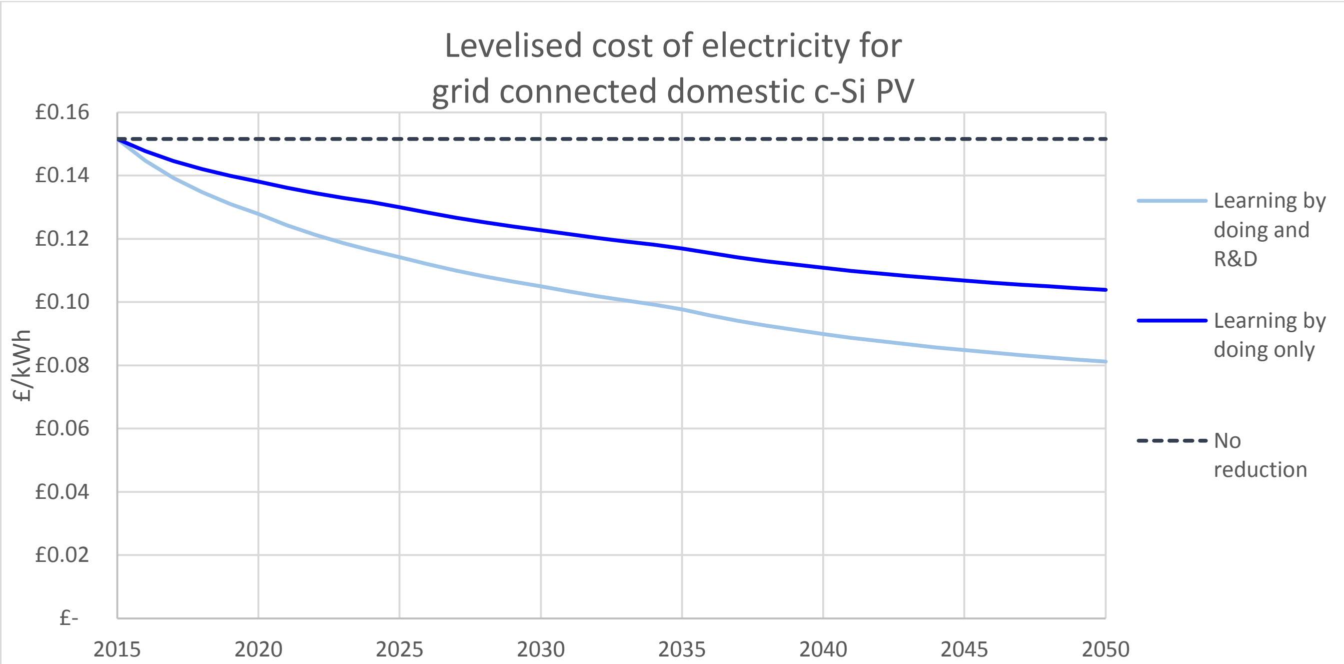
[22] The LCOE does not include integrations costs and is particularly sensitive to the WACC and utilisation rate, for which we use 7% and 10% respectively. LCOEs are calculated using technology costs as at August 2015. LCOEs estimated using other assumptions may differ. Also, lower strike prices of £50/MWh and £79.23/MWh were agreed in the first CfD allocation round in February 2015, although, by definition, these are at the lower end of the range and may not reflect the true cost.

Table 2 Breakdown of domestic rooftop crystalline silicon PV levelised cost

Component	Descriptions	Share of 'Levelised cost of Energy' in 2015
Cell	Wafer, contacts etc., all components of a single cell	21%
Balance of module	Supporting layer (e.g. glass / plastic), encapsulation, anti-reflective coating, metal back, frame, electrical junction box. Essentially everything required to connect and contain an array of cells	9%
Inverter	Changes direct current (DC) to alternating current (AC)	11%
Balance of system	All other components including wiring, racking etc.	39%
Installation	Labour required to set up and commission a system	7%
Maintenance	Labour required to ensure system operation throughout lifetime	10%
Decommissioning	Labour required to withdraw system from service after useful lifetime	3%

This is an example of one particular PV technology and application – grid-connected domestic rooftop c-Si PV.
Source: E4tech and Carbon Trust analysis.

Figure 3 Potential impact of innovation on costs



Source: E4tech and Carbon Trust analysis[23].
This is an example of one particular PV technology and application – grid-connected domestic rooftop c-Si PV.

[23] LCOEs were calculated using a 7% WACC and a 10% capacity factor; system lifetime was assumed to be 20 years, and inverter lifetime 10 years.

Cost savings through economies of scale and innovation

Crystalline silicon solar PV panels have reduced in cost by ~90%[7] over the last 20 years and further cost reductions of ~50% are possible between 2015 and 2050. Subsequent generations of PV could be cheaper in the long term, and offer other advantages (e.g. transparency, colour, flexibility, weight).

It is estimated, although with less certainty, that there is a cost reduction opportunity in solar thermal[3] technologies of ~35% between 2015 and 2050.

Cost reduction opportunities for solar power vary across different technologies. Historically, solar PV costs have been dominated by module costs. These will continue to be an important source of cost reduction, especially for concentrator PV where module efficiency is the main cost driver. However, balance of system (BoS), installation standardisation and system optimisation will also be increasingly important sources of cost reduction.

As a more mature technology it is expected that cost reductions in c-Si will mostly be due to 'learning by doing', while R&D plays a greater role in the cost reduction of thin film technologies by improving performance and durability of functional layers and coatings.

Innovation and cost reduction for emerging (3G) technologies, such as perovskite or organic cells, will be dominated by R&D in the short to medium term. These innovations will need to reduce costs, increase efficiencies and lifetimes; and ensure the products can be effectively integrated into energy systems.

The largest cost components for concentrated solar power are the mirror field (parabolic troughs or heliostats), power block and thermal storage. It is expected that performance improvements in these components, as well as economies of scale in plant size and manufacturing industry will be the main cost reduction drivers.

Solar thermal[3] technologies share a similar story. Mature technologies such as flat plate or evacuated tube will see their costs reduced mainly as a consequence of 'learning by doing' effects. On the other hand, the costs of emerging hybrid technologies that combine solar thermal and solar PV in one product will be driven down mainly by R&D.

Storage requirements will be quite different in off-grid and on-grid applications. In off-grid applications storage can be a significant part of the total cost and will tend to be used to capture the majority of the daytime power output, for discharge overnight or potentially over multiple days. Whereas in on-grid applications, storage will tend to be used more to flatten the top of high peaks and smooth sudden output transitions. This will lead to quite different innovation priorities. In both cases, batteries will have to be optimised for the diurnal-nocturnal charge-discharge cycle – a specific pattern that pushes to specific chemistries and designs.

Table 3 summarises the cost reduction potential and sources for the solar technologies considered in this report. .

Table 3 Potential cost savings from innovation by sub-area

Sub-area	Focus/ technology	Near-term innovation impact potential on LCOE		Source of improved potential
		2015-2020	2015-2050	
1st Gen PV	Domestic	16%	46%	Mainly 'Learning by Doing' (LbD) reductions in manufacturing costs of modules and Balance of System (BoS) components. Innovative design to reduce material costs and labour time in mounting. Controllers to enable surplus generation to be diverted to immersion heaters, EVs, batteries or other forms of storage. Innovative inverter topologies improving efficiencies. Management processes developed through experience allowing for efficient installation.
	Commercial	15%	45%	
	Utility-scale	14%	40%	
	Off-grid	21%	51%	
2nd Gen PV	Domestic	22%	64%	Improved performance and durability of functional layers; BoS tailored to 2nd generation PV and building integration. More efficient, cost effective TCO deposition processes.
	Commercial	19%	60%	
	Utility-scale	17%	51%	
	Off-grid	5%	49%	

3rd Gen PV	All	8%	66%	Increased efficiencies and lifetimes; effective integration into energy systems. Improving automation of encapsulation to prolong lifetime. Cost effective TCO deposition processes. Synthesis of high efficiency materials for light capture. Innovative BIPV design to facilitate integration & reduce additional installation time.
CPV	All	25%	68%	Increased efficiencies and lifetimes; effective integration into energy systems. Development of novel manufacturing processes, e.g. Laser Grooved Buried Contact cells, high volume production of epitaxial wafers.
CSP	All	5%	45%	Cost reductions in manufacture of concentrating optics; improved thermal storage and demonstrated durability. Scalable production processes for high efficiency molten salts.
Solar Thermal[3]	Flat Plate	14%	34%	Mainly LbD reductions in manufacturing costs. Use of novel materials / novel designs to improve efficiency of thermal storage tanks; conversion of existing hot water cylinder to twin coil. Use of innovative working fluid. Design of building integrated collectors to reduce installation time. Development of concentrators using non-imaging optics to increase water temperature.
	Evacuated tube	12%	31%	
Hybrid	All	15%	49%	Reduced manufacturing costs and improved integration into building energy systems.

Source: E4tech and Carbon Trust analysis.

Value in meeting emission and energy security targets at lowest cost

Based on potential cost improvements and the deployment scenarios used (which take into account the UK's emission reduction targets and energy security constraints), we estimate that R&D in solar technologies could reduce the cost of their deployment in the UK by £14.7bn (£9.1 – 26.9bn) to 2050.

While the UK is expected to play an important role in innovation in emerging and low TRL technologies it is worth noting that, due to the maturity and consolidation of the global solar energy market, we expect most of this cost reduction to be delivered by innovation that occurs outside the UK.

Power

In the medium deployment scenario, the cost reduction opportunities for solar power are £32.2bn over 2010-2050. As shown in, the majority of this, £17.7bn (55%), is from 'learning by doing' improvements, while the remaining £14.5bn (45%) in savings comes from 'learning by R&D'.

Due to the expected domination of UK deployment by c-Si, most of the savings are expected to occur in this technology with about two thirds of the savings coming from domestic rooftop and utility scale deployment of c-Si alone; Figure 6 shows the contribution of each technology to the overall value of R&D in reducing UK deployment costs.

From a component perspective, the greatest contribution to the savings in the power sector comes from R&D in BoS, followed by cell and balance of module. The savings from R&D associated with each component are shown in Figure 7. It is worth mentioning that the value of innovation in storage reported here only considers the benefits of cost reductions in solar products with in situ storage. If considering storage from an overall UK energy system perspective its contribution to cost reductions could be much greater; this treatment is considered in the EN&S TINA[19].

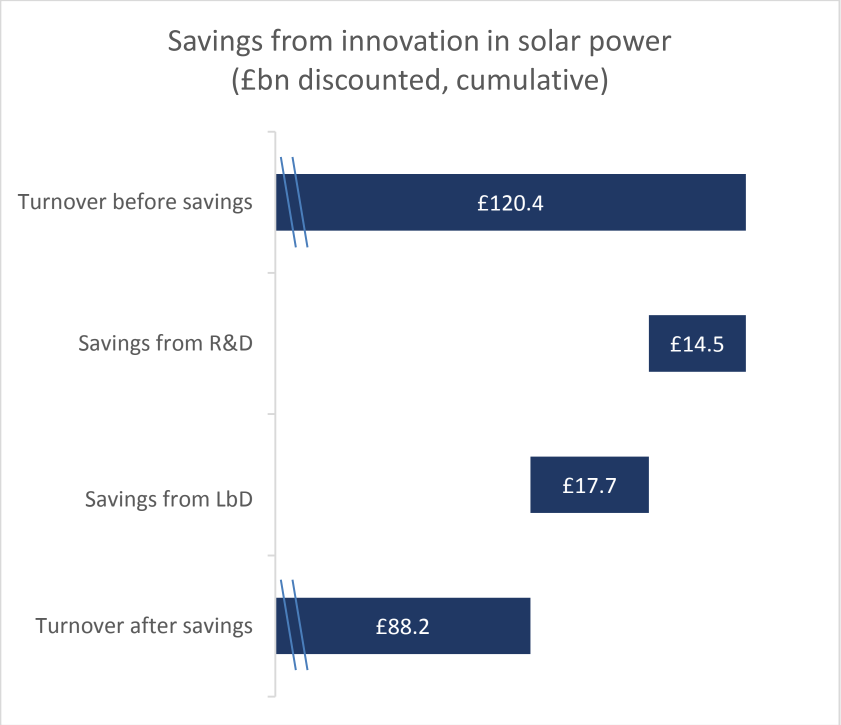
Heat

The cost reduction opportunities for heat in the Medium deployment scenario are much smaller than those for power at £0.5bn over 2010-2050. Figure 5 shows that the majority of this, £0.4bn (71%), is from 'learning by doing' improvements, while savings from 'learning by R&D' account for the remaining £0.2bn (29%).

Our analysis suggests that most of the expected savings will happen through the deployment of flat plate solar water heaters; Figure 6 shows the contribution of each technology.

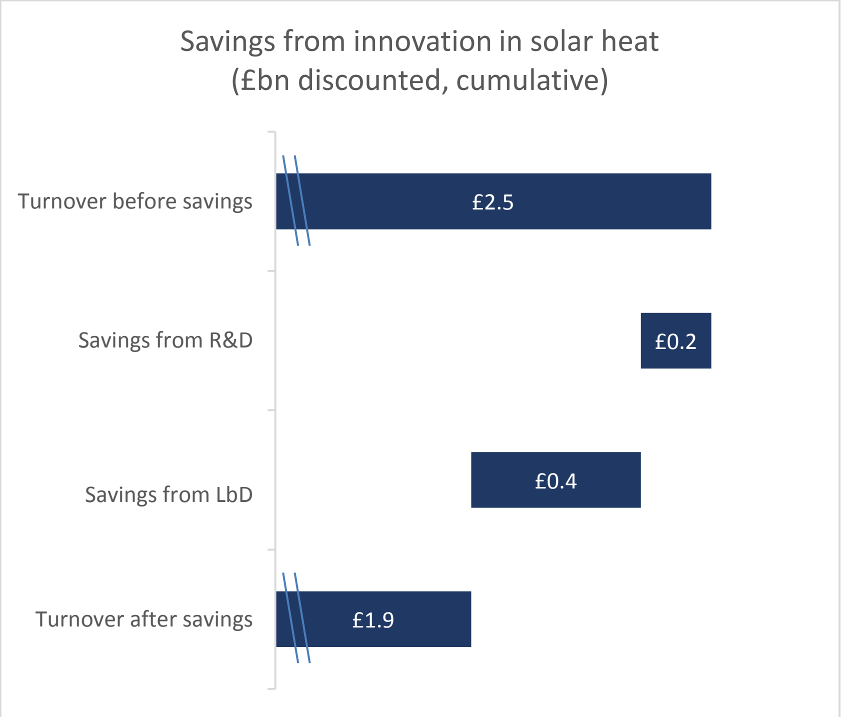
From a component perspective, the component which will contribute the most to R&D-driven savings in the water heating sector is installation followed by maintenance and balance of collector. The savings from R&D associated with each component are shown in Figure 7.

Figure 4 Potential cost savings from solar power 2015-2050[24]



Source: E4tech and Carbon Trust analysis.

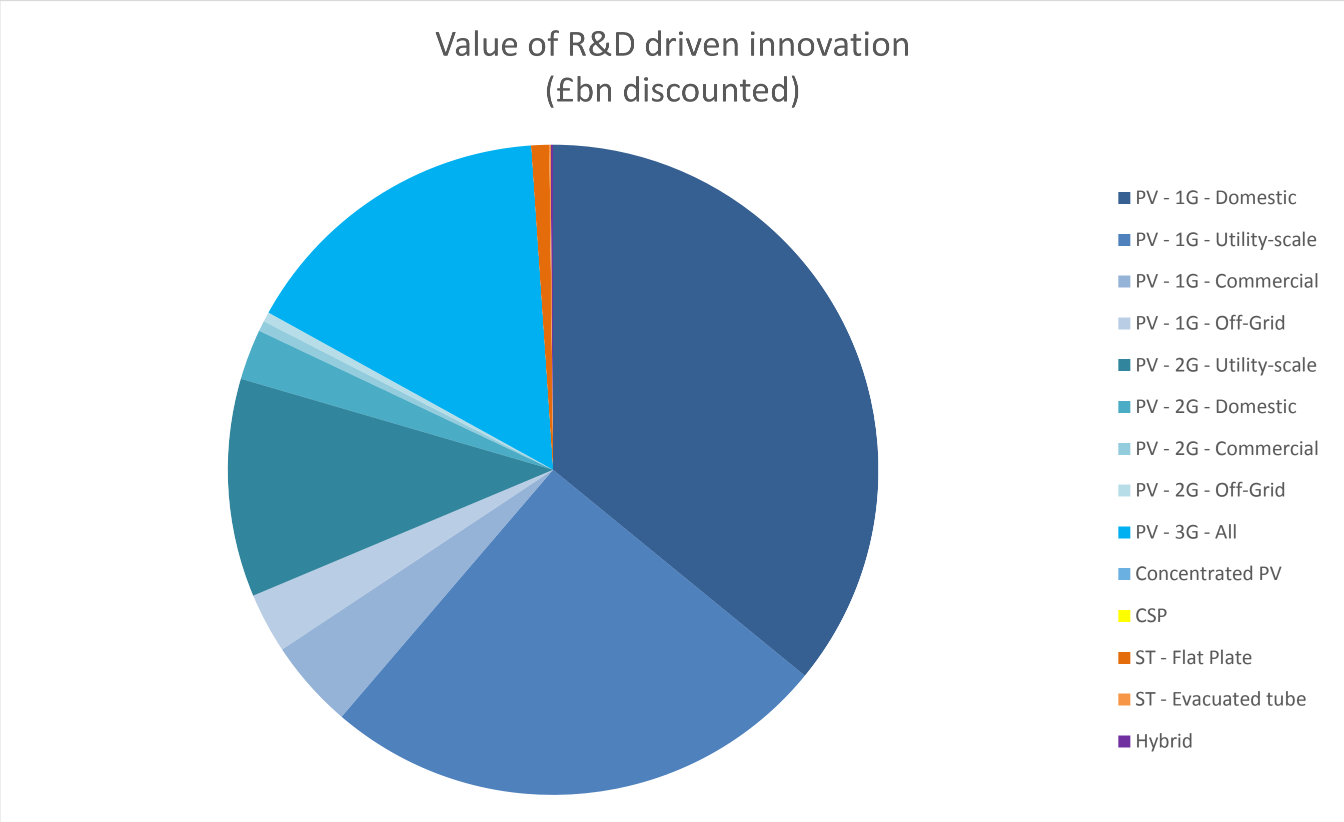
Figure 5 Potential cost savings from solar heat 2015-2050[24]



Source: E4tech and Carbon Trust analysis.

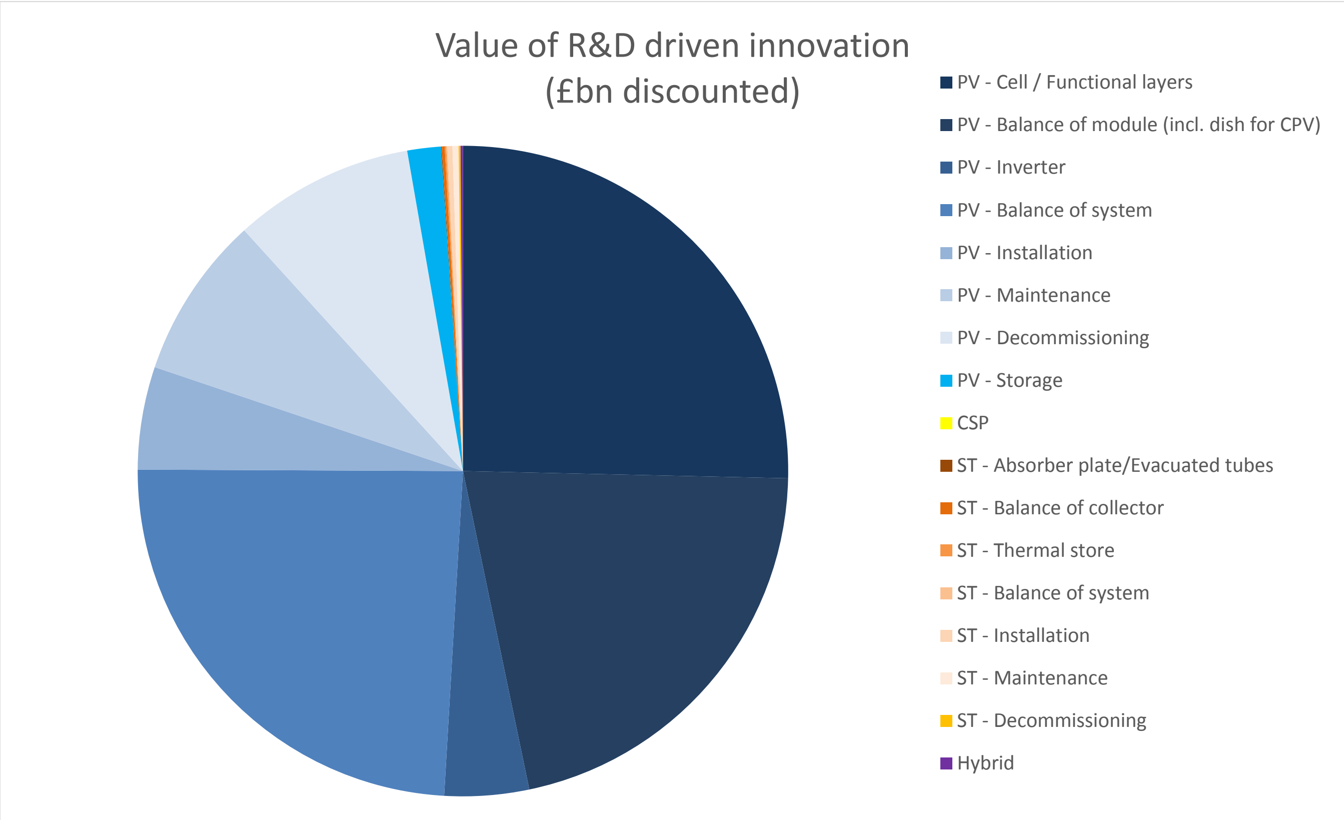
[24] Medium scenario shown; figures are discounted and cumulative over the 2015-2050 period.

Figure 6 Value of innovation per technology sub-area (all technology components, cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

Figure 7 Value of innovation per technology component (all technology sub-areas, cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

Green growth opportunity

A large global solar energy market

Solar power is expected to play a major role in global energy systems in the years to come. The IEA estimates that drivers such as fossil fuel prices and further cost reductions of renewables will translate into significant deployment of solar energy in all scenarios. Three scenarios from the IEA's Energy Technology Perspectives[25] have been used to estimate the Low, Medium and High global deployment scenarios to 2050 for solar PV, whereas the Low, Medium and High solar thermal global deployment scenarios are all scaled from one deployment scenario in the IEA's Solar Heating and Cooling Roadmap[26].

- **Low scenario** (power: 454 GW by 2025, 1813 GW by 2050; heat: 811 GW by 2025, 1,464 GW by 2050). Power deployment is based on the 4D scenario which takes into account current policies to limit emissions; heat deployment is scaled off the Solar Heating and Cooling roadmap.
- **Medium scenario** (power: 560 GW by 2025, 2,785 GW by 2050; heat: 1,178 GW by 2025, 2,929 GW by 2050). Power deployment is based on the 2D scenario which gives an 80% chance of limiting temperature increase to 2^{o}C; heat deployment is scaled off the Solar Heating and Cooling Roadmap.
- **High scenario** (power: 1,239 GW by 2025, 4,674 GW by 2050; heat: 1,468 GW by 2025, 4,438 GW by 2050). Power deployment is based on the hi-Ren[27] scenario which is a variant of 2DS scenario with slower deployment of nuclear and CCS, thus more rapid deployment of solar and wind; heat deployment is based on the Solar Heating and Cooling Roadmap.

Across the range of scenarios, the global market turnover in 2050 could grow to £285bn (£159 – 432bn, undiscounted) for the power sector and £99bn (£51 – 148bn, undiscounted) for heat.

The UK's role in the global solar markets

The UK's strengths in academic and corporate research, combined with a track record in technology innovation and high value manufacturing provide a platform for the UK solar industry to build on. There are opportunities to export those skills and knowledge and, if exploited effectively, that expertise could provide the potential to create and export world-leading commercial technologies.

In our medium scenario, UK shares of the global market are expected to be around 3% for PV, 1% for solar thermal and 0.4% for CSP. More specifically, the UK has strengths in some of the core capabilities needed (e.g. materials science, technology integration) and could take a strong position in certain sub-areas (e.g. building integration, novel PV chemistries currently at low TRLs, mounting systems, power electronics, glass substrates, thermal storage and high temperature engineering). As a result the UK's potential share of market value in emerging PV technologies could be as high as 7%.

Economic value

Competing successfully in global markets could add £1.4bn (£0.9 – 2.2bn) per annum in Gross Value Added (GVA) to the UK economy by 2050 and £18.7bn (£13 – 32.9bn) cumulatively to 2050 (including displacement[28]). Overall, this role of the UK in the global solar market would be expected to support about 50 (33 – 81) thousand full-time jobs by 2050.

As shown in Figure 8 the current overwhelming dominance of global solar PV markets by c-Si suggests that most of the future economic value will continue to come from c-Si systems. Nevertheless the economic value from 3G PV technologies is expected to be considerable at £3.2bn (£2.4 – 5.2bn). It is possible that early stage PV technologies could end up having more favourable properties than c-Si, which could translate into lower costs, new applications and therefore higher deployment than our scenarios assume. If this were the case, and if the UK could convert its current research strengths in these technologies into a larger share of global PV manufacturing, there would be a significant increment to the economic value the UK could capture.

The UK is expected to capture a relatively large amount of economic value, £2.5bn (£0.8 – 5.2bn), from CSP considering that no deployment of this technology is expected in the UK. The UK has strengths in many of the components and core capabilities required for CSP as well as a long track record of delivering large engineering projects in some of the likely geographies, however not having any home market for CSP could make it difficult to capture this value.

The parts of the UK market which tend not to be internationally traded could be relatively large, with a turnover of approximately £5.2bn (£3.9 – 9.0bn) in 2050. Maintenance and installation and decommissioning are the main contributors to this with £2.4bn, £1.1bn and £1.7bn of GVA, respectively, from UK companies selling into the UK market.

Interestingly, Figure 9 shows that the components with the largest contribution to cumulative UK GVA, at

[25] The Low, Medium and High global solar PV deployment scenarios are based respectively on the 4DS, 2DS and hiRen scenarios in IEA, Energy Technology Perspectives 2014.

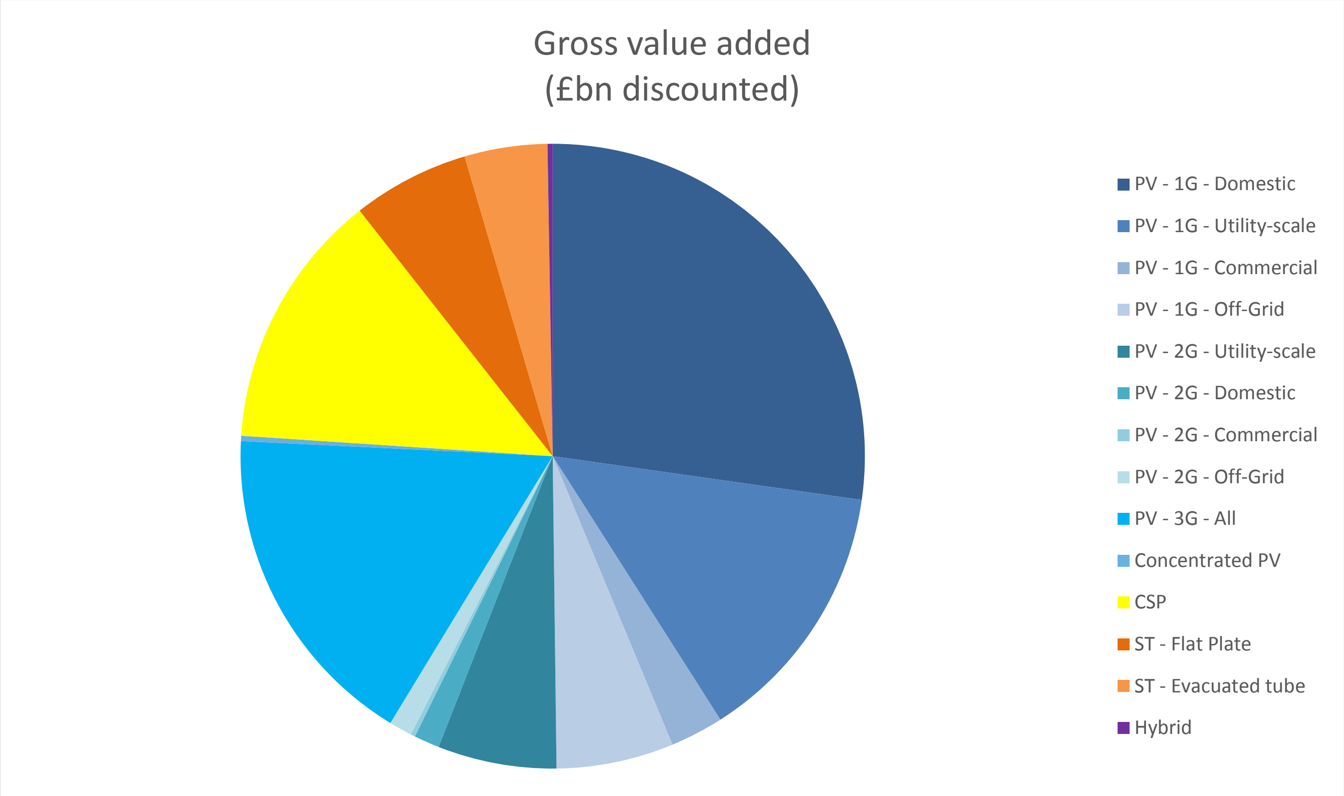
[26] The Low, Medium and High global solar thermal deployment scenarios are respectively 33%, 66% and 100% of the scenario in IEA, Technology Roadmap – Solar Heating and Cooling 2012.

[27] IEA, Energy Technology Perspectives – Solar Photovoltaic Energy Technology Roadmap (2014)

[28] 50% displacement of GVA is assumed in all TINAs.

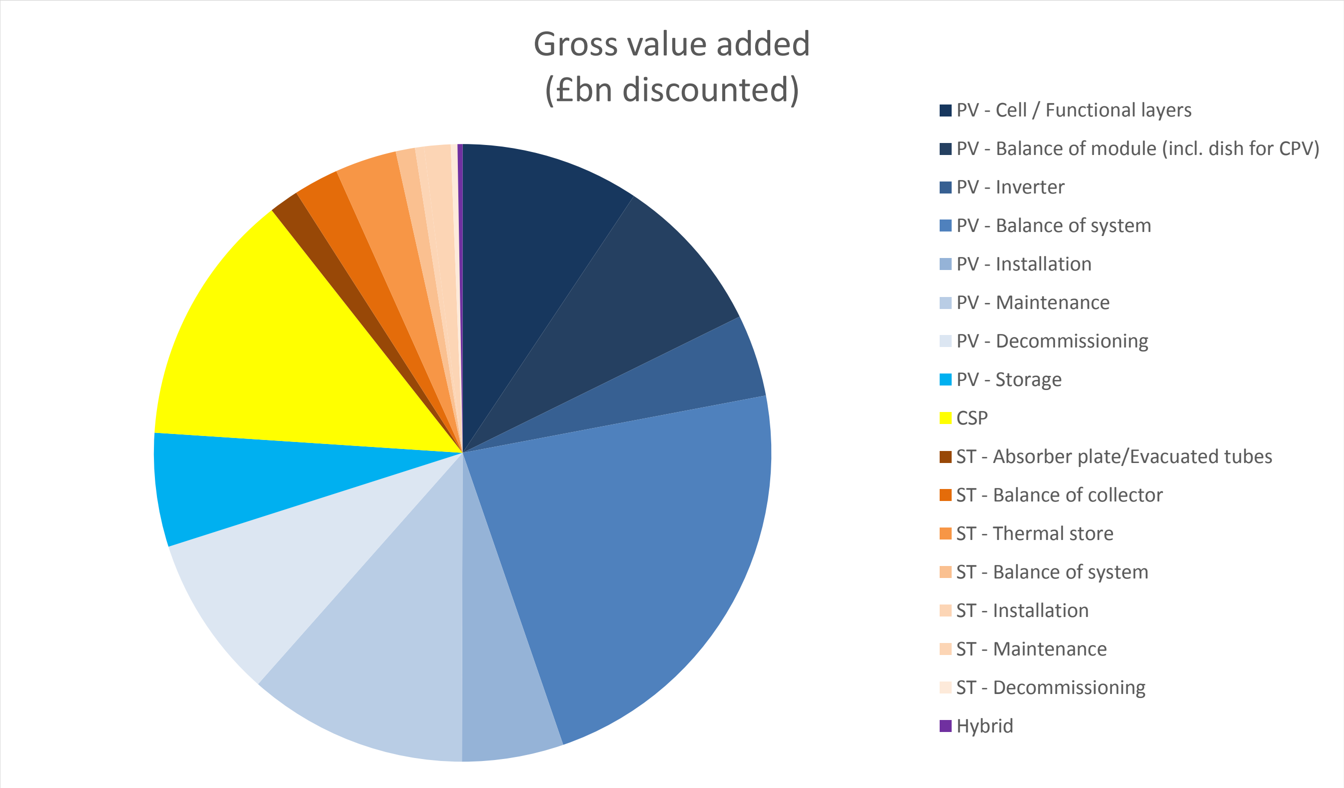
approximately £5.5bn (£3.9 – 9.5bn), are not the traditional core components but the Balance of System (BoS) components. This is because rapid cost reductions in core components have left BoS the largest contributor to total cost and this is an area of relatively high competitive strength for the UK.

Figure 8 UK economic value by technology sub-area (cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

Figure 9 UK economic value by technology component (cumulative 2015-2050)



Source: E4tech and Carbon Trust analysis.

The case for public sector intervention

Market failures impeding innovation

In general, the market failures and barriers to innovation in solar technologies are minor relative to other low carbon technologies, but there are some areas where public sector intervention is required to unlock the identified opportunities.

The UK has the potential to take a leading position in future solar technologies, currently at low TRL, but the dominant position of the incumbent technologies (i.e. c-Si which occupies a 90% market share) makes it difficult for the private sector to invest in the innovation required.

Some of the other technologies that the UK could have export strengths in are unlikely to be deployed in large volumes in the UK (e.g. concentrated solar power (CSP) and concentrator PV (CPV)) making private sector investment in the UK more risky.

In the building construction sector, there are multiple barriers that make it difficult for companies to invest in innovation in building-integrated PV and ST. In general, the building sector is very conservative and incentives to innovate are split between end customers and the supply chain. Furthermore, the lack of appropriate standards for installation procedures hinders deployment of novel technologies.

Finally hybrid PV-T technologies are severely disadvantaged by current UK incentive mechanisms. They do not benefit from the incentives accessible to other thermal technologies (i.e. the domestic RHI), despite PV-T products being fully tested and accredited as solar thermal products, and they receive the same incentives as simple PV (i.e. the FiT) despite being more complex and less mature products, though with potentially higher efficiency. This discourages UK innovation in PV-T.

Possibility to rely on others

In general solar technologies are globally commoditised and many other countries have significantly higher solar resources as well as longer innovation track records in solar energy. Therefore, in general, the UK can rely on other countries to intervene in driving innovation with the focus, and at the pace, required by the UK energy system, although this could put the economic value from exports at risk.

However there are specific sub-areas where the UK has different needs than other countries. In particular, building integrated PV and solar thermal technologies will have to deal with building requirements specific to the UK. Similarly, there will be differences found in the building stock that will require solutions unlikely to be developed abroad (e.g. design of roof mounting). Likewise, differences in weather conditions may lead to solutions developed abroad having sub-optimal performance in the UK, but this difference is likely to be minor.

Although the UK could largely rely on other countries to deliver the innovations required to hit environmental targets at least cost, the economic value from exporting UK products and services to other countries is dependent on the UK being internationally competitive in key technologies and component areas. Well-targeted public sector support for innovation in solar technologies will be necessary to achieve that competitiveness and capture the economic value available.

Table 4 Market failures and barriers to innovation in solar technology areas

Technology	Sub-area	What market failures and barriers to innovation exist?[29]	Aggregate Assessment
PV	**Cell / Functional layers**	▪ Dominance of c-Si PV by the Far East causes a perception that the UK will be unable to capture value from innovation in other PV technologies (e.g. thin film, 3rd generation) – ***Insufficient / unclear returns to R&D.*** ▪ Unwillingness to invest in newer technologies (e.g. thin film and 3rd gen.) which are currently marginal (c-Si is currently ~90% of the market) – ***Technology investors unwilling to invest.*** ▪ Financing models are based on 20-25 year lifetime of c-Si PV, lifetimes of many next-gen technologies are much lower – ***Technology investors unwilling to invest.***	Moderate failure
PV	**Balance of module**	▪ Focus on standard test conditions assessment and £/kW as performance metric disadvantages thin film technologies[30]. ▪ Failures of early 3rd generation companies is deterring subsequent investors, particularly for high capex investments and 'valley of death' phase – ***Technology investors unwilling to invest.*** ▪ Development of durable anti-reflective coatings hampered by lack of investment in fundamental R&D for this technology – ***Technology investors unwilling to invest.***	Minor failure
PV	**Balance of system**	▪ Unwillingness to invest in dedicated thin film BoS hardware due to dominance of c-Si – ***Technology investors unwilling to invest.*** ▪ Existing 'standard' components not suitable for BIPV (e.g. MC4 connector) – ***Key component technologies are missing or costly.*** ▪ High cost barriers for SMEs demonstrating products / components – particularly in real world conditions (e.g. running demonstration sites in MENA) – ***Enabling infrastructure and facilities are unavailable.***	Moderate failure (significant for demo of 3rd generation)
PV	**Installation**	▪ Dominance of c-Si makes installers unwilling to learn thin film specific installation skills – ***Supply chain not fully engaging with innovators.***	Moderate failure
PV	**Maintenance, decommissioning, inverter & storage**	No failures[31]	No failures[31]
CSP	**All**	▪ Lack of a likely UK market deters investment in necessary innovations (e.g. thermal storage) – ***Insufficient (unclear) returns to R&D.*** ▪ Lack of real-world performance data charting performance over lifetime in a variety of climates – ***Organisations lack the skills and resources to grow.***	Moderate failure
Solar thermal[3]	**All**	▪ Lack of general understanding that complete heating provision is possible with solar thermal[3] deters investment in the sector – ***Lack of coordination amongst players.*** ▪ Difficult to compete for investment with PV which has higher incentives and a simple installation – ***Technology investors unwilling to invest.*** ▪ Lack of district heating schemes and inter-seasonal storage – ***Lack of coordination amongst players.***	Minor failure
BIPV / BIST	**Building integrated**	▪ Split incentives between end customers and supply chain – ***Insufficient (hard to capture) returns to R&D, Supply chain not fully engaging with innovators.*** ▪ Conservatism and lack of awareness in construction industry- ***Supply chain not fully engaging with innovators.*** ▪ BIPV supply chain is complex and resists change – ***Supply chain not fully engaging with innovators.*** ▪ Difficult to establish standardised installation procedures due to diversity of products in immature market – ***Lack of coordination amongst players.*** ▪ Certification standards can be burdensome and inappropriate – ***Organisations lack skills and resources to grow.***	Significant failure
Hybrid solar PV-T	**All**	▪ Lack of general awareness of the technology deters investment in innovation – ***Insufficient (unclear) returns to R&D.*** ▪ Deployment incentives do not recognise the lower maturity and higher complexity of hybrid PV-T, compared to simple PV or ST, and are insufficient to allow it to compete, deterring investment in innovation (PV-T is not eligible for domestic RHI and receives the same FiT as simple PV) – ***insufficient returns to R&D.***	Moderate

Source: E4tech and Carbon Trust analysis.

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[29] The eight 'barriers to innovation' highlighted in bold and italics in the table above are symptoms of the following four underlying market failures: 1) negative externality of CO_2 not adequately reflected in price of carbon; 2) RD&D spillover due to insufficient ability to protect IP; 3) Imperfect information, often due to high transaction costs; and 4) public goods, especially high CAPEX infrastructure.

[30] This barrier is most similar to the recognised barrier 'Existing regulations obstruct test and demo', although strictly the issue is with a test standard, not a regulation.

[31] There are many market failures in energy storage, as detailed in the EN&S TINA, but no failures specific to the innovations needed for solar technologies.

Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas of innovation with the biggest relative benefit to the UK and where they complement existing or planned initiatives (both in the UK and abroad).

Most of the potential value of solar energy to the UK is in economic green growth, rather than savings to the energy system.

Innovation areas with the biggest relative benefit from UK public sector activity/investment

The areas of innovation with the highest relative benefit from UK public sector activity/investment are:

- Building integrated technologies where the UK needs to address market barriers specific to the UK building requirements and stock, where innovative solutions will not be designed abroad and the UK has an opportunity to establish a leading position internationally.
- PV balance of system (BoS) components which offer the largest opportunity both to reduce costs and to create value from business creation.
- Novel technologies, where the UK could take a strong position in certain sub-areas.

Table 5 Benefit of UK public sector activity/investment by sub-area and technology type

Component	Value in meeting emissions targets at low cost £bn[8]	Value in business creation £bn[8]	Extent market failure	Opportunity to exclusively rely on others	Benefit of UK public sector activity/ investment (without considering costs)
PV – Cell / Functional layers	3.7 (2.3 – 6.2)	1.8 (1.4 – 2.9)	Moderate failure	Yes	Low – medium
PV – Balance of module (including dish for CPV)	3.1 (1.6 – 5.6)	1.6 (1.2 – 2.7)	Minor failure	Yes	Low
PV – Inverter	0.6 (0.4 – 0.9)	0.8 (0.6 – 1.5)	No failure	Yes	Low
PV – Balance of system	3.5 (2.6 – 6.0)	4.2 (3.4 – 7.0)	Moderate failure	Yes	Medium
PV – Installation	0.7 (0.5 – 1.3)	1.0 (0.9 – 1.1)	Moderate failure	Partly, due to building specific requirements	Low
PV – Maintenance	1.2 (0.3 – 2.3)	2.2 (1.2 – 3.4)	No failure	Partly, due to differences found in the building stock	Low
PV – Decommissioning	1.3 (1.1 – 1.7)	1.6 (1.6 – 1.6)	No failure	Yes	Low
PV – Storage	0.2 (0.2 – 0.4)	1.1 (0.8 – 2.0)	No failure	Yes	Low
CSP	0.00 (0.00 – 0.00)	2.5 (0.8 – 5.2)	Moderate failure	Yes	Low
Solar thermal[3]	0.14 (0.03 – 2.18)	1.9 (1.1 – 5.4)	Minor failure	Yes	Low
BIPV / BIST[9]			Significant failure	No	Medium
Hybrid PV-T	0.02 (0.01 – 0.2)	0.05 (0.03 – 0.1)	Moderate failure	Yes	Low
Total	**14.7 (9.1 – 26.9)**	**18.7 (13.0 – 32.9)**			**Low**

Source: E4tech and Carbon Trust analysis.

Existing innovation support

The UK is supporting many of the areas highlighted above. This is through a combination of policies to incentivise demand ("pull") as well as support supply-side ("push") innovation programmes (Table 6).

Table 6 Summary of current/recent UK public sector activity/investment[32]

Market pull (demand side)	Technology push (supply side)	Enablers
• Revenue support through **Banded Renewables Obligation, FiT, CfD, RHI.** • Carbon price, via the **EU ETS.**	• **SUPERGEN Solar challenge** – up to £5 million available to support projects that help address key challenges in solar technology. • **EPSRC** – basic R&D support and international collaborations. • **Energy Catalyst** – funding for innovative businesses and researchers from any sector who can address the challenges facing the energy sector. • **SPECIFIC**[33] **–** £20 million R&D project to develop functional coatings to turn buildings into power stations (2011-2016). A second phase of funding of £26m has been approved (2016-2021). • **SOLAR-ERA.NET** – FP7 funded European network of national and regional funding organisations and R&D and innovation programmes to undertake joint strategic planning, programming and activities for R&D and innovation in the area of solar electricity generation. • **Centre for Doctoral Training in New and Sustainable Photovoltaics** – a multicentre team of seven universities training students to transform state-of-the-art R&D into new PV technologies. • **Horizon 2020 –** the biggest EU Research and Innovation programme so far with nearly €80 billion of funding available over 7 years (2014 – 2020). • **Energy Entrepreneurs Fund** – a £40m fund to support the development and demonstration of novel, innovative technologies in a broad range of technology groups across the energy efficiency, power generation and energy storage sectors (2010 –2016). • **IEA solar heating & cooling energy technology initiative** – one of the first programmes of the IEA, established in 1977 to promote the use of all aspects of solar thermal energy.	• **Solar Energy Systems Special Interest Group –** a KTN cross-sector team to identify the key areas of UK technological innovation excellence and connect these areas to maximise their impact in both the UK and overseas. • **SUPERGEN SuperSolar Hub** a consortium of Institutions with the aim of creating a strong photovoltaics R&D community in the UK. • **Solar Europe Industry Initiative** – set up to improve the competitiveness and ensure the sustainability of the technology and to facilitate its large-scale penetration in urban areas and as free-field production units, as well as its integration into the electricity grid. • **BRE National Solar Centre –** established in 2012 to provide independent evidence based information on solar energy systems and related topics.

Source: E4tech and Carbon Trust analysis.

[32] Some of these programmes are European but the UK public sector is involved.
[33] Sustainable Product Engineering Centre for Innovation in Functional Coatings.

Potential priorities for public sector innovation support

In the previous sections we identified the innovation needs with the highest economic benefit as well as the market barriers hindering these innovations.

Table 7 lists the main priorities for public sector innovation support within different technology sub-areas.

To achieve the identified benefits from innovation, it will be necessary to continue supporting R&D in novel technologies with breakthrough potential where the UK could have a strong market position. This analysis suggests public sector support for low TRL technologies should focus on PV balance of system and balance of module components and the active layers (efficiency and lifetimes) of new PV technologies. Support for early stage research in balance of module components could also be valuable, particularly if they could be applied to multiple types of thin film PV. This early stage innovation support could be in the form of competitions and directed research designed to achieve specific cost reduction and performance improvement targets.

Another priority for public investment in solar energy is removal of market barriers in building-integrated solar technologies. This could be best achieved through demonstration projects led by large building developers to coordinate and incentivise the many different stakeholders along the supply chain. Support for standard development and knowledge sharing would also help to raise awareness and remove barriers.

To support technologies which are not well suited to UK conditions (CPV and CSP), international partnering will be required to demonstrate these technologies in sunnier climates. Public sector support to facilitate this partnering could be very helpful and would be relatively low cost.

The level of deployment of solar energy technologies shown in the medium and high scenarios, especially during the period to 2030, will create integration challenges at local and national levels. Consequently, innovation in integration technologies, such as system flexibility enablers, will be a high priority for the UK; at an energy systems level this is considered in the EN&S TINA[19].

Table 7 Potential solar innovation priorities and support

Sub-area	Potential innovation priorities	Current activities/ investments	Future potential activities	Indicative scale of public funding
PV active layer	Novel active layers with improved cost, performance (efficiency, durability), and possibly other benefits: flexibility, weight, transparency, colour.	• SUPERGEN Solar Challenge • Energy Catalyst • SPECIFIC • Centre for Doctoral Training in New and Sustainable Photovoltaics • Energy Entrepreneurs Fund	Support basic and applied R&D in 3rd generation technologies.	High millions of £
PV balance of module	Surroundings for thin film active layers with improved performance e.g. anti-reflective / self-cleaning / superhydrophobic coatings, barriers layers, edge seals etc.	• Energy Catalyst	Support basic/applied R&D and challenges/competitions for components which could be used in multiple types of thin film PV.	Low tens of millions of £
PV balance of system	Improvements in BoS components and their integration to reduce capital, installation and maintenance cost, and ease their integration with buildings.	• Energy Catalyst	Applied R&D and challenges/ competitions with specific cost reduction and performance targets for solar technology balance of system components where the UK is strong and for integration of manufacturing with building materials.	Low tens of millions of £
BIPV & BIST	Improved awareness within the construction industry of the potential for current technologies, to allow private sector investment in future technologies Innovative design to facilitate integration.	• SPECIFIC • SUPERGEN Solar Challenge • Energy Entrepreneurs Fund	Demonstration projects with large building developers and support for sector coordination to remove market barriers.	High tens of millions of £
All emerging solar technologies	Lower costs and delays for testing the performance of new technologies from prototype to market entry stages.	• BRE National Solar Centre • SUPERGEN SuperSolar Hub • SPECIFIC	Support standard setting and testing infrastructure to remove barriers to product development and launch for novel technologies.	High tens of millions of £
CSP / CPV	Better understanding of regional differences in requirements for technologies unlikely to be deployed significantly in the UK.	• IEA solar heating & cooling programme	Support international partnering to facilitate demonstration of UK technologies in foreign climates.	Hundreds of thousands of £

Source: E4tech and Carbon Trust analysis.

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