PHOTONICS TECHNOLOGIES and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Summary Report

17th February 2012

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PHOTONICS 21

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Executive Summary

Executive Summary

This document presents the results of a study, carried out for the Photonics European Commission Directorate General for Communications Networks, Content and Technology (DG CONNECT) of the European Commission to analyse Europe's market positioning in **green photonics technologies** and assess the potential to develop promising new technologies. It primarily focuses on technologies that can be exploited over the period to 2015 and the barriers that will need to be overcome to maximise Europe's global market share. In addition it also identifies attractive technologies for the period to 2020 and the related barriers to exploitation.

The European photonics industry is a major contributor to EU industrial output. It had a turnover of €55 billion in 2008 and employed 290,000 people[1]. Photonics technologies support a wide range of industrial activities and can make a large impact on the low carbon economy, assisting Europe to meet the targets set for 2020. Photonics technologies underpin photovoltaics, energy efficient lighting and displays, energy efficient communications, advanced sensors and instrumentation (in energy and environmental applications) and laser based clean manufacturing.

This document presents the results of a study to assess Europe's market positioning in these green photonics technologies, the potential of promising new technologies, the expected socio-economic and environmental impact of take-up and the importance of these technologies to the low carbon economy. It primarily focuses on technologies that can be exploited over the period to 2015 and the barriers that will need to be overcome to maximise Europe's global market share. It also identifies attractive technologies for the following period to 2020 and related barriers to exploitation. It concludes with a number of potential intervention options that address barriers to adoption and exploitation of photonics. The study methodology consisted of desk research, stakeholder consultations, industry workshops and strategic analysis.

The results from the analysis of the five green photonic technologies can be summarised as follows:

[1] The Leverage Effect of Photonics Technologies: the European Perspective, EC, March 2011 (ref: SMART 2009/0066) and Photonics in Europe Economic Impact, Photonics 21 and Optech Consulting, December 2007

- Global **photovoltaics** based energy generation capacity grew by a factor of five to just under 40MWp between 2007 and 2010[2], mainly driven by incentives, such as feed-in tariffs. Around 75% of capacity is in Europe, with Germany having the most capacity (~17 MWp), followed by Spain and Italy. Silicon technologies hold a dominant market share (of over 80%). Silicon will continue to dominate the market for the foreseeable future with other technologies holding minor market shares. Organic photovoltaics is a longer term option. Current technology developments are focused on materials, cell, module and manufacturing technology improvements to achieve lower cost electricity generation. This will overcome the most significant barrier to deployment, which is cost. The Far East is becoming the main manufacturing region for photovoltaics and will account for an estimated 50% of global manufacturing in 2015[2]. Significant growth is expected in the European installed photovoltaics capacity, assuming that the strong incentive regime continues. It is estimated that photovoltaics can produce 12% of Europe's energy needs by 2020[3]. Achieving this target would result in an increase to the gross value added of the European photonics industry in 2020 of over €21 billion, assuming it retains its current market share. Further it is estimated that adoption of photovoltaics technologies will save over 65 billion tonnes of CO_2 equivalent by 2050 compared to the current energy generation mix. Furthermore, photovoltaics offer an effective way to quickly increase generation capacity and its greenhouse gas emission per kilowatt hour generated is similar to other renewable energy technologies[4].

- **Energy efficient lighting** is a rapidly developing application for photonics technologies. Light emitting diodes (LEDs) are already available in lighting applications, competing with existing technologies and winning increasing market share. In the longer term, organic LEDs (OLEDs) will emerge to address lighting and display applications. The current global market for all types of lamp (including LED modules) was estimated at over €11 billion per annum in 2010[5]. The market is expected to grow to €24 billion by 2020, with LEDs accounting for over

[2] PV Status Report 2011 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2011
[3] Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace, 2011
[4] Photovoltaic Energy – Electricity from the Sun, EPIA, December 2009
[5] J.P. Morgan Cazenove, "Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED", March 2010 and McKinsey & Co "Lighting the Way. Perspectives on the Global Lighting Market, July 2011

90% of this market[5]. The key barrier to uptake is again cost. Europe has traditionally been strong in this market with Philips and Osram being leading global players. There are clear and significant environmental benefits from adopting energy efficient lighting technologies. It is estimated that between 40% and 70%.energy saving (using advanced control systems) can be achieved using energy efficient lighting rather than current technologies[6]. This would lead to a saving of over 640 million tonnes of CO_2 per annum.

- **Energy efficient communications** are critically dependent on a range of photonics materials, components and systems. The market for photonics in communications is driven by the dramatic growth in demand for capacity in communication networks and it is expected that the global optical communications equipment market will grow by 50% between 2009 and 2020 to a value of €15.4 billion[7]. There will be significant demand over this period for a range of new photonics technologies, such as photonic integrated circuits, tunable lasers, transmitters, receivers and multiplexing components. The European industry is in a good position to win a significant share of these markets based on its recognised manufacturing and research capability. Market growth will be maximised if a common pan-European strategy can be agreed for the communications infrastructure to allow the high volume manufacture of components to be developed. This growth will provide significant economic and social benefits to Europe and photonics technologies will enable the enhanced communications infrastructure to operate in an energy efficient manner.

- **Advanced sensors and instrumentation** includes photonics based sensing and instrumentation technologies used in the energy generation industry, in monitoring of greenhouse gases (GHG) emissions from industry and in transport. This is a regulation driven application, with an estimated global market of €500 million in 2009[8]. Future growth is expected to be driven by increasing demand in developing countries. Europe is in a strong position to exploit these growing markets based on its established global market position. Growth could be increased if legislative and instrument type approval requirements that encourage

[6] "Energy efficient lighting - a summary of "Green Switch" facts", Philips, December 2007 and the Second Strategic Research Agenda in Photonics, Photonics 21, January 2010
[7] Photonics 21 Strategic Research Agenda, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf
[8] Monitoring Greenhouse Gases, Chemical and Engineering News, August 9th, 2010

the use of proven technologies and thus inhibit adoption of new technologies could be overcome. The potential economic, social and environmental impacts are modest here compared to the other photonics technologies reviewed. The most significant impact is that improved sensor capability will provide better support to the implementation of regulation.

- **Clean manufacturing** is defined as applications where a laser beam interacts with materials in a production process, to change the form of the material or its shape and to the technology associated with producing and forming laser beams for manufacturing operations. A number of different laser systems have been developed to address a market valued at almost €4.5 billion in 2010[9]. Europe plays a very major role in this field and is expected to continue to do so through the development of enhanced laser systems. It is assumed that market growth could be increased if the capabilities of lasers as manufacturing tools were more widely understood by potential users.

These analyses indicate that green photonics is already a multi €billion global market, which is expected to grow in all five segments for the foreseeable future. It is also clear that photonics technologies are essential in each of these applications and that Europe has an established position in all areas. Key industry stakeholders assert that Europe has an internationally recognised research capability and is consistently strong in materials and device development and manufacture but less so in systems[10].

The ongoing development of these green photonics technologies is expected to achieve significant economic, social and environmental impacts. They will make a significant contribution to the 2020 low carbon economy targets. In particular

- Photovoltaics will make a major contribution to the 2020 renewable energy generation target - potentially 12% of EU energy requirements may be satisfied by photovoltaics compared to a global figure of 0.2% in 2010[11]

[9] Industrial Laser Solutions for Manufacturing (ILS) (www.industrial-lasers.com), January 2011
[10] Feedback from stakeholder interview programme and workshops carried out as part of this study
[11] Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace, 2011

- The use of energy efficient lighting and communications can achieve an estimated 40% energy saving compared to using current technologies

- Photonics components in communications will make an estimated contribution of 0.15% reduction in energy consumption, 5% of the overall energy saving of 3% that is estimated to be achieved through the use of modern communications systems

A wide range of barriers to deployment and market development of photonics technology were identified. These barriers are shown in Figure 1:

Theme	Barrier
Photovoltaics	PV Generation Costs
	Competition
	Investment Risk
	Incentive Regime
	Awareness
	Supply Chain Gaps
	Grid Integration
	Regulations, Standards and Certification
Energy Efficient Communications	A Lack of Clarity in Market Requirements - exhibited by - The Lack of an Optimum Strategy for FTTH - "Piecemeal" Investment in Communication Strategies - EU Competition Policy - Fragmented National Policies
	A Lack of Funding for Development and Commercialisation of Photonic Technologies - exhibited by - A Fragmented European Supply Chain - Capital Cost of Entry to Photonics is Huge - A Lack of Support for Technology Commercialisation
	Emerging 100G Standards
	Lack of Global Semiconductor Manufacturers in Europe
	High Labour Costs
	Potential REACH Restrictions

Theme	Barrier
Energy Efficient Lighting	High Costs
	Perverse Subsidies
	Principal-Agent Conflict
	Intellectual Property
	Low Quality Lighting
	Incomplete Standards
	Materials Development
	Quality of Light
	Rapid Obsolescence
	Prolifigation of Light
Displays	Material Costs
	Low Volume Manufacturing
	Display Lifetime
	Fast Multicoloured e-paper Displays
Advanced Sensors & Inst.	Legislation
	Instrument Type Approval Regquirements
	Market Size
Clean Manufacturing	Lack of Awareness of the Potential of Lasers in "Green" Manufacturing
	Lack of Product Design Capability
	Lack of Effective Legislation
	Economics Drives Industrial Decisions

Figure 1: Summary of Barriers to Uptake of Photonics Technologies

Potential interventions to address these barriers and support the uptake of photonic technologies have been identified. These have been classified under the following four themes and are listed in the table below.

1. Research, development and innovation programmes
This will ensure that Europe retains its leading international position in the development of emerging green photonics technologies. These programmes should be structured to include near market (applied) technology development in addition to typical R&D activities and a stronger emphasis should be placed on developing manufacturing technology

2. Subsidised market development programmes
This will encourage and support near market development of emerging technologies, encourage the uptake of emerging technologies and catalyse investment in manufacturing capacity.

3. Market "re-engineering"
This theme will focus on changing (optimising) market conditions to facilitate the adoption and uptake of green photonics technologies. It will address specific characteristics of key market applications for green photonics technologies (e.g. feed-in tariffs for PV or revised subsidy regimes in energy efficient lighting), so its design needs to be customised for each specific technology.

4. Overcoming regulatory and standards issues
The objective of this theme is to optimise the market environment for, and the competitive position of, green photonics technologies by ensuring that regulatory and legislative issues are identified and addressed in a timely manner and a proactive constructive approach is taken to standards and their development

Specific areas for action in each relevant theme are identified for all five green photonic technologies are shown in the table below.

	Intervention Options												
	R&D and Commercia-lisation Programmes			Subsidised Market Development Programmes				Market Re-engineering			Regulation and Standards		
	RD&I Programmes	Near Market R&D Programmes	Proof of Concept Programmes	Novel Incentive Schemes	Prototype Development Programmes	Demonstrator Programmes	Capital Grant Programmes	Revised Incentive Regimes	Influencing Market Structure	Pre-Commerical Procurement	Standards Development Programme	Regulation Simplification	Regulation Monitoring Programme
Photovolltaics	•	•	•	•	•	•	•	•					
Energy efficient Lighting		•	•	•	•	•	•	•	•	•	•		
Displays	•	•			•	•							
Communications		•	•			•	•		•	•			•
Advanced Sensors and Inst.	•	•			•	•						•	
Clean Manufacturing					•	•	•						

Figure 2: Proposed Interventions for each Green Photonics Technology

The overall focus of the first two of these intervention options is fully consistent with the analysis carried out by the High Level Expert Group on Key Enabling Technologies[12]. The recommendations of this study go further and address market conditions, regulatory and standards issues. It is estimated that the total cost of these interventions will exceed €500 million and that the interventions will have a large scale potential economic, social and environmental impact, including:

- Retention of Europe's strong position in the global photonics industry
- Industrial turnover increased by over €20 billion by 2020
- Increased employment of over 500,000 by 2020
- Enhanced quality of life for the people of Europe
- A major contribution to 2020 low carbon policy targets, especially
  - Generation of 12% of the EU energy requirements by 2020
  - Reduction of greenhouses gases in excess of 8 billion tonnes of CO_2 equivalent by 2020

[12] Final Report, High Level Expert Group on Key Enabling Technologies, European Commission, June 2011

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Annexes:

Glossary

Acronym	Description
CEMS	Continuous Emission Monitoring Sensors
CO2	Carbon Dioxide
DG Infso	Information Society and Media Directorate General, European Commission
EEL	Energy Efficient Lighting
EU	European Union
FTTH	Fibre to the Home
GDP	Gross Domestic Product
GHG	Green House Gas
GPON	Gigabit-capable Passive Optical Networks
GVA	Gross Value Added
ICT	Information and Communication Technology
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NGPON	Next generation Passive Optical Network
OLED	Organic Light Emitting Diode
PV	Photovoltaics
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
SME	Small and Medium Enterprise
SONET/SDH	Synchronous Optical Network / Synchronous Digital Hierarchy
TW	Terawatt
WDM	Wave Division Multiplexing
WDM-PON	Wave Division Multiplexing Passive Optical Networks

Note:

Exchange rates of €1 = £0.87 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source.

Introduction

1

1. Introduction

This document presents the results of a study, carried out for the Photonics European Commission Directorate General for Communications Networks, Content and Technology (DG CONNECT) of the European Commission to analyse Europe's market positioning in **green photonics technologies** and assess the potential to develop promising new technologies. It primarily focuses on technologies that can be exploited over the period to 2015 and the barriers that will need to be overcome to maximise Europe's global market share. In addition it also identifies attractive technologies for the period to 2020 and the related barriers to exploitation.

The photonics industry, its importance to the low carbon economy, the study methodology and the structure of this report are described below. Analysis of green photonics technologies, assessment of their potential impact in addressing low carbon economy targets and identification and analysis of development options for Europe are then summarised in the following sections and described in detail in supporting Annexes.

1.1 The Photonics Industry

Photonics is defined as "the science and technology of the harnessing of light"[13]. It includes the generation, utilisation, detection and management of light. Therefore photonics is used in a wide range of applications. The segmentation of the global photonics market[14], estimated at €270 billion in 2008, is shown opposite:

The European industry holds over 20% of the world market with an out-

[13] Lighting the Way Ahead, The Second Strategic Research Agenda in Photonics, Photonics 21, January 2010,
[14] Final Report, High Level Expert Group on Key Enabling Technologies, European Commission, June 2011

put of €55 billion[14], an increase from €43.5 billion in 2005[15]. Significant growth is expected in the period to 2015 as shown opposite:

The industry provided employment of 290,000 in 2008.

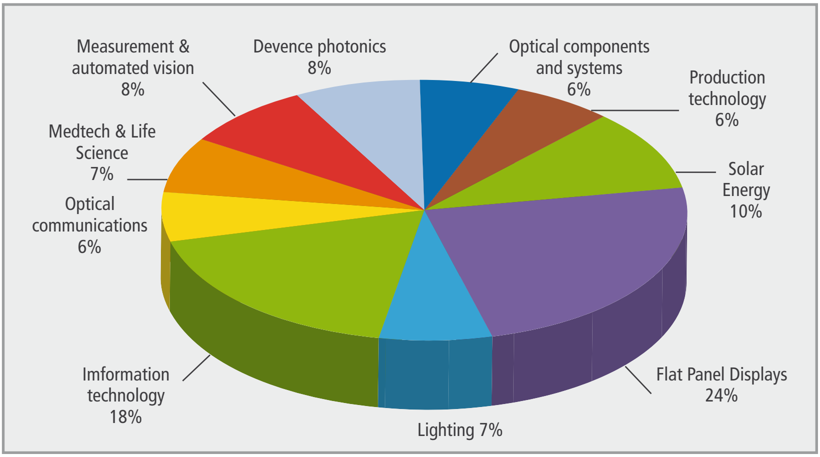

Figure 3: Segmentation of the Global Photonics Industry (2008)

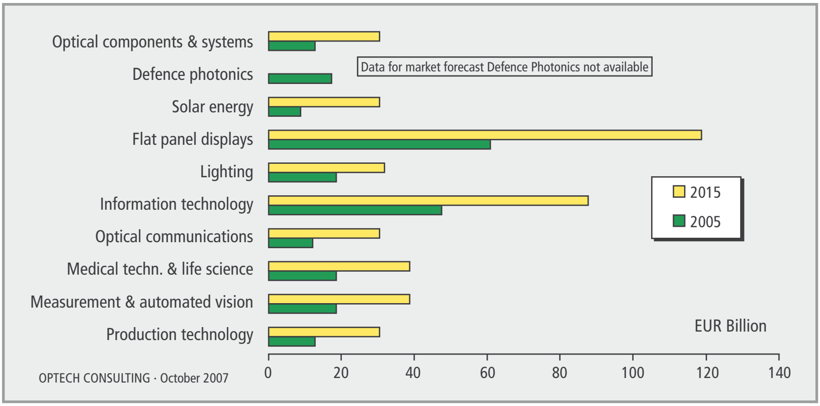

Figure 4: European Photonics Industry - Projected Growth

[15] The Leverage Effect of Photonics Technologies: the European Perspective, EC, March 2011 (ref: SMART 2009/0066) and Photonics in Europe Economic Impact, Photonics 21 and Optech Consulting, December 2007

1.2
Photonics and the Low Carbon Economy

The importance of the photonics industry's potential contribution to a sustainable future has been widely recognised[14,16,17] as its outputs can be used to generate energy and reduce energy consumption, greenhouse gas emissions and pollution.

These "green photonics" technologies, which are the subject of this report, are gaining increasing importance in light of international targets for a low carbon economy. The targets set for Europe[18] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

As a result, there are significant opportunities for the photonics industry. For example, Lebby[19] expects the green segment of the global photonics component market to grow by over 500% in the period from 2008 to 2020. Goetzeler[16] identified four key economic areas driven by developments in photonics. Goetzeler further specified the potential impact as follows:

- **Communications** - where next generation networks will increase bandwidth while reducing power consumption at the same time

[16] Green Photonics – Towards a Sustainable Energy Economy, Martin Goetzeler, CEO of Osram and President of Photonics 21, Presentation at "High Level Event for ICT and Energy Efficiency, The European Commission, 19-20 March 2009 (http://ec.europa.eu/information_society/events/ict4ee/2009/index_en.htm)
[17] Green Photonics Initiatives: The Role of Optoelectronics in a Sustainable Future, Michael Lebby, CEO, OIDA
[18] 20 20 by 2020, Europe's Climate Change Opportunity, European Commission, COM (2008) 30 final, January 23rd 2008
[19] Michael Lebby, CEO OIDA, Presentation at "High Level Event for ICT and Energy Efficiency, The European Commission, 19-20 March 2009 (http://ec.europa.eu/information_society/events/ict4ee/2009/index_en.htm)

- **Lighting and Displays** - where new lighting technologies can save more than 30% of electricity used
- **Photovoltaics** - where as little as 10m^2 of photovoltaic panels can avoid 40 tonnes of CO_2 over its lifetime
- **Manufacturing** - where laser processing produces lightweight structures that reduce power consumption of products

In addition, Lebby[19] highlights the importance of sensors and spectroscopy for process control, environmental monitoring and energy recovery.

The green potential for these five photonics technologies are reviewed in this report.

1.3 Objectives, Methodology and Report Structure

This study was commissioned to provide a robust, independent body of evidence for DG CONNECT to develop its priorities for the forthcoming Horizon 2020 Programme and other policy-related photonics initiatives (e.g. the Digital Agenda for Europe, the Green Paper on "Lighting the Future: Accelerating the Deployment of Innovative Lighting Technologies, the ICT 2013 Work Programme and the Competitiveness and Innovation Framework Programme). Its overall aims are to analyse Europe's market positioning in green photonics technologies that are particularly relevant for building a future low carbon economy and their potential for further development. It focuses on promising new photonics technologies that could be made available for market deployment in the next five years and the barriers to overcome to achieve significant market share for Europe.

The methodology was designed to address the eight specific objectives defined by the European Commission[20], namely

- Overview existing green photonics technologies and today's related markets and market players
- Identify and analyse promising new green photonics technology developments for market deployment in the period 2011-2015
- Identify and analyse the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
- Overview major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
- Analyse Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
- Assess the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
- Assess how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
- Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries

The methodology used to achieve these objectives comprised of a combination of desk based research, stakeholder consultations, industry workshops and strategic analysis. Each of the five selected green photonics technologies was reviewed separately. These reviews are summarised in Section 2 and presented in detail in Annexes 1 to 5, which are:

Annex 1: Photovoltaic Technologies and Applications
Annex 2: Energy Efficient Lighting and Displays Technologies and Applications
Annex 3: Energy Efficient Communications Technologies and Applications
Annex 4: Advanced Sensors and Instrumentation Technologies and Applications
Annex 5: Clean Manufacturing Technologies and Applications

[20] Tender Specification – Photonics Technologies and Markets for a Low Carbon Economy (SMART 2010/0066)

The key points from these reviews were then compared to identify opportunities, barriers and the potential impact of green photonics technologies. This comparison assesses similarities in the status and issues for each green photonics technology and the differences between the technologies and why these differences are important. Strategic options for the development of the European photonics industry to address the challenges and opportunities of the low carbon economy are then presented together with estimates of the potential socio-economic and environmental impacts that can be achieved. The contribution that green photonics technologies can make to low carbon policy targets in the EU 2020 strategy is then described. The report concludes with recommendations on the way forward to develop green photonics technologies in Europe.

Summary – The Status of Green Photonics Technologies

2

2.1
Photovoltaics

Photovoltaics is already an established application of photonics technologies, accounting for 10% of the global photonics market in 2008[21]. In this study optical and electro-optics materials, solar cells and modules, photovoltaic systems and associated photonics based manufacturing techniques have been included in the analysis.

Silicon and thin film[22] based photovoltaic modules and concentrator systems are the key current technologies. Organic based systems are emerging technologies. The current focus for all technologies is to maximise system efficiency and reduce cost through enhanced solar cell efficiencies and optimised manufacturing techniques. Major improvements in the efficiencies of all types of solar cell have been achieved, but the industry is striving for more to increase competitiveness and market share.

It is estimated that the global production capacity of photovoltaic electricity was 35 Gigawatts in 2010, with Europe accounting for over 25 Gigawatts of capacity[23]. This market has been developed using financial incentives (Feed-in Tariffs) because photovoltaics is not cost competitive with traditional electricity generation methods. Silicon is currently the dominant technology with a market share of over 80%[23]. Thin film technologies account for around 15% and concentrator and emerging technologies around 5%. It is expected that silicon and thin film technologies will still retain 95% of the market in 2015, reducing to 85% by 2020 as concentrator and emerging technologies develop market share.

China is the leading manufacturing region with its global market share expected to reach 35% by 2015, compared to a figure of 15% for Europe[24]. Other Far East economies are also developing capacity and it is expected that the region will hold more than 70% of global manufac-

[21] Final Report, High Level Expert Group on Key Enabling Technologies, European Commission, June 2011
[22] Copper indium gallium diselenide [CIGS] and cadmium telluride [CdTe]
[23] Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace, 2011
[24] PV Status Report 2010 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2010

turing by 2015[25]. Therefore manufacturing capacity in the Far East has developed by supplying the European market, which currently accounts for over 70% of the global market.

Major investments are being committed globally by the research and industrial communities to develop more efficient photovoltaic systems and thus enhance the competitiveness of the technology. Developments in materials, cells, modules and manufacturing technologies are underway for **all** photovoltaics technologies to achieve lower cost electricity generation and thus competitiveness with other energy sources. In the longer term novel solar cell designs and the application of nanotechnologies are expected to further enhance efficiencies. These activities are detailed in a number of published technology and industry roadmaps[26].

There are major initiatives in the USA, Japan, China, Korea and Taiwan to develop photovoltaic manufacturing and energy generation capacity. In the USA and Japan these initiatives are focusing on investing in both generating capacity and developing the indigenous manufacturing sector (e.g. the Sunshot Initiative in the USA[27]) while in China, Korea and Taiwan the major investments to date have been in developing manufacturing capacity – currently these three countries are exporting almost all production output. Feed-in tariffs are the main incentives to support investment in generating capacity in all countries, with each having customised incentive packages that suit its demographics and political objectives.

The interventions in Japan and the USA that focus on a combination of technology development, industry development and implementation of a photovoltaics generation infrastructure offer models to develop an indigenous photovoltaic industry. The Solar Europe Industry Initiative[28], led by the European photovoltaics industry, has already prepared an action plan for Europe that is similar to these initiatives. It proposes support of technology development, manufacturing development and systems integration and estimates a budget of €1,300 million to fund its programme.

[25] PV Status Report 2011 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2011

[26] These have been prepared by e.g. European Photovoltaics Industry Association (EPIA), The International Energy Agency and The European Commission Joint Research Centres – these are fully referenced in Appendix A1.

[27] US Department of Energy, see http://www1.eere.energy.gov/solar/sunshot/

[28] Solar Europe Industry Initiative (SEII), Summary Implementation Plan 2010 – 2012, EPAI and The Photovoltaic Technology Platform, February 2010

The SWOT analysis for Europe, as outlined in Annex I, shows strong policy drivers for renewable energy capacity development, internationally recognised scientific capability in key technologies, significant investment in R&D and a competitive position in emerging technologies. However, the lack of competitiveness and investment in manufacturing and the limited support for commercialisation and new manufacturing opportunities suggests that the declining share of global markets held by Europe will continue. This is underlined in the recently published annual report by the European Commission Joint Research Centre[25]. Europe's major opportunities are to develop and exploit new technologies, either to enhance the design of current PV systems or to exploit emerging technologies. If it can successfully address these opportunities then a stronger European industry can be developed.

Significant growth is expected in the European photovoltaics market, if there are strong financial incentives and reductions in the cost of photovoltaic energy generation. It is estimated that photovoltaics can produce 12% of Europe's energy needs by 2020[23].

It is expected that emerging photovoltaic technologies will gain a share of future markets. Concentrator technologies are expected to gain a significant market share in Mediterranean countries and will hold an estimated 4.5% of the market by 2020. Organic photovoltaics is considered a longer term option with initial markets in electronic devices and consumer products – but it is expected to remain a niche technology until 2020 at the earliest.

It is estimated that the development of photovoltaics in Europe could lead to an additional 400,000 jobs in Europe by 2020 (compared with 2009 figures)[24]. This is higher than the employment for the whole European photonics industry in 2008. The increase in gross value added of the European photonics industry in 2020 would be over €21 billion. This of course is based on the most optimistic scenario and assumes no issues that will delay market growth. However, it must be recognised that there are potential supply chain issues with some key chemical elements (e.g. Indium) where projected demand exceeds current supply. Additional sources of supply and alternative materials are being investigated to address this issue.

Photovoltaics offer practical low cost options to provide energy to remote communities. It therefore delivers important quality of life benefits.

The adoption of photovoltaics will offer significant environmental benefits. It is estimated by EPIA and Greenpeace[29] that it could generate 12% of Europe's energy needs by 2020 and save an overall total of 65 billion tonnes of CO_2 equivalent, compared to the current energy generation technology mix, by 2050[23]. The need to recycle end of life equipment has already been recognised and the recycling organisation, PV Cycle, has been established by the industry.

The major barrier to the deployment of photovoltaics is the current cost of energy generation. At present photovoltaic systems are more expensive than established technologies, but grid parity[30] is expected to be achieved in some areas of Europe (e.g. Italy) by 2013 and in almost all others, including Northern European countries by 2020. Additional key barriers include competition from other regions, an apparent lack of the type of incentives that are available in the Far East[31] (e.g. low cost capital and soft loans), a reluctance to invest in European production leading to supply chain gaps (especially for developing technologies) and the lack of a stable feed-in tariff system.

These barriers can be addressed by the following intervention actions:

1. **PV Generation Costs** are currently not competitive with other electricity generation technologies, although this situation is likely to change over the period from 2013 to 2020. These improvements will only be achieved through developments in product and process technology that will result in cell efficiency and electricity generation cost improvements. Therefore, key initiatives to overcome these barriers are

   a) **Research, development and innovation programmes,** focusing on materials, device and manufacturing development. These programmes should support all PV technologies, including longer term emerging technologies where Europe is currently in a strong R&D position

[29] Solar Generation 6: Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace 2011
[30] Grid parity is the point at which alternative means of generating electricity is at least as cheap as grid power
[31] "US Senator accuses China over solar jobs", www.optics.org, 18th October 2011

b) **Near market product development programmes,** such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe. In the short term these programmes should focus on technologies that will enhance the performance and manufacturing of silicon, thin film and concentrator technologies

2. **Competition,** as the Far East becomes the dominant manufacturing region for photovoltaic systems. To quantify the situation, the recently published PV Status Report 2011[32] estimates that by 2015 the Far East will be responsible for over 70% of world-wide PV manufacturing capacity.

   It is important that Europe responds to this situation by encouraging development of its indigenous manufacturing capacity. This can be achieved by

   a) **Capital Grant Programme,** focusing on materials and device manufacturing equipment to develop European manufacturing capacity. This should be a long term programme that supports all PV technologies. In the short term the focus should be on silicon, thin film and concentrator technologies while in the longer term it should support development of manufacturing capability for newer technologies (e.g. large area deposition techniques and roll to roll processing) where Europe is currently in a strong R&D position.
   b) **Development of novel incentive schemes**, which would encourage development of European manufacturing capacity. For example it has been highlighted[33] that building integrated photovoltaics (BIPV) is dependent on the building specifications and regulations in different countries and thus requires customised approaches rather than standard panels. These national regulations are listed as a barrier to the development of photovoltaics in Europe in Annex 1 but this intervention transforms it into an advantage for indigenous suppliers of customised products.

3. **Incentive Regimes** that are different from country to country and tend to be changed without warning depending on the political priorities in each country. This leads to uncertainty, which inhibits investment.

[32] PV Status Report, 2011, European Commission JRC, 2011
[33] Interview programme completed as part of this study

A coherent Europe wide incentive regime that is guaranteed for an agreed period should be implemented. This regime should be designed to reflect the different market conditions in different countries (e.g. weather conditions, gap to grid parity, etc).

4. **Supply Chain Gaps** in the European photovoltaics industry that relate, for example, to the availability of some key materials and to the need for new manufacturing technologies to support emerging technologies.

This barrier can be overcome by

a) **Research, development and innovation programmes,** focusing on materials, device and manufacturing development. These programmes, similar to 1), above should support all PV technologies, including longer term emerging technologies where Europe is currently in a strong R&D position
b) **Near market product development programmes,** such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe.
c) **Capital Grant Programme,** focusing on materials and device manufacturing equipment to develop European manufacturing capacity.

In addition, the actions specified under 1, 3 and 4 above would also address an additional barrier identified, namely **investment risk.**

Grid Integration, although a high priority barrier, is not assessed further in this study as it is considered to be beyond the scope of photonics technologies.

To conclude, the potential for photonics technologies to enable photovoltaics to become more cost effective and competitive is significant. Similarly, the potential of photovoltaics to contribute to low carbon economy targets is equally important. The industry is highly focused on developments that enhance the competitiveness of existing technologies rather than on novel approaches. Developments in silicon, thin film, emerging and concentrator technologies are all highly relevant to the development of enhanced photovoltaics systems but it must be recognised that in the short term financial incentives and market engineering will be essential to ensure financially viable photovoltaics systems.

2.2
Energy Efficient Lighting and Displays

Energy efficient lighting and displays are rapidly developing applications for green photonics technologies. Some energy efficient lighting technologies are already well proven, are competitive with established technologies and are winning an increasing share of the lighting market. New technologies are also under development. Displays have become ubiquitous with wide ranging applications in industry, medicine and consumer products. Flat panel displays have become the standard with Liquid Crystal Display (LCD) technologies dominating, although a number of Organic Light Emitting Diode (OLED) and e-paper technologies are beginning to win a small share of the market.

In this study we have focused on Light Emitting Diodes (LEDs) and OLEDs as the key energy efficient lighting technologies. LEDs are rapidly maturing in terms of technology and current developments are focusing on product design and lifetime optimisation. For displays we have considered LCD technology and the wide range of emerging new display technologies, such as OLEDs and e-paper technologies. OLEDs are an emerging technology that will address lighting and display applications. Current development activities are addressing performance, lifetime, manufacturing and application issues. E-paper technologies (such as electrophoretic displays and cholesteric liquid crystal displays) are also emerging with current developments focusing on demonstrating the potential performance of the technology.

The current global market for light bulbs is estimated at over €11 billion per annum[34]. LEDs currently hold a small share of this market but it is expected that this will grow to over 90% market share by 2020[34]. LEDs will find applications in signs, displays and automotive applications as well as general lighting.

[34] J.P. Morgan Cazenove, "Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED", March 2010 and McKinsey & Co "Lighting the Way. Perspectives on the Global Lighting Market, July 2011

The global display market was valued at over €90 billion in 2011[35] and is dominated by LCD technology. The current market for OLED technologies is around €1 billion but this is expected to increase significantly over the next 5 to 10 years[36]. Market values of over €6 billion are estimated for 2017[36]. Similarly the market for e-paper technologies is expected to grow to over €3 billion by 2016[37].

Europe has traditionally been strong in the lighting industry. Philips and Osram are currently leading global players and have diverse product portfolios covering traditional, LED and OLED developments. Osram was the world's third largest producer of LEDs in 2010 and Philips fourth. In addition there are over 1,000 other companies in the lighting equipment industry (lamps and luminaires) in Europe[38]. The position in displays is not so positive with display manufacturing being mainly established in the Far East. Europe has a strong position in the OLED market space through the activities of major global materials/chemicals companies and smaller device development and manufacturing companies. This is supported by a strong academic research and development capability.

A number of new technologies are being developed at all stages of the LED supply chain – such as improved sapphire and silicon substrates, novel down convertor materials and enhanced technologies for die and light engine performance. A number of technology developments are also being carried out on OLEDs covering materials, device, system, standardisation and manufacturing challenges. These activities are detailed in the relevant technology and industry roadmaps published[39].

There are major initiatives to support research and development and deployment of energy efficient lighting in the USA, Japan, Korea, Taiwan and China. In the USA these initiatives support R&D, manufacturing capacity and market development. Similarly Japan is supporting R&D and industrial development and the government expects 100% market penetration for (O)LED lighting equipment by 2020[40]. China has made a major commitment to the development of a LED manufacturing industry

[35] Global TV Trends in the Flat Panel Display Market, DisplaySearch, November 2010
[36] OLED Display and OLED Lighting Technology and Market Forecast, DisplaySearch, September 2010
[37] E-Paper Opportunities 2009, NanoMarkets
[38] European Lamp Companies Federation(ELC) and the Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires (CELMA)
[39] Towards Green Electronics in Europe, Strategic Research Agenda- Organic and Large Area Electronics, photonics 21, OE-A, EPOSS and Opera, November 2009
[40] Japanese Government, Basic Energy Plan, 2010

and has invested billions of dollars to achieve this aim[41]. As a result it is expected that China will become a major player in the global LED market by 2015. A key feature in all these regions is the co-ordinated approaches developed between the public and private sectors, which is in contrast to the currently fragmented position in Europe.

A SWOT analysis for European energy efficient lighting industry, based on stakeholder consultation, is included in Annex 2. It highlights strengths as strong policy drivers for low carbon solutions, a strong base of leading materials, lighting and production equipment companies and an internationally recognised research and development capability. However, the fragmented, uncoordinated approach in Europe, comparatively low investments and the high cost manufacturing base in Europe means that the Far East is likely to dominate future manufacturing. Europe's major opportunity in energy efficient lighting (EEL) is to develop new technologies and highly functional lighting systems.

Significant growth in the market demand for LEDs is expected over the next 5 to 10 years, by product substitution rather than overall market growth. It is expected that architectural markets will initially be penetrated followed by retail display and consumer markets. Predictions indicate that volume OLED based devices will only begin to emerge around 2020.

The strengths of the European display industry are its capabilities in the development of new OLED technologies, although the dominance of SMEs and the lack of a strong global brand are likely to affect Europe's ability to access large volume global markets. In a similar way to energy efficient lighting, OLED based products are expected to emerge in volumes in the 2015 to 2020 period.

It is estimated[42] that the turnover of the lighting industry in Europe will increase by over €3 billion by 2019 and that employment will increase by over 115,000 in the same period. This growth is expected to be due to new LED and OLED technologies, especially in the design, manufacturing and sales of lighting fixtures.

[41] MOCVD and LED Supply/Demand Outlook, Ross Young, IMS Research, presentation at demicon West, July 19th 2010 (see http://imsresearch.com/blog/MOCVD_and_LED_SupplyDemand_Outlook/167)
[42] World Lighting Fixtures to 2014, Freedonia Group Market Report, 2010

Energy efficient lighting and displays will offer a number of social benefits. These include improved visual comfort and light quality, improved safety, reduced light pollution and improved health.

There are clear and significant environmental benefits from adopting energy efficient lighting technologies. It is estimated that between 40% and 70%.energy saving (using advanced control systems) can be achieved using energy efficient lighting rather than current technologies[43]. This would lead to a saving of over 640 million tonnes of CO_2 per annum.

There are a number of barriers to the development of energy efficient lighting technologies. These include high capital costs, low light / colour quality, low market awareness, the financial support provided to competing technologies and an incomplete set of standards. The development and adoption of new display technologies are also inhibited by technology, market and financial barriers, although technology barriers dominate, as expected for an emerging technology.

These barriers can be addressed by a number of interventions, as follows

1. **High Capital Cost** of energy efficient lighting compared to traditional light sources. Energy efficient lighting capital costs are currently uncompetitive and this will inhibit market penetration.

   This barrier can be overcome by

   a) Subsidised market development programmes, such as demonstrator programmes and investment incentives.

   These programmes should focus on public sector infrastructure and industrial and commercial buildings

   b) RDI and commercialisation programmes, including near market R&D and proof of concept programmes

   These should focus on near market technologies such as improved substrates, down converter materials, die performance and light engine performance to endeavour to develop more cost effective technologies.

[43] "Energy efficient lighting - a summary of "Green Switch" facts", Philips, December 2007 and the Second Strategic Research Agenda in Photonics, Photonics 21, January 2010

2. **Subsidies** for other light sources, such as compact fluorescent lighting, that are inflating the price differential of energy efficient lighting (e.g. Chinese government subsidies for compact fluorescent lighting[44])

   This barrier can be overcome by revising the subsidy regime. This may include

   - Removal of subsidies for other light sources and introduction of a disposal tax
   - Introduction of similar subsidies for energy efficient lighting products
   - Discounted energy prices for energy efficient lighting users

3. **Principal-Agent Conflict**, where there is no incentive for the principal (the infrastructure owner) to invest in higher cost lighting as they do not benefit from subsequent lower operational costs.

   This issue can be addressed by

   a) Energy cost incentives for energy efficient lighting use

   These may include capital grant support for investment in energy efficient lighting or subsidised prices for energy efficient lighting products

   b) Development of innovative cost models for energy efficient lighting investment

   These would enable the investor in energy efficient lighting systems to share in the subsequent saving in energy costs.

4. **Lack of Clarity** on whether to focus on commercial or residential markets due to uncertainties about how the markets will develop.

Investment in market development programmes in both market sectors will catalyse growth of both. This can be achieved by capital grant support for investment in energy efficient lighting or subsidised prices for energy efficient lighting products.

[44] http://news.cens.com/cens/html/en/news/news inner 32453.html

5. **Incomplete Standards.** New standards are required that take into account the characteristics of energy efficient lighting products.

A standards development programme is required that addresses the need for standards for, e.g.

- LED fixture lifetime
- Flicker and stroboscopic performance
- Light metric definitions
- Colour shift and power consumption performance

6. **Lack of SME Growth** and suppression of innovation due to the lack of attractive RDI and manufacturing support funding.

7. **Supply Chain Competition** that is threatening the strong position of the European energy efficient lighting supply chain.

Barriers 6 and 7 may be addressed by business development support programmes. These programmes need to include:

a) Proof of concept programme, focusing on the near market technologies such as improved substrates, down converter materials, die performance and light engine performance to endeavour to develop more cost effective technologies
b) Capital grant support programmes for investment in energy efficient lighting production equipment.

The opportunity for Europe in displays is likely to focus on novel technologies. The major barriers to uptake for these novel display technologies relate to materials costs, supply chain structures and the need to improve the performance of incumbent technologies. These could be addressed by the following intervention actions:

1. **Materials costs** of key components are currently not competitive for OLED market development.

   This barrier can be overcome by RDI programmes focusing on development of high performance, low cost materials options.

These should focus on emitter, backplane and encapsulation materials technologies.

2. **Supply chain structure.** The European displays supply chain is small and fragmented and there is no apparent strategic technologies identified for development.

   This barrier can be also be addressed by RDI Programmes. These should focus on OLED device development and manufacturing technologies as well as materials.

3. **Incumbent technologies are improving,** reducing the interest in investment in new technologies.

   Performance improvements in OLED technologies are essential to achieve competitive performance. Investment in materials, device and manufacturing RDI programmes will enhance performance and thus the competitive position of OLEDs

In summary, it is expected that solid state lighting will hold a significant market share by 2020, based on further developments of existing technologies, driven mainly by legislative requirements. There are significant opportunities for Europe to exploit this market growth through development of its existing industry.

OLED technologies will be further developed to address opportunities in both lighting and displays, competing with other technology solutions. OLED technologies are already used in small displays (e.g. mobile phones) and it is expected opportunities for increased display size will continually arise in the future. Competition from a number of other novel technologies, some of which offer the distinct benefit of being reflective rather than emissive will continue and flexible displays is expected to become an important market application.

2.3
Energy Efficient Communications

Photonic technologies already play a central role in today's telecommunications and data infrastructure. They underpin the infrastructure (from information provider to end user), data networks, data centres and communication networks. The supply chain includes the manufacture of electro-optic materials, components and devices and their subsequent integration into communication networks.

Key existing photonics technologies range from materials (e.g. optical fibre, silicon, III-V materials, liquid crystals and numerous other electro-optic materials) to components (e.g. lasers, photodetectors, modulators, filters, amplifiers and switches) and to systems and sub-systems (e.g. photonic integrated circuits, gigabit-capable passive optical network (GPON), wave division multiplexing (WDM), next generation passive optical network (NGPON) and synchronous optical network / synchronous digital hierarchy (SONET/SDH)). These are being developed to address demand for high capacity fibre based communication networks and infrastructures.

The current market for photonics in communications is driven by the dramatic growth in demand for capacity in communication networks. This is due to the bandwidth demands of the new mobile and fixed technologies that are being adopted by consumers. The optical communications equipment market is expected to grow from €10.4 billion in 2010 to €17 billion by 2017[45] while the optical communications component market is expected to double between 2009 and 2020 to €6.2 billion[45]. European companies or companies with significant European operations[46] were estimated to have a 45% market share of the global optical networking equipment market in 2008[47]. There are key European players at all stages of the photonics value chain and the industry has a strong presence in

45 Photonics 21 Strategic Research Agenda, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf

46 European companies include, for example, Draka, Gooch and Housego, Genexis, Proximion, Alcatel Lucent and Ericsson while global companies with major European operations include Corning, Oclaro, Cisco and Fujitsu.

47 Altera press release [http://www.lightreading.com/document.asp?doc_id=206206]

research and development activity. However, a number of corporate acquisitions by Chinese companies is reducing the independence of the European company base (e.g. Huawei's recent acquisition of CIP to add to its existing network of research centres in Europe).

There is a wide range of promising new photonics technologies, all of which will have a significant impact on the energy efficiency of communication networks. These include photonic integrated circuits, tunable lasers, transmitters, receivers, multiplexing components and un-cooled operation. Adoption of these technologies is expected to begin between 2011 and 2015, with full implementation in the period to 2020. Over the longer term higher and higher performance demands will be placed on photonic components and this will require new materials and device designs. It is estimated that the use of photonics components will contribute 5% of the energy saving (estimated at 3% of energy usage) used through the optimised use of communications technologies.

National governments are not driving investment in green photonics technologies for communications in the same way as for photovoltaics and energy efficient lighting. Activities outside Europe tend to be organised by institutions, companies and academia and are typically driven by capacity expansion and cost reduction requirements rather than energy efficiency (e.g. Infinera initiatives to develop large scale photonics integration). Major global players, such as AT&T, Bell Labs, Huawei and Chunghwa Telecom[48], have recently joined forces to try to improve energy efficiency in communication technologies and have set a goal of increasing efficiency by 1000 in 5 years[49]. It is estimated that the application of photonics technologies will contribute 5% of this target.

The SWOT analysis for Europe, included in Annex 3, shows that it has an historic strength in photonic materials, components and systems, an internationally recognised research capability and a large group of high technology SMEs. However, the industry is increasingly under threat from lower cost Far East imports and its own inability to commercialise the results of research and development activities[50].

Significant growth is expected in the markets for optical communications

[48] A full list is available at http://www.greentouch.org/index.php?page=members
[49] http://www.greentouch.org/index.php?page=about-us
[50] Stakeholder interview programme completed as part of this study

equipment and photonics components as described above. A number of new photonics technologies will be required, such as integrated laser arrays, photodetector arrays, tunable lasers, high bandwidth photodiodes, optical amplifiers, optical modulation components and integrated wave division multiplexers, but it is difficult to predict which ones as this is dependent on the network architectures selected. European companies are expected to be leading in the development of new technologies and are likely to benefit from developing markets if they are able to bridge the gap between research and commercial exploitation.

The demand for photonics technologies to address the ever increasing growth in communication networks is expected to double between 2005 and 2015[51]. This is in line with the growth in the telecommunications sector itself[45].

A number of barriers to the adoption of new technologies have been identified[52]. These are generally linked to

- Insufficient clarity in market requirements, caused by a number of factors such as the lack of a common approach for development of the European fibre infrastructure, fragmented national policies, the impact of EU competition policy on investment in the fibre infrastructure and the lack of a standardised deployment approach by public sector organisations and network operators
- Insufficient investment in product development and commercialisation by optical component companies
- Insufficient capacity and capability in high volume silicon manufacture in Europe to apply its expertise to the development of a high volume, cost competitive European photonic industry.

There are also concerns regarding potential restrictions that will arise due to REACH categorisation of InP as a hazardous material and the registration and precautions that users will be required to follow.

These barriers and concerns are inhibiting investment in next generation networks and the underpinning photonics technologies.

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[51] Strategic Research Agenda for Photonics, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf

[52] Stakeholder interview programme completed as part of this study

Each of these issues can be addressed by the following intervention actions as follows:

Barrier 1: Insufficient clarity in market requirements

This barrier and its subsidiary issues can be addressed by the following intervention options:

a. Demonstrator programmes that show the potential of different technical approaches (e.g. GPON, point to point and WDM-PON) to FTTH
b. Capital grant programmes to support investment in preferred technical approaches to FTTH, determined by the demonstrator programmes proposed – this intervention will therefore follow successful demonstration programmes
c. Developing a common European strategy and establishing the European communications infrastructure as a regulated monopoly
d. R&D and commercialisation programmes. These should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration, as already delivered by the European Commission and national governments.

Barrier 2: Insufficient funding for near market development and commercialisation of photonics technologies

This barrier and its subsidiary issues can be addressed by the following intervention options:

a. Near market R&D and commercialisation programmes.
b. Proof of concept and demonstrator programmes
   These should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration.
c. Capital grant programmes to support investment in facilities for photonics manufacturing.

Barrier 3: Insufficient capacity and capability in high volume silicon manufacture in Europe

It is considered unlikely that new large scale manufacturing facilities can be established in Europe. Therefore, it is proposed that this barrier can be partially addressed by interventions options that influence the market to invest in the development, demonstration and potential adoption of new photonics technologies, such as pre-commercial procurement programmes. Further, if these can be linked to interventions that are designed to achieve clarity in market requirements (see Barrier 1, above) then it is considered that the impact is likely to be more significant.

Concern 1: Potential REACH restrictions

The potential restrictions to company operations that will be caused if key materials (e.g. InP) are registered under REACH is causing significant uncertainty in the industry. The industry is itself responding to the current situation but it is important that similar issues do not arise in the future. This concern can be addressed by an intervention that monitors ongoing European Chemical Agency activities, identifies potential issues at an early stage, influences key stakeholders on behalf of the photonics industry and catalyses photonics industry activity as required.

Of course, this intervention is appropriate to monitor and address REACH activities that may affect any green photonics technologies.

It is clear that communications technology is very important to Europe, and it is important that we continue to focus on development of new technologies. Communications traffic will increase "super-linearly"[53] over the next five years. It is essential therefore that new photonics and other technologies and network architectures are deployed in this expansion to avoid the energy usage of communications networks rising in the same way as the traffic. This will be partly achieved by the development of lower energy photonics components and integrated components, but the biggest opportunity will be in the greater use of photonics transport deeper into the network, e.g. optical distribution to cell antennas in mobile networks and in access networks, as this is the most efficient way of transmitting information. The photonics technologies required are determined from network architectures and systems designs, that are developed based on assumptions on what photonics technologies are expected to become available. New network architectures will optimise performance and power efficiency differently, and at present the focus is on performance.

[53] Greater than a linear increase but not as large as exponential

Europe needs to foster the development of new photonics products incorporating new power efficient technology by reducing the risks to individual companies through collaborative project support, policy making and international standards. This will give a clear direction for product development and help broaden the market size for European manufacturers. Europe can learn from the experiences of widespread fibre access deployments in Japan and South Korea.

2.4
Advanced Sensors and Instrumentation

The application of photonics based sensing and instrumentation technologies in the energy generation industry, transport and for monitoring green house gas (GHG) emissions from industry was analysed in this study. These applications have been chosen as they have the greatest impact on the transfer to a low carbon economy.

The requirements for industrial emission and related fugitive source measurements using photonics technologies are driven by legislation[54]. These are generally based on EU legislation, which in turn is based on pollution limits to protect human health effects and prevent damage to the environment. Photonic or optical based technologies are used extensively in both existing and new emissions monitors. They rely on the ability of the pollutants to absorb optical, ultra-violet and infra-red radiation.

The worldwide market for continuous emission monitoring equipment was estimated at around €500 million in 2009 with estimates of growth to €700 million by 2013[55]. Market growth is expected to be in developing countries, especially those in the Far East.

Europe has a number of key suppliers of photonics based instrumentation

[54] http://ec.europa.eu/clima/policies/ets/index_en.htm, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF and http://ec.europa.eu/environment/waste/landfill_index.htm

[55] Continuous Emission Monitoring Systems Worldwide, ARC Advisory Group, 2009

that operate on a global scale and a number of highly innovative niche market players. This part of the photonics industry, due to its rather small scale, tends to adopt technologies developed for other applications. It is expected that new sources (e.g. lasers, LEDs and broadband sources), new and enhanced detection techniques and new materials and optics will be exploited to develop enhanced sensors and instrumentation.

Formal initiatives outside of Europe are restricted to the USA, Japan, Korea and Saudi Arabia and, to a lesser extent, China. They are generic photonics or sensor initiatives rather than technology specific.

The main strengths of the European industry are its established position as a market leader[56] and its reputation, its existing globally competitive company base and its leading position in key market sectors (e.g. Continuous Emission Monitoring Systems). Its high cost base compared to elsewhere is a key weakness.

It is expected that the market will generally grow in line with GDP in the developed world but increased adoption of environmental controls in industry in the developing world will lead to faster worldwide growth. The introduction of new regulation (e.g. for greenhouse gas emissions[57] and carbon capture and storage[58]) will offer additional market growth opportunities. It is also expected that Europe will retain its current position as a market leader.

Given the rather limited size of the markets the potential impacts are modest compared to the other photonics technologies reviewed. The most significant impact is that improved sensor capability will underpin future legislation.

Three major barriers to deployment of new technology were identified – regulations (due to the constraints on the types of instrument that can be used), instrument type approval requirements and the relatively small scale of the market (which does not justify focused investment in new product development).

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[56] Published evidence on market share is not available but key industry stakeholders all assert that Europe holds this position

[57] http://ec.europa.eu/clima/policies/ets/index_en.htm

[58] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

These barriers can be addressed by the following actions:

1. **Legislation and instrument type approval requirements,** being barriers to the adoption of innovative sensor and instrumentation technologies.
   These barriers can be overcome by

   - Prototype development and demonstrator programmes that show the performance and suitability of innovative technologies
   - Rationalisation and simplification of the regulatory requirements to demonstrate "equivalence" of innovative technologies

2. **Market Size,** being such that it will not support much dedicated product development activities.

   This barrier can be overcome by a dedicated research, development and innovation programme focusing on developing technologies (e.g. lasers and detectors) that are optimised for sensing applications. It must be noted that due to the small scale of the market the economic impact accrued is likely to be modest. However, such an intervention would underpin Europe's leading position in a key enabling technology for the low carbon economy.

In summary, this is a relatively small scale application for photonics technology but one that is critically important to support the application and enforcement of regulation.

2.5 Clean Manufacturing

Applications where a laser beam interacts with materials in a production process to change the form of the material or its shape, and the technologies associated with producing and forming laser beams for manufacturing operations were analysed in this study. The terminology 'lasers for materials processing' is used to generically describe this area of manufacturing.

The most important current technologies are diode lasers, disc lasers, fibre lasers, carbon dioxide lasers, high peak power and high pulse energy lasers and beam delivery systems.

The global industrial laser **systems** (defined as a machine tool incorporating a laser source) market was valued at almost €4.5 billion in 2010[59]. The global sales of laser **sources** included in these machine tools were estimated at €1.1 billion in 2010 with Europe's share estimated at €600 million[60]. Europe's share of the predicted market for laser sources is expected to be at least €850 million per annum in 2020, an increase of €250 million from its current position. The main market segments were metal processing (dominated by metal cutting but including welding and surface engineering), marking and engraving. Europe plays a major role in both manufacture of laser materials processing equipment and its use. A number of the major global companies are either European owned (e.g. Trumpf and Rofin Sinar) or have major facilities in Europe (e.g. Coherent).

The key future technologies are expected to be high beam quality diode lasers, high power single mode fibre lasers and kilowatt class ultrafast lasers. Green and dual wavelength lasers, UV laser sources and fibre optic and beam delivery systems are also expected to be important in the future. These new laser sources and their associated equipment, such as beam delivery systems, are becoming significantly more efficient in the way they convert electrical energy into optical energy. For example, original laser welding lines in the automotive industry employed many lasers with efficiencies of only 3%. These can now be replaced by laser sources capable of the same manufacturing process but operating at efficiencies of up to 40%.

No specific initiatives to support the development of lasers in clean manufacturing were identified in other global regions. Clean (or green)

[59] Industrial Laser Solutions for Manufacturing (ILS) (www.industrial-lasers.com), January 2011. Industrial Laser Solutions for Manufacturing has been publishing an annual economic review of industrial laser markets for 25 years. These figures are constructed in terms of sales of laser sources used in manufacturing applications and then in terms of processing systems which include these laser sources. The data is assembled using information from about 30 publicly listed companies, known to be important players in the area. This is further supplemented by discussions with other companies as felt relevant in any particular year. The figures quoted for 2010 are listed as estimated, only because some organisations 4th quarter results for 2010 are as yet not known. No data are currently available which relate these figures specifically to the sub-set, aspects of clean or green manufacturing.

[60] Power Laser Trends, Dr Ch. Harder, Swiss Photonics and Laser Network, July 2009. Data is compiled from IOA, Laser focus World and OIDA sources

manufacturing is being developed at a global level, with environmentally benign manufacturing emerging as a significant competitive factor between companies. However, there is no evidence to date that this has included the specific use of lasers in manufacturing.

Europe currently has a strong position in the global lasers industry based on its historic leading position in the industry and its continuing strong industrial and research base. Most of the world's major laser companies have their headquarters in Europe. There are, however, concerns that Europe's high cost base may affect its position in Far East markets that will lead, over time, to a weaker position in Europe, particularly if Far East companies actively seek to expand their own production of lasers for materials processing.

The global market for lasers in materials processing is expected to grow by over 40% in the period to 2020, with the Far East being the most attractive regional market. Fibre and solid state pumped lasers are expected to demonstrate the largest growth over this period. It is expected that Europe will retain its current strong market position over this period, particularly if it can successfully exploit Far East markets. This will provide added employment but the levels could not be quantified. Economic benefits will be offered to user sectors through lower materials, operational and maintenance costs. An estimate of the potential value of this was not available.

Laser processing offers a wide range of environmental benefits to users which include:

- Reduced electrical consumption of more efficient lasers
- Reduced GHGs equivalents
- Production of less toxic by-products
- Less use of helium and other rare gases, which are currently used in laser based manufacturing systems
- Reduction in fumes generated during cutting processes
- Reduced use of raw materials in production
- Zero defect manufacturing will reduce scrap and waste
- Laser processes offer the potential of repair rather than scrap and replace, particularly for high value products
- Use of laser based solvent free cleaning techniques
- Removal of fouling in marine environments

- Efficient methods of assisting nuclear decommissioning
- Use of lasers for production of hybrid structures
- Manufacture of nano-particles
- Use of lasers in aspects of manufacture involving 'light-weighting'
- Use of lasers in battery applications for electric vehicles
- Efficient manufacture of photovoltaics (covered reporting Annex 1 of this study

The main barriers to maintaining and expanding Europe's position in green manufacturing with lasers were cited by key industry stakeholders as a lack of awareness of the capability of the laser as a manufacturing tool, a lack of product design capability using laser manufacturing and the fact that economics, rather than 'greening', is the major industry driver.

These barriers can be overcome by a combination of demonstrator and capital grant programmes, as follows:

1. **Insufficient awareness by those implementing manufacturing solutions of the potential of lasers in clean manufacturing,** leading to the selection of alternative approaches.

   This barrier can be overcome by education and demonstrator programmes to show the potential of lasers in sustainable manufacturing. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the green, technical and business benefits of using lasers. Such applications might include aspects of light-weighting in the automotive industry showing how the benefits might be applied to other products. Other possibilities include the use of lasers in the production of photovoltaics, quantifying the benefits offered for replacing toxic chemical processes.

2. **Insufficient product design capability.** Product designers have little knowledge of the capabilities (and constraints) of laser based manufacturing technologies, which inhibits the application of these technologies in industry.

   This barrier can also be overcome by education demonstrator programmes that show the potential of lasers in a range of sustainable manufacturing roles. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the design, technical and business benefits of using lasers as well as the green manufacturing potential.

3. **Economics drives industrial decisions.** These typically focus on the initial capital costs only and neglect longer term operational and environmental benefits.

   A capital grant or equity/loan programme for the introduction of laser based clean manufacturing technologies will address this barrier. Furthermore, the scale of the grant available should be linked to the expected environmental benefits of adopting the laser based manufacturing technologies.

Potential Impact of Green Photonics Technologies

3

In summary, Europe has an established and strong laser industry and it is expected that it can retain this position in the future. There are a number of new technologies under development to extend the potential applications of lasers and Europe is in a strong position to exploit these. These all offer a range of competitive and environmental benefits to users, although these could not be quantified.

The potential economic, social and environmental impacts, if green photonics technologies are deployed, have been detailed for each green photonics technology in Annexes 1 to 5. These impacts can be summarised below.

Potential Economic Impact

A total increase in industrial turnover of over €20 billion by 2020 and increased employment of over 500,000 is estimated as shown below:

	Increased Economic Activity	Job Creation	Competitiveness in Customer Sectors
Photovoltaics	GVA in 2020 is €21.5 billion higher than current figure	Additonal 150,000 jobs in 2015, increasing to 397,500 jobs in 2020	N/A
Energy Efficient Lighting and Displays	Increased sectoral turnover of €3.1 billion between 2009 and 2019	Creation of 115,000 jobs by 2019 compared to 2008	N/A
Energy Efficient Communications	Increased sectoral turnover of €3.1 billion per annum between 2009 and 2020	Correlation between ICT and GDP implies enhanced economic performance	
Advanced Sensors and Instrumentation	Limited change - niche industry		Lower operating costs
Clean Manufacturing	€2.25 billion growth in turnover between 2011 and 2020	Increased employment	"Lower procurement and operational costs Enhanced product quality"

Figure 5: Potential Economic Impacts

Potential Social Impact

A number of different social impacts will be delivered by adoption of photonics technologies. The key impacts are summarised in the following table:

	Inclusion	Quality of Life
Photovoltaics	Power to remote communities. Self generating energy. Provides increased autonomy and protection from increased energy prices	
Energy Efficient Lighting and Displays	Better light quality. Improved visual comfort. Reduced crime. Reduced light pollution Improved safety	
Energy Efficient Communications	High speed access to a range of high bandwidth applications and services.	
Advanced Sensors and Instrumentation	N/A	"Improved air quality monitoring. Enhanced performance of processing industry"
Clean Manufacturing	N/A	Enhanced product quality (e.g. medical implants)

Figure 6: Potential Social Impacts

Potential Environmental Impact

A number of significant environmental impacts are expected. In particular, photovoltaics will potentially provide 12% of the EU energy requirement by 2020 and all green photonics technologies will contribute a reduction of greenhouse gases in excess of 8 billion tonnes CO2 equivalent by 2020. These are summarised in the following diagram:

	Renewable Energy Generation	CO2 Equivalent Reduction		Waste Materials and Recycling
		In Manufacturing	In Use	
Photovoltaics	Potentially 12% of EU demand by 2020 (462 TW/hr) so 60% of 2020 target)		Estimated 540 million tonnes reduction in 2020 (49% of 2020 target)	PV recycling infrastructure established
Energy Efficient Lighting and Displays	N/A	2% of energy used to make traditional lamp	Estimated reduction of over 640 million tonnes per annum (58% of 2020 target)	Addressed by the WEEE Directive
Energy Efficient Communications	N/A		Contribution to the energy saving of communications infrastructures and systems	
Advanced Sensors and Instrumentation	N/A	N/A	Improved process control Reduced GHG emissions	N/A
Clean Manufacturing	N/A	N/A	Reduced energy consumption	Reduction in toxic byproducts in manufacturing processes

Figure 7: Potential Environmental Impacts[61]

[61] Estimates of contribution to 2020 targets based on data from Greenhouse gas emissions in

To summarise, this analysis indicates that:

- A large economic impact will be accrued through the adoption of photovoltaic, energy efficient lighting and energy efficient communication technologies. The output of, and employment in, the photonics industry in Europe will be significantly enhanced if these technologies are adopted at the scale presented in the industry analyses (Annexes 1 to 5).
- All green photonics technologies will make major social impacts. A number of inclusion and quality of life benefits will be gained.
- Photovoltaics can make a major contribution to European targets for renewable energy, with an estimated 12% of European energy demand achievable for 2020. This represents 60% of the target set for all renewable energy in the EU 2020 strategy
- All green photonics technologies will make a major contribution to reduction in energy consumption and the emission of greenhouse gases. Developments in advanced sensors and instrumentation technology will have a unique role to play as these developments will offer industry the tools to enhance its measurement capability and thus the ability to reduce emissions. Photonics technologies used in energy efficient communications will make a major contribution to minimising the inevitable continual increase in energy use as the demand for capacity continues to grow.
- Development of these green photonics technologies will not cause any major issues with waste management and recycling. In fact the industry has already been active in developing recycling capacity for end of life products. (e.g. PV Cycle[62]). However, it is likely that activities will need to be developed to recover scarce elements (e.g. gallium, indium and some rare earth materials) from end of life lighting and display products.

The contribution of green photonics technologies to low carbon targets is discussed further in the following section.

Europe: a retrospective trend analysis for the period 1990 - 2008, European Environmental Agency report No 6/2011

62 http://pvcycle.org

Contribution to Low Carbon Policy Targets

4

The potential contribution to low carbon policy targets if green photonics technologies are adopted by industry have also been detailed in Annexes 1 to 5. These contributions, at a global level, can be summarised as follows[63]:

	Contribution to Low Carbon Economy Targets		
	Renewable Energy Generation	**Reduced Green House Gases**	**Reduced Energy Consumption**
Photovoltaics	**Major** Inceasing to a potential 12% share of EU energy requirements in 2020 (462 TWh). Equal to 60% of 2020 target.	**Major** Estimated 540 million tonnes reduction in 2020 and a total of 2 billion tonnes by 2020 compared to current energy mix* Saving in 2020 equal to 49% of 2020 target.	N/A
Energy Efficient Lighting and Displays	N/A	**Major** Over 640 million tonnes of CO2 per annum by using energy efficient lighting** Saving in 2020 equal to 58% of 2020 target.	**Major** An estimated energy saving of between 40% and 70% with LEDs compared to incandescent lamps
Energy Efficient Communications	N/A	**Minor**	**Minor** A contribution to reduced energy consumption****
Advanced Sensors and Instrumentation	N/A	**Minor** Technology will have monitoring role - its use will provide the evidence that user industries are meeting regulatory requirements.	
Clean Manufacturing	N/A	**Moderate** Will offer enhanced energy efficiency in user sectors*****	

* based on optimum (12%) uptake of photovoltaic technologies in 2020
** assuming a 40% energy saving
*** based on data from the US Telework Research Network
**** it is estimated by industry stakeholders that photonics components will contribute 5% to energy efficiency achievements in communications
***** a number of examples are listed in Section 2.5, but the impact could not be quantified
N/A not applicable
Savings compared to 2020 targets are already detailed in Figure 7

Figure 8: Contribution to Low Carbon Policy Targets

Further discussions on each of these contributions to the low carbon economy are included in Annexes 1 to 5.

63 Detailed reports on each green photonics technology (Annexes 1 to 5 of this report)

Comparison of the Opportunities for Green Photonics Technologies

5

5.1
Market Development and Opportunities for Growth

The global market for green photonics is already a multi €billion market and is expected to grow for the foreseeable future. Growth rates in each application will vary and will be influenced by technology developments and market specific factors, as summarised in Section 2, above.

In each application it is clear that there are already high levels of investment in developing new and improved products with enhanced performance. These developments will lead to increased penetration in key markets (e.g. photovoltaics and energy efficient lighting), improved functionality of products (e.g. advanced sensors and instrumentation and clean manufacturing) and / or enhanced infrastructures (e.g. energy efficient communications). These trends are also summarised in detail in Annexes 1 to 5.

So there are significant opportunities for growth of the European green photonics industry.

5.2
The Importance of Green Photonics Technologies and Europe's Competitive Position

The importance of green photonics technologies in each application market and the competitive position of Europe's green photonics industry in these markets can be summarised as follows:

	Role for Photonics	Competitive Position of Europe			
		Research and Development	Manufacturing		
			Materials	Devices	Systems
Photovoltaics	Essential	Strong	Strong	Strong	Weak/Medium
Energy Efficient Lighting and Displays	Essential	Strong	Strong		Weak/Medium
Energy Efficient Communications		Medium/ Strong	Strong	Strong	Medium
Advanced Sensors and Instrumentation	Highly Relevant	Strong	Medium/Strong		
Clean Manufacturing	Essential	Strong	Strong	Strong	Strong

Figure 9: The Importance of Photonics in Key Markets and Europe's Competitive Position

Note; Here "essential" indicates that these applications are totally dependent on photonics while "highly relevant" indicates that while photonics is very important, there are other technologies that could be used.

This table shows that Europe is consistently strong in research and development and in manufacturing of materials and devices but not in systems manufacturing, although the development work for this is often completed in Europe. It also highlights the important role of photonics technologies in all application areas. Photonics technologies underpin devices, products and systems in all application areas and thus will have a central role in future development and exploitation in each application area.

The challenge for Europe is to identify how it can best exploit its recognised capability and build on its current market position. This is discussed further in Section 7.

Barriers to Market Development

6

A number of barriers to development and uptake were identified for each green photonics technology. These are highlighted in Section 2, above and described in detail in Annexes 1 to 5. They can be classified and ranked in terms of importance in the following figure:

Theme	Barrier	Classification						Importance	Action Timeline	Relative Cost to Implement
		Financial	Regulatory	Policy	Technical	Industrial	Market			
Photovoltaics	PV Generation Costs	●			●			High	Immediate	High
	Competition					●		High	Immediate	Very High
	Investment Risk	●						Medium	Immediate	High
	Incentive Regime	●						High	Immediate	High
	Awareness			●				Medium	Immediate	Low
	Supply Chain Gaps					●		High/Medium	Mid-term	High
	Grid Integration						●	High	Mid-term	High
	Regulations, Standards and Certification		●					Medium	Mid-term	Low
Energy Efficient Lighting	High Costs	●						High	Immediate	High
	Perverse Subsidies	●						High	Immediate	Medium
	Principal-Agent Conflict		●					High	Immediate	Medium
	Intellectual Property		●		●			Medium	Immediate	Medium
	Low Quality Lighting		●					Medium	Immediate	Medium
	Incomplete Standards		●					Medium	Mid Term	Medium
	Materials Development				●			Medium	Mid Term	Medium
	Quality of Light				●			Low	Mid Term	Medium
	Rapid Obsolescence				●			Low	Mid Term	Medium
	Profligation of Light		●					Low	Long Term	Medium
Displays	Material Costs				●			High	Immediate	Medium
	Low Volume Manufacturing				●			Medium	Mid Term	High
	Display Lifetime				●			Medium	Immediate	Medium
	Fast Multicoloured e-paper Displays				●			Low	Mid Term	Medium
Energy Efficient Communications	Insufficient Clarity in Market Requirements - exhibited by									
	- The Lack of an Optimum Strategy for FTTH	●						High	Immediate	High
	- "Piecemeal" Investment in Communication Strategies	●						High	Immediate	High
	- EU Competition Policy			●				High	Immediate	Low
	- Fragmented National Policies			●				High	Immediate	Low
	Insufficient Funding for Development and Commercialisation of Photonic Technologies - exhibited by									
	- A Fragmented European Supply Chain	●						High	Immediate	High
	- Capital Cost of Entry to Photonics is Huge	●						Medium	Immediate	Medium
	- A Lack of Support for Technology Commercialisation			●				Medium	Immediate	Low
	Emerging 100G Standards		●					Medium	Mid Term	High
	Insufficient Global Semiconductor Manufacturers in Europe					●		High	Immediate	High
	High Labour Costs					●		Medium	Immediate	High
	Potential REACH Restrictions		●					High	Short Term	High
Advanced Sensors & Inst.	Legislation		●					High	Immediate	Low
	Instrument Type Approval Requirements		●					Medium	Immediate	Low
	Market Size						●	High	Immediate	Medium
Clean Manu-facturing	Lack of Awareness of the Potential of Lasers in "Green" Manufacturing				●			High	Immediate	Low
	Lack of Product Design Capability				●			High	Immediate	Low
	Lack of Effective Legislation		●					Medium	Immediate	Low
	Economics Drives Industrial Decisions	●						High	Immediate	Medium

Figure 10: Barriers to Uptake of Green Photonics Technologies

Recommendations - Strategic Development Options for Europe

7

7.1

Strategic Development Themes

Policy intervention options have been identified to address the barriers listed above and support the uptake of photonics technologies, as described in section 2. These can be classified for all green photonics technologies in four "strategic development themes" as shown in the following Figure:

			Strategic Development Themes and Intervention Options												
			Theme 1: R&D and Commercialisation Prog.			Theme 2: Subsidised Market Development Programmes				Theme 3: Market Re-engineering			Theme 4: Regulation and Standards		
			RD&I Programmes	Near Market R&D Programmes	Proof of Concept Programmes	Novel Incentive Schemes	Prototype Development Programmes	Demonstrator Programmes	Capital Grant Programmes	Revised Incentive Regimes	Influencing Market Structure	Pre-Commercial Procurement	Standards Development Programme	Regulation Simplification	Regulation Monitoring Programme
Key Barriers to Market Development	Photovoltaics	PV Generation Costs	●	●	●										
		Competition				●			●	●					
		Incentive Regime								●					
		Supply Chain Gaps	●	●	●	●			●						
		Investment Risk	●	●	●	●	●	●	●	●					
	Energy efficient Lighting	High Capital Cost		●	●	●	●	●	●						
		Perverse Subsidies								●	●	●			
		Principal- Agent Conflict				●			●	●	●	●			
		Competing Market Priorities				●			●	●	●	●			
		Incomplete standards											●		
		Insufficient SME Growth		●	●	●			●						
		Supply Chain Competition		●	●	●			●						
	Displays	Materials Costs	●	●											
		Supply Chain Structure	●	●											
		No Dominant Application for Flexible Displays					●	●							
		Competitiveness of Incumbent Technology	●	●											
	Communications	Insufficient Clarity in Market Requirements		●	●			●	●		●				
		Insufficient Funding for Applied Developmentand Commercialisation		●	●			●	●						
		Insufficient Global Semiconductor Manufacturers in Europe										●			
		The Uncertainty caused by Potential REACH Restrictions													●
	Advanced Sensors and Inst.	Legislation					●	●						●	
		Market Size	●	●			●	●							
	Clean Manufacturing	Insufficient Awareness by Users of the Potential of Lasers in Clean Manufacturing					●	●							
		Insufficient Product Design Capability using Laser Manufacturing					●	●							
		Economics Drives Industrial Decisions							●						

Figure 11: Collation of Potential Interventions

This classification under four themes provides a robust framework for strategic development options for Europe.

It is clear that the five photonics technologies analysed are already critically important to the growth of low carbon applications and that a number of emerging technologies are likely to increase this importance. Further, as already indicated, these photonics technologies could have a major impact on the 2020 targets for a low carbon economy, particularly photovoltaics and energy efficient lighting.

We therefore recommend that a significant investment is made to overcome barriers to adoption and to continue the development and exploitation of emerging green photonics technologies.

We further recommend that the strategic development themes identified above are used as a strategic framework for further investment. These strategic development themes are

1. **Research, Development and Innovation Programmes**
   It is important that the European Commission's funding programmes for research, development and innovation continue. This will ensure that Europe retains its leading international position in the development of emerging green photonics technologies. However, these programmes should be structured to also include near market (applied) technology development and a stronger emphasis should be placed on developing manufacturing technology and on technology commercialisation. This theme is fully in line with the conclusions of the High Level Expert Group on Key Enabling Technologies[12].

   Actions to enhance the co-ordination of existing programmes and projects, to develop clusters of knowledge and capability, should also be implemented to catalyse potential collaboration and exploitation activities.

2. **Subsidised Market Development Programmes**
   The overall objectives of this sub-theme are to encourage and support near market development of emerging technologies, encourage the uptake of these technologies and catalyse investment in manufacturing capacity. These objectives can be achieved by proof of concept and prototype development programmes that will drive commercialisation

of technologies already being developed in Europe. For example, in the case of photovoltaics this would include novel silicon and thin film cell designs, concentrator technologies and organic photovoltaics. Specific examples for the other green photonics technologies are included in Annexes 1 to 5.

3. **Market Re-engineering**
   The objective of this theme is to change (optimise) market attractiveness by introducing, for example, optimised incentives (e.g. feed-in tariffs or subsidies), innovative funding packages (e.g. payment schemes for energy efficient lighting solutions that incentivises their implementation), pre-commercial procurement programmes or innovation oriented regulatory schemes that facilitate the adoption and uptake of green photonics technologies. It focuses on the specific characteristics of key market applications for green photonics technologies, as discussed in Section 2, above, so its design needs to be customised for each specific technology. Specific requirements for each green photonics technology are summarised in Section 2 and described in detail in Annexes 1 to 5.

4. **Overcoming Regulatory and Standards Issues**
   The objective of this theme is to optimise the attractiveness of the market for, and the competitive position of, green photonics technologies by ensuring that:

   - Regulatory and legislative issues, such as REACH regulations, are identified and addressed in a timely manner
   - A proactive constructive approach is taken to standards and standards development for two themes in particular, energy efficient lighting and advanced standards and instrumentation. Specific examples for Energy Efficient Lighting and Displays include:
     a. LED Fixture Lifetime
     b. Flicker and stroboscopic performance
     c. Light metric definitions

7.2

Prioritisation of Interventions and Potential Impacts

These strategic development options are compared in the following table that highlights their relevance to each green photonics technology, the scale of investment required and the expected impact. This table shows the potential of a number of these initiatives to make a significant impact on development of green photonics technologies.

		Relevance to Green Photonics Technologies								
		Photovoltaics	Energy Efficient Lighting	Energy Efficient Communications	Advanced Sensors and Instrumentation	Clean Manufacturing	Investment Scale (over 5 years)	Importance	Timescale for Economic Impact	Scale of Impact
Theme 1 R&D and Commercialisation Programmes	(a) R&D Programmes	●	●	●	●		> €100 million	High	Long	High
	(b) Near Market R&D Programmes	●	●	●	●		> €100 million	High	Medium	High
	(c) Proof of Concept Programmes	●	●	●	●		> €100 million	High	Medium	High
Theme 2 Subsidised Market Development Programmes	(a) Novel Incentive Schemes	●	●				€25 - €50 million	High	Medium	High
	(b) Prototype Development Programmes	●	●		●	●	€50 - €100 million	High	Medium	High
	(c) Demonstrator Programmes	●	●		●	●	to be defined	Medium	Short	High
	(d) Capital Grant Programme	●	●	●		●	to be defined	Medium	Short	High
Theme 3 Green Photonics Market "Re-engineering"	(a) Revised Incentive Schemes*	●	●				€0*	High	Short	High
	(b) Influencing Market Structure		●	●			€10 million	High	Short	High
	(c) Pre-commercial Procurement		●	●			€50 million	High	Medium	High
Theme 4 Overcoming Regulatory and Standards Issues	(a) Regulation Monitoring Programme**			●			€1 million	Medium	Medium	Medium/ Small
	(b) Regulation Simplification				●		€3 million	Medium	Medium	Medium/ Small
	(c) Standards Development Programme		●				€25 million	High/ Medium	Medium/ Long	Medium

Notes:
The investment scales quotes are estimates that have been developed as part of this project
The scale of impact refers to the growth of the relevant green photonics technology
Small, medium and high are used to qualitatively rank the relative impact on growth of each green photonics technology
* It is assumed that the costs will be incurred by national programmes
** This initiative was specifically identified to address issues in energy efficient communications but is considered relevant to all themes

Figure 12: Comparison of Strategic Development Options

7.3
Recommendations

A number of intervention options to overcome the barriers identified and to support the uptake of green photonics technologies have been identified and assessed. These have been presented under four strategic development themes (see section 7.1) and the estimated costs and the potential impact of these assessed. This shows that a large impact is expected from a number of these interventions.

We would therefore recommend the following priority actions:

1. **Continued Support for Photonics Technologies in Forthcoming ICT Work Programmes**
   Future calls for the ICT work programme should include calls for collaborative R&D projects in

   - Photovoltaics, focusing on materials, cell and manufacturing technology development for emerging technologies (organic and concentrator photovoltaics)
   - Energy efficient lighting, targeting the development of high performance, low cost OLED materials and device and manufacturing technology developments
   - Energy efficient communications, specialising on silicon photonics, all optical technologies and photonics integration

   In addition a dedicated call for lasers and detectors for sensing applications should be included. The budget allocated to this call should be modest, reflecting the potential economic impact that may be accrued.

   There should also be calls for:

   - Development and demonstration of measurement technologies to support standards for energy efficient lighting, focusing on key metrology issues, such as LED fixture lifetime, light metric definitions, flicker and stroboscopic performance and colour shift and power consumption performance

- Support actions to
  - Establish a pilot initiative to monitor and influence regulation that may affect green photonics technologies and their applications
  - Investigate options to simplify regulation in a way that would encourage adoption of novel sensor technologies

2. **Introduction of "Near Market" RDI, Prototype Development and Demonstrator Programmes within Framework and CIP Programmes**
   This recommendation is fully consistent with the Report of the High Level Expert Group on Key Enabling Technologies (EC, June 2011). When funding is available for these types of project it should be used to support

   - Proof of concept and commercialisation of technologies already under development in Europe in photovoltaics, energy efficient lighting, and energy efficient communications technologies
   - Prototype development and demonstrator programmes in all five green photonics technologies to provide robust evidence of the technical and financial benefits of using these technologies.

   The specific technology themes that should be addressed are detailed in annexes 1 to 5.

3. **Extension of Pre-Commercial Procurement Initiatives,** in both framework and CIP programmes. These should focus on demonstrating the potential of energy efficient lighting and showcasing preferred communication infrastructures

4. **Influence Proposed Investment in the Digital Agenda** to achieve an integrated, next generation network. The proposed €9.2 billion Digital Agenda broadband investment[64] by the European Commission offers an ideal opportunity to encourage a standardised, "future proof" fibre deployment approach in Europe.

5. **Establishment of Working Groups to Investigate Options to Optimise Subsidies for Photovoltaics and Energy Efficient Lighting.** These working groups should focus on ways to support the European photonics

[64] http://ec.europa.eu/information_society/newsroom/cf/item-detail-dae.cfm?item_id=7430&language=default

and associated industries and the adoption of the optimum technologies to achieve low carbon targets.

In addition, recommendations of the High Level Expert Group on Key Enabling Technologies to develop combined financing for large pilot line (or manufacturing) investment should be supported and the importance of funding photonics technologies stressed if this support mechanism is established.

Finally, it is recommended that the future growth of green photonic technologies in Europe is monitored and the impact of new initiatives carefully evaluated. This can be achieved by using the evidence in this report to establish a robust evidence base on current green photonics technologies and reviewing how this has grown on a regular basis (e.g. every three years).

PHOTONICS TECHNOLOGIES

and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Annex 1:

Photovoltaics Technologies and Applications

17th February 2012

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Executive Summary

Executive Summary

This document, which reviews photovoltaic applications of photonics, summarises relevant technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity.

Photovoltaics is already an established application of photonics technologies, accounting for 10% of the global photonics market in 2008[1]. In this study optical and electro-optics materials, solar cells and modules, photovoltaic systems and associated photonics based manufacturing techniques have been included in the analysis.

Silicon and thin film[2] based photovoltaic modules and concentrator systems are the key current technologies. Organic based systems are emerging technologies. The current focus for all technologies is to maximise system efficiency and reduce cost through enhanced solar cell efficiencies and optimised manufacturing techniques. Major improvements in the efficiencies of all types of solar cell have been achieved, but the industry is striving for more to increase competitiveness and market share.

It is estimated that the global production capacity of photovoltaic electricity was 35 Gigawatts in 2010, with Europe accounting for over 25 Gigawatts of capacity[3]. This market has been developed using financial incentives (Feed-in Tariffs) because photovoltaics is not cost competitive with traditional electricity generation methods. Silicon is currently the dominant technology with a market share of over 80%[3]. Thin film technologies account for around 15% and concentrator and emerging technologies around 5%. It is expected that silicon and thin film technologies will still retain 95% of the market in 2015, reducing to 85% by 2020 as concentrator and emerging technologies develop market share.

[1] Final Report, High Level Expert Group on Key Enabling Technologies, European Commission, June 2011
[2] Copper indium gallium diselenide [CIGS] and cadmium telluride [CdTe]
[3] Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace, 2011

China is the leading manufacturing region with its global market share expected to reach 35% by 2015, compared to a figure of 15% for Europe[4]. Other Far East economies are also developing capacity and it is expected that the region will hold more than 70% of global manufacturing by 2015[5]. Therefore, manufacturing capacity in the Far East has developed by supplying the European market, which currently accounts for over 70% of the global market.

Major investments are being committed globally by the research and industrial communities to develop more efficient photovoltaic systems and thus enhance the competitiveness of the technology. Developments in materials, cells, modules and manufacturing technologies are underway for **all** photovoltaics technologies to achieve lower cost electricity generation and thus competitiveness with other energy sources. In the longer term novel solar cell designs and the application of nanotechnologies are expected to further enhance efficiencies. These activities are detailed in a number of published technology and industry roadmaps[6].

There are major initiatives in the USA, Japan, China, Korea and Taiwan to develop photovoltaic manufacturing and energy generation capacity. In the USA and Japan these initiatives are focusing on investing in both generating capacity and developing the indigenous manufacturing sector (e.g. the Sunshot Initiative in the USA[7]) while in China, Korea and Taiwan the major investments to date have been in developing manufacturing capacity – currently these three countries are exporting almost all production output. Feed-in tariffs are the main incentives to support investment in generating capacity in all countries, with each having customised incentive packages that suit its demographics and political objectives.

The interventions in Japan and the USA that focus on a combination of technology development, industry development and implementation of a photovoltaics generation infrastructure offer models to develop an indigenous photovoltaic industry. The Solar Europe Industry Initiative[8], led by

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[4] PV Status Report 2010 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2010

[5] PV Status Report 2011 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2011

[6] These have been prepared by e.g. European Photovoltaics Industry Association (EPIA), The International Energy Agency and The European Commission Joint Research Centres

[7] US Department of Energy, see http://www1.eere.energy.gov/solar/sunshot/

[8] Solar Europe Industry Initiative (SEII), Summary Implementation Plan 2010 – 2012, EPAI and The Photovoltaic Technology Platform, February 2010

the European photovoltaics industry, has already prepared an action plan for Europe that is similar to these initiatives. It proposes support of technology development, manufacturing development and systems integration and estimates a budget of €1,300 million to fund its programme.

The SWOT analysis for Europe, as outlined in Annex I, shows strong policy drivers for renewable energy capacity development, internationally recognised scientific capability in key technologies, significant investment in R&D and a competitive position in emerging technologies. However, the lack of competitiveness and investment in manufacturing and the limited support for commercialisation and new manufacturing opportunities suggests that the declining share of global markets held by Europe will continue. This is underlined in the recently published annual report by the European Commission Joint Research Centre[5]. Europe's major opportunities are to develop and exploit new technologies, either to enhance the design of current PV systems or to exploit emerging technologies. If it can successfully address these opportunities then a stronger European industry can be developed.

Significant growth is expected in the European photovoltaics market, if there are strong financial incentives and reductions in the cost of photovoltaic energy generation. It is estimated that photovoltaics can produce 12% of Europe's energy needs by 2020[3].

It is expected that emerging photovoltaic technologies will gain a share of future markets. Concentrator technologies are expected to gain a significant market share in Mediterranean countries and will hold an estimated 4.5% of the market by 2020. Organic photovoltaics is considered a longer term option with initial markets in electronic devices and consumer products – but it is expected to remain a niche technology until 2020 at the earliest.

It is estimated that the development of photovoltaics in Europe could lead to an additional 400,000 jobs in Europe by 2020 (compared with 2009 figures)[4]. This is higher than the employment for the whole European photonics industry in 2008. The increase in gross value added of the European photonics industry in 2020 would be over €21 billion. This of course is based on the most optimistic scenario and assumes no issues that will delay market growth. However, it must be recognised that there are potential supply chain issues with some key chemical elements (e.g. Indium) where projected demand exceeds current supply. Additional sources of supply and alternative materials are being investigated to address this issue.

Photovoltaics offer practical low cost options to provide energy to remote communities. It therefore delivers important quality of life benefits.

The adoption of photovoltaics will offer significant environmental benefits. It is estimated by EPIA and Greenpeace[9] that it could generate 12% of Europe's energy needs by 2020 and save an overall total of 65 billion tonnes of CO_2 equivalent, compared to the current energy generation technology mix, by 2050[3]. The need to recycle end of life equipment has already been recognised and the recycling organisation, PV Cycle, has been established by the industry.

The major barrier to the deployment of photovoltaics is the current cost of energy generation. At present photovoltaic systems are more expensive than established technologies, but grid parity[10] is expected to be achieved in some areas of Europe (e.g. Italy) by 2013 and in almost all others, including Northern European countries by 2020. Additional key barriers include competition from other regions, an apparent lack of the type of incentives that are available in the Far East[11] (e.g. low cost capital and soft loans), a reluctance to invest in European production leading to supply chain gaps (especially for developing technologies) and the lack of a stable feed-in tariff system.

These barriers can be addressed by the following intervention actions:

1. **PV Generation Costs** are currently not competitive with other electricity generation technologies, although this situation is likely to change over the period from 2013 to 2020. These improvements will only be achieved through developments in product and process technology that will result in cell efficiency and electricity generation cost improvements. Therefore key initiatives to overcome these barriers are
   a) **Research, development and innovation programmes**, focusing on materials, device and manufacturing development. These programmes

[9] Solar Generation 6: Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace 2011
[10] Grid parity is the point at which alternative means of generating electricity is at least as cheap as grid power
[11] "US Senator accuses China over solar jobs", www.optics.org, 18th October 2011

should support all PV technologies, including longer term emerging technologies where Europe is currently in a strong R&D position

b) **Near market product development programmes,** such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe. In the short term these programmes should focus on technologies that will enhance the performance and manufacturing of silicon, thin film and concentrator technologies

2. **Competition,** as the Far East becomes the dominant manufacturing region for photovoltaic systems. To quantify the situation, the recently published PV Status Report 2011[12] estimates that by 2015 the Far East will be responsible for over 70% of world-wide PV manufacturing capacity.

   It is important that Europe responds to this situation by encouraging development of its indigenous manufacturing capacity. This can be achieved by

   a) **Capital Grant Programme,** focusing on materials and device manufacturing equipment to develop European manufacturing capacity. This should be a long term programme that supports all PV technologies. In the short term the focus should be on silicon, thin film and concentrator technologies while in the longer term it should support development of manufacturing capability for newer technologies (e.g. large area deposition techniques and roll to roll processing) where Europe is currently in a strong R&D position.

   b) **Development of novel incentive schemes,** which would encourage development of European manufacturing capacity. For example it has been highlighted[13] that building integrated photovoltaics (BIPV) is dependent on the building specifications and regulations in different countries and thus requires customised approaches rather than standard panels. These national regulations are listed as a barrier to the development of photovoltaics in Europe in Annex 1 but this intervention transforms it into an advantage for indigenous suppliers of customised products.

[12] PV Status Report, 2011, European Commission JRC, 2011
[13] Stakeholder interview programme completed as part of this study

3. **Incentive Regimes** that are different from country to country and tend to be changed without warning depending on the political priorities in each country. This leads to uncertainty, which inhibits investment.
   A coherent Europe wide incentive regime that is guaranteed for an agreed period should be implemented. This regime should be designed to reflect the different market conditions in different countries (e.g. weather conditions, gap to grid parity, etc).

4. **Supply Chain Gaps** in the European photovoltaics industry that relate, for example, to the availability of some key materials and to the need for new manufacturing technologies to support emerging technologies.

   This barrier can be overcome by:
   a) **Research, development and innovation programmes,** focusing on materials, device and manufacturing development. These programmes, similar to 1), above should support all PV technologies, including longer term emerging technologies where Europe is currently in a strong R&D position

   b) **Near market product development programmes,** such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe.

   c) **Capital Grant Programme**, focusing on materials and device manufacturing equipment to develop European manufacturing capacity.

In addition, the actions specified under 1, 3 and 4 above would also address an additional barrier identified, namely **investment risk**.

Grid Integration, although a high priority barrier, is not assessed further in this study as it is considered to be beyond the scope of photonics technologies.

To conclude, the potential for photonics technologies to enable photovoltaics to become more cost effective and competitive is significant. Similarly, the potential of photovoltaics to contribute to low carbon economy targets is equally important. The industry is highly focused on developments that enhance the competitiveness of existing technologies rather than on novel approaches. Developments in silicon, thin film, emerging and concentrator technologies are all highly relevant to the development of enhanced photovoltaics systems but it must be recognised that in the short term financial incentives and market engineering will be essential to ensure financially viable photovoltaics systems.

Table of Contents

Glossary

Acronym	Description
µm	Micrometre
µS	Microsecond
2D	Two Dimensional
3D	Three Dimensional
AlN	Aluminium Nitride
AMOLED	Active Matrix Organic Light Emitting Diode
AMEPD	Active-Matrix Electrophoretic Display
AMS	Automated Measuring System
APD	Avalanche Photodiode
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act (2009)
a-Si	Amorphous Silicon
ASP	Average Selling Price
AWG	Arrayed Waveguide Grating
BAT	Best Available Technology
BIPV	Building Integrated Photovoltaics
CAGR	Compound Annual Growth Rate
CALiPER	US Department of Energy Commercially Available LED Product Evaluation and Reporting Programme
CCS	Carbon Capture and Storage
CCT	Correlated Colour Temperature
CD/M^2	Candela per Meter Squared
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformité Européenne
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires
CEM	Continuous Emissions Monitors
CEMS	Continuous Emissions Monitoring Systems
CEN	European Committee for Standardisation
CEN TC 264	CEN Standards Committee
CFL	Compact Fluorescent Light
CFP	C-Form Factor Pluggable
CIE	International Commission on Illumination
CIGS	Copper Indium Gallium Diselenide
CIP	Centre of Integrated Photonics
CO	Carbon Monoxide

CO_2	Carbon Dioxide
CPV	Concentrator Photovoltaics
CQS	Colour Quality Scale
CRI	Colour Rendering Index
CRT	Cathode Ray Tube
CSM	Sustainable Manufacturing
CuZnSnSe	Copper Zinc Tin Selenide
CVD	Chemical Vapour Deposition
CW	Continuous Wave
DCICC	Dynamic Coalition on Internet and Climate Change
DFB	Distributed Feedback
DG ENV	Environment Directorate, European Commission
DIAL	Differential Absorption Lidar
DLP	Digital Light Projection
DMD	Digital Micro-mirror Device
DOE	Department of Energy
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electroabsorption Modulator
EBM	Environmentally Benign Manufacturing
EC	European Commission
EC JRC	European Commission Joint Research Centres
EDFA	Erbium Doped Fibre Amplifier
e-ink	Electronic Ink
EISA	Energy Independence and Security Act
EL	Electroluminescent
ELC	European Lamp Companies Federation
EML	Electroabsorption Modulated Laser
EMS	Environmental Management System
EN 15267	European Standard for Instrument Type Approval
EN 1911	Standard method for monitoring HCl
e-paper	Electronic Paper
EPA (US)	Environment Protection Agency
EPI	Epitaxy
EPIA	European Photovoltaic Industry Association
ESL	Electronic Shelf Label
ETV	Environmental Technologies Verification Scheme
EU	European Union
EU-ETS	European Emissions Trading Scheme
FBG	Fibre Bragg Grating
FEC	Forward Error Correction

FED	Field Emission Display
FP	Fabry Perot
FP8	Framework Programme 8
FPD	Flat Panel Displays
fs	Femtosecond
FTIR	Fourier Transform Infra red
FTTC	Fibre to the Kerb or Building
FTTH	Fibre to the Home
GaN	Gallium Nitride
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GDP	Gross Domestic Product
GE	General Electric
GEPON	Gigabit Ethernet Passive Optical Network
GHG	Greenhouse gas
GLS	General Lighting Service
GPON	Gigabit-Capable Passive Optical Network
gw	Gigawatt
HB-LED	High Brightness Light Emitting Diode
HCl	Hydrogen Chloride
HDTV	High Definition Television
HTPS	High Temperature PolySilicon
IALD	International Association of Lighting Designers
ICT	Information and Communications Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ILS	Industrial Laser Solutions for Manufacturing
InAsSb	Indium Arsenic Antimonide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infra Red
ISO	International Standards Organisation
ISO 14001	International environmental quality standard
ITO	Indium Tin Oxide
ITRI	Industrial Technologies Research Institute, Taiwan
ITU	International Telecommunications Union
JRCM	Japan R&D Centre of Metals
kg	Kilogramme

KOPTI	Korean Photonics Technology Institute
KTN	Knowledge Transfer Network
kW	Kilo Watt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LED	Light Emitting Diode
LEP	Light Emitting Polymer
LIDAR	Light detection and Ranging
lm/W	Lumens per Watt
LTE	Long Term Evolution
LTPS	Low Temperature PolySIlicon
MACT	Maximum Achievable Control Technology
MCERTS	UK Product Certification Scheme
MEMS	Microelectromechanical Systems
MIIT	Ministry of Industry and Information Technology
MOVCD	Metal-Organic Chemical Vapour Deposition
MP3	Media Player
Mtoe	Million tonnes oil equivalent
MW	Megawatt
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
NEDO	New Energy and Industrial Technology Development Organisation
NER 300	Support Programme for Installations of Innovative Renewable Energy Technology and CCS in the EU
NGLI	Next Generation Lighting Initiative
NGLIA	Next Generation Lighting Industry Association
NGO	Non Governmental Organisation
NGPON	Next Generation Passive Optical Network
NMP	Nanotechnology, Materials and Production Technologies
nm	Nanometre
NO_x	Nitrous Oxide
NPL	National Physical Laboratory
NREL	National Renewable Energy Laboratories
NRZ	Non Return to Zero
ns	Nanosecond
OEM	Original Equipment Manufacturer
OIML	International Organisation of Legal Metrology
OLED	Organic Light Emitting Diode
OLT	Optical Line Terminal

ONU	Optical Network Unit
OPV	Organic Photovoltaics
OVPD	Organic Vapour Phase Deposition
OXC	Optical Cross Connect
PDA	Personal Digital Assistant
PDP	Plasma Display Panels
PIC	Photonic Integrated Circuit
PLED	Polymer Light Emitting Diode
PM	Particulate Monitoring
PMEPD	Passive Matrix Electrophoretic Display
PMLCD	Passive Matrix Liquid Crystal Display
PMOLED	Passive Matrix Organic Light Emitting Diode
PMP	Portable Media Player
PON	Passive Optical Network
POP	Point of Presence
POS	Point of Sale
PPE KTN	Photonics and Plastic Electronics Knowledge Transfer Network
ps	Picosecond
PSD	Power Spectral Density
p-Si	Polycrystalline Silicon
PV	Photovoltaics
PVI	Photovoltaic International
PVTP	Photovoltaic Technology Platform
QC / QCL	Quantum Cascade (laser)
QPSK	Quadrature Phase Shifting Keying
R&D	Research and Development
RDI	Research, development and Innovation
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RGB	Red, Green Blue
RMB	Chinese currency
ROADM	Reconfigurable Optical Add Drop Multiplexer
R2R	Roll to Roll
RoI	Return on Investment
SCR	Selective Catalytic Reduction
SED	Surface-conduction Electron-emitter Display
SEMI	Global Industry Association Serving the Manufacturing Supply Chain for the Micro- and Nano-electronics Industries

SERDES	Serilaiser/Deserialiser
Si	Silicon
SiC	Silicon Carbide
SME	Small and Medium Enterprise
SMOLED	Small Molecule Organic Light Emitting Diode
SOA	Semiconductor Optical Amplifier
SONET/SDH	Synchronous Optical Network/ Synchronous Digital Hierarchy
SSL	Solid-State Lighting
STN	Super-Twisted Nematic
SWOT	Strengths, Weaknesses, Opportunities and Threats
Tb	Terabyte
TCO	Transparent Conducting Oxide
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing Passive Optical Networks
TEC	Thermo-Electric Cooler
TFT	Thin Film Transistor
TDL	Tunable Diode Laser
TN	Twisted Nematic
TV	Television
TWh	Terra Watt Hour
TWI	The Welding Institute
UBA	German Type Approval Scheme
USD	United States Dollar
USP	Unique Selling Proposition
UV	Ultra Violet
VCSEL	Vertical Cavity Surface Emitting Laser
VDSL	Very-High-Bit-Rate Digital Subscriber Line
VFD	Vacuum Fluorescent Display
VOC	Volatile Organic Compound
WDM	Wave Division Multiplexing
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
WOLED	White Organic Light Emitting Diode

Notes:

Exchange rates of €1 = £0.87 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source

Introduction

1

1. Introduction

This document, which reviews photovoltaic applications of photonics, summarises relevant technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity. It has been prepared to address the following specific objectives and to underpin a summary report on the potential of green photonics technologies in Europe:

1. Overview of existing green photonics technologies and today's related markets and market players
2. Identification and analysis of promising new green photonics technology developments for market deployment in the period 2011-2015
3. Overview of major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
4. Analysis of Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
5. Assessment of the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
6. Assessment of how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
7. Identification and analysis of the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
8. Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries.

Each of these objectives is addressed in turn in the following eight sections of this report.

1.1 Overview – Photovoltaics

Photovoltaics, defined as the "direct conversion of sunlight into electricity" is already an established application of photonics and already accounts for 10% of the global photonics market[14]. Figure 1 shows a schematic photovoltaics supply chain.

This diagram shows that the photovoltaics industry includes technologies ranging from electro-optical materials to systems. The fundamental importance of materials, photonic systems and the cell efficiencies, which can be achieved, are critical to the future of photovoltaics.

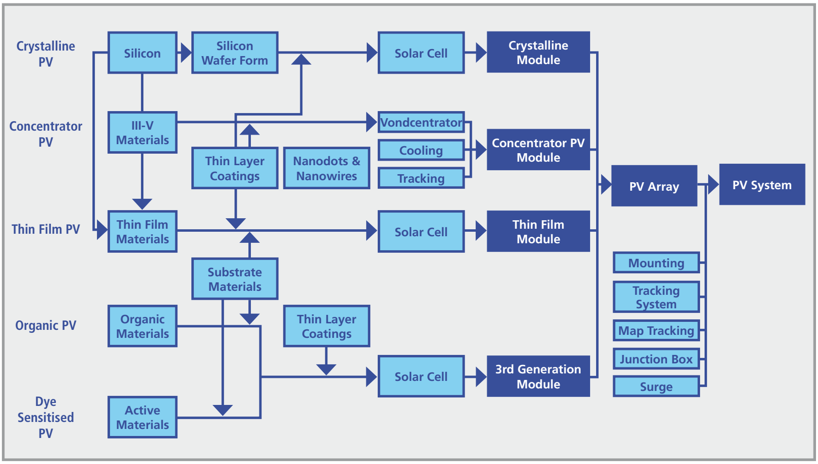

Figure 1: Typical Photovoltaics Supply Chain

For this study, photonics activity within photovoltaics is defined as shown in Figure 1. It therefore includes:

- Optical and electro-optical materials and thin films, including novel approaches to optimise efficiency

[14] Final Report, High Level Expert Group on Key Enabling Technologies, European Commission, June 2011

- Solar cells and modules
- PV systems, including concentrator systems
- Associated photonics based manufacturing technologies

It does not include aspects relating to balance of systems and grid connection. Although these are very important aspects in development of photovoltaic generation capacity in Europe, especially when the photovoltaics market share increases, these are not considered relevant in the context of photonics technologies.

Overview of Existing Green Photonics Technologies and Today's Related Markets and Market Players

2

2.1
Existing Technologies

Photonics technologies fundamentally underpin photovoltaics. Photonic materials and structures are the building blocks of all types of photovoltaic cells and other photonics systems, such as lasers, are critical to solar cell manufacturing systems.

2.1.1 Silicon

The traditional solar cells material, as already indicated, is crystalline silicon (see Figure 2, which shows the basic silicon core and associated thin layers), which currently accounts for almost 90% of the market and is expected to remain the dominant technology (>50% of the market) until at least 2020[15]. Options for enhancement of silicon solar cells are therefore critical in this study. Already there is a major global focus on optimising the efficiency (performance and cost) of silicon cells – based on reduced materials consumption (e.g. reduced consumption of silicon in the core), improved cell concepts (e.g. enhanced light trapping, tandem cells, back contact cells) and optimised manufacturing processes.

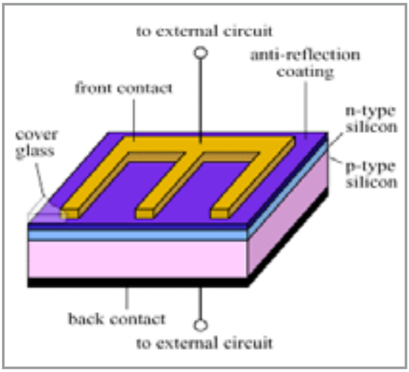

Figure 2: Typical Si Cell

Improved cell concepts are designed to absorb and utilise larger percentages of the sun's energy. The absorption spectra of sunlight for silicon is shown in Figure 3[16], which indicates how the performance of silicon solar cells are limited by losses due to thermalisation and low energy photons which pass through the cells. These losses lead to a theoretical maximum efficiency of around 30%. To date efficiencies in single crystal silicon of 25% in the laboratory (see Figure 7) and 19%[17] in manufacturing are being achieved.

[15] Technology Roadmap, Solar Photovoltaic Energy, International Energy Agency, 2010
[16] Provided by Goldschmidt, Fraunhofer ISE
[17] Mark Osborne, www.pv-tech.org, 08 Feb 2011

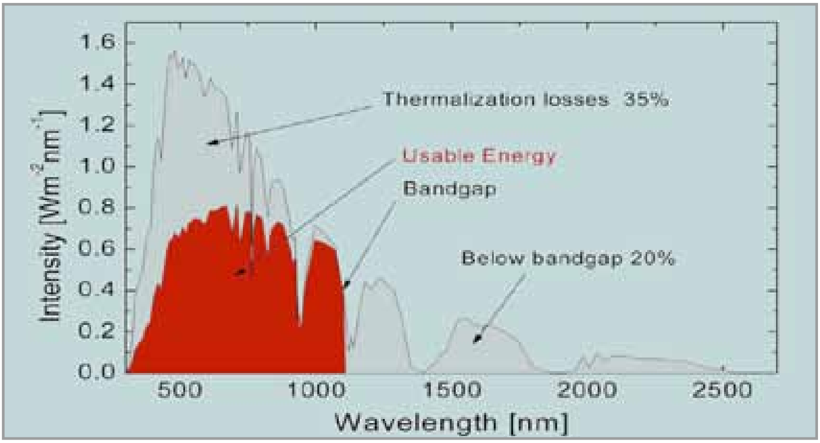

Figure 3: Silicon Absorption Data

2.1.2 Thin Film Photovoltaics

Thin film solar cells are the main competition to bulk silicon, with the market share expected to increase significantly over the period to 2020 as shown in Figure 10 below. There are essentially three thin film options, copper indium gallium diselenide (CIGS), cadmium telluride (CdTe) and silicon, where the absorbing materials are deposited at micrometre thicknesses on a low cost substrate. The structure for a CIGS cell[18] is shown in Figure 4.

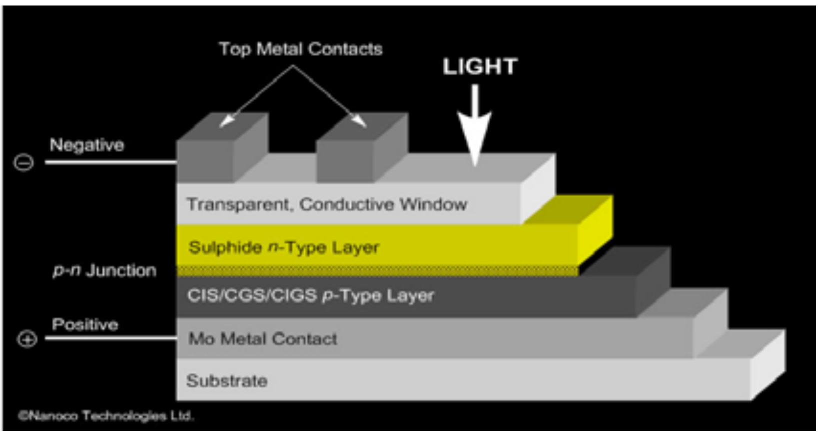

Figure 4: Typical CIGS Cell

18 http://www.nanocotechnologies.com/content/CommercialApplications/Solar.aspx

The industry is striving to optimise the efficiency of thin film cells through enhanced cell efficiencies and optimised manufacturing processes. Raw materials consumption is already low. These cell structures do offer significant potential for large area deposition, roll to roll (R2R) manufacturing and packaging, hence minimising costs.

However, there are concerns[19] about the materials used in thin film cells, especially Cadmium, Tellurium, Indium and Gallium, due to toxicity and/or availability issues. The US Department of Energy summarises its analysis of the supply risk of a number of key materials for clean energy (including photovoltaics) as shown in Figure 5:

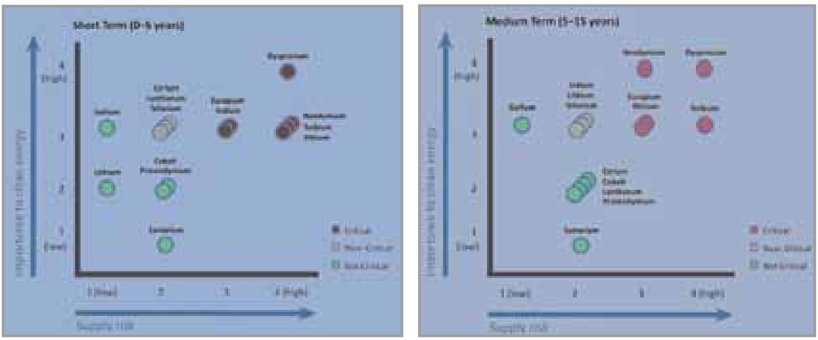

Figure 5: Analysis of Short and Medium Term Supply Issues with Key Materials

As a benchmark, there are no concerns regarding the availability of silicon.

The importance of achieving high production throughput for both silicon and thin film solar cells is recognised in the recent European Commission joint NMP:Energy call (NMP.2011.1.2-1) for proposals for "development and up-scaling of innovative photovoltaic cell processes and architectures to pilot-line scale for industrial processes".

2.1.3 Novel / Emerging Technologies

In the longer term, novel or emerging photovoltaic technologies are expected to gain some market share (as also shown in Figure 10) – due to the potential of low cost, large area, transparency and flexibility. These may be based on novel inorganic technologies, dye sensitised solar cells or fully organic (OPV) approaches. These technologies are considered a

[19] Critical Materials Strategy, US Department of Energy, December 2010

"long term play" by the industry but there is already manufacturing capacity available (e.g. Konarka in the USA) and they are already being used in niche applications (e.g. charging of mobile phones). As discussed below, these technologies are expected to be used in additional applications once efficiency, performance, lifetime and reliability are demonstrated in early niche applications. This is discussed in more detail in section 5.3.

Concentrator Technologies

These above technologies are classed as "flat plate technologies", although thin film structures are expected to be flexible when deposited on plastic substrates. They are complemented by concentrator technologies (CPV), where lenses are used to focus the light on high-efficiency solar cells, typically based on Gallium Arsenide, as shown in Figure 6[20]. These systems are currently moving from pilot facilities to commercial scale applications[21] – the first stand alone CPV systems were recently set up in Egypt under European Commission funding[22].

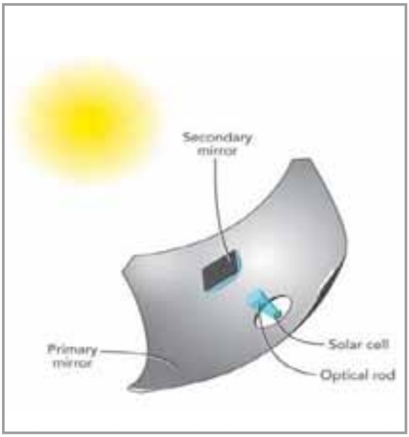

Figure 6: Typical CPV Structure

In Europe, current activities are focusing on optimised system efficiency and cost via optical systems, module assembly, lower cost tracking systems, solar cell efficiency and optimised manufacturing and installation. Significant performance improvements in all these different approaches have been demonstrated over the last 25 years. Cell efficencies have been monitored closely by, for example, NREL[23], on a global basis, as shown in Figure 7.

This figure shows how the efficiencies of all types of photovoltaic cell have improved, although as indicated above, further enhancements in cell efficiency are required. Of course, due to the different basic materials, performance data and cell designs, these trends cannot be easily compared.

[20] The Global Energy Network Institute, www.geni.org
[21] Solar Photovoltaic Energy Technology Roadmap, OECD/International Energy Agency, 2010
[22] New Applications for CPVs – A Review of Project "NACIR", PV and Nanotechnology Workshop, Aix Les Bains, September 2010
[23] Lawrence Kazmerski, National Renewable Energy Laboratory (NREL), April 2010

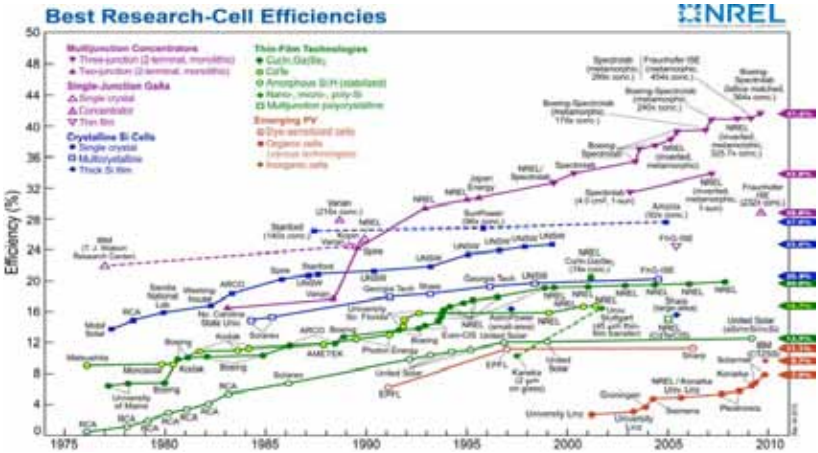

Figure 7: Developments in PV Cell Efficiencies (1975–2010)

2.1.4 Manufacturing Technologies

Laser systems play an increasingly important role in photovoltaic manufacturing. Uses of lasers currently include[24]:

- Structuring of thin films – ultra short laser pulses are used to selectively remove coatings
- Laser beam doping - for selective emitter formation in silicon solar cells
- Soldering and welding of solar modules
- Edge isolation – electrical isolation of solar cell faces using nanosecond pulse lasers
- High speed drilling for novel (back contact) solar cells

Furthermore, lasers are also considered to be critical to the development of some of the future novel concepts which will optimise efficiency of current systems.

[24] Lasers in Photovoltaics, Fraunhofer ILT

2.2
Current Market

It is estimated[25] that in 2010 the global production capacity of photovoltaic electricity was more than 35 gigawatts (GW), a significant increase from 23 GW in 2009. The distribution by global region[26] is shown in Figure 11, below. This shows radical growth and the resultant dominance of Europe as a user of photovoltaics over the last eight years. It also shows the development of photovoltaic capacity in the rest of the world, which is now beginning to grow rapidly. The development and implementation of guaranteed pricing systems (feed-in tariffs) in combination with other support measures (e.g. clear, simplified administrative and planning procedures and ease of access to the grid) in Europe has already underpinned market development and will continue to be critical to the future development of European photovoltaic capacity.

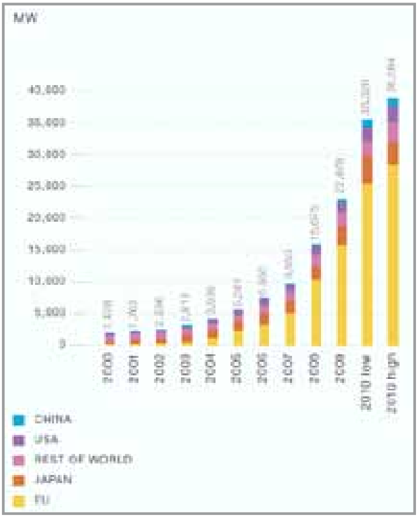

Figure 8: Global Installed PV Capacity

The European Photovoltaics Industry Association (EPIA)[25] reports Germany was a pioneer in the development of feed-in tariffs and, as a result, had a 53% share of the global PV installed capacity in 2009. Now more than 40 countries have introduced feed-in tariffs for renewable energy systems, including photovoltaics, which are expected to lead to significant developments in photovoltaic capacity in these countries

2.2.1 Market Drivers

The influence of these incentives in developing market demand cannot be

[25] Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World, EPIA and Greenpeace, 2011

[26] Global Market Outlook for Photovoltaics until 2014, EPIA, May 2010

over-estimated. They have been critical to market development, and will continue to be essential until grid parity is reached. For example, installations in Spain in 2008 totalled 2.7GW compared to a global figure of just over 6gw, due to the Plan de Energies Renovables en Espana[27]. However, in 2009 when incentives were much less available, installed capacity reduced to 0.1gw, as shown in Figure 9, below[28], which also shows the increase in capacity in other key European countries. However, these incentives need to be carefully designed – continuity and strategic design are key features which are claimed to have been lacking in incentives to date.

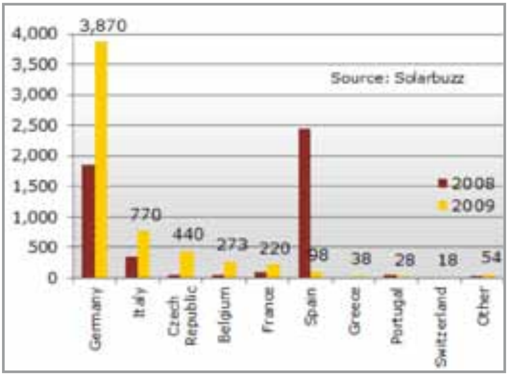

Figure 9: European Growth in the Installed PV Generation Base

Further, it is argued that if these incentives were focused on "building integrated photovoltaics" (BIPV) then this would encourage customisation at a national level (to address national building regulations) and resultant development of national industries. However, it is recognised, due to the requirements for customisation, that BIPV is not a low cost option.

It is expected that the historic growth of photovoltaic energy generation will continue, with estimates of installed photovoltaic capacity under a number of scenarios developed by organisations such as EPIA and The International Energy Agency (IEA). This is discussed further in section 5.3.

2.2.2 Relative Positioning of Different Technologies

Figure 1 highlighted several different materials systems. Silicon, however, dominates the market and is expected to do so for the foreseeable future, as shown in Figure 10.

Silicon benefits from the large body of experience on the material gained in the electronics industry, whereas thin film capability was developed from scratch.

[27] PV Status Report 2010 – Research, Solar Cell Production and Market Implementation of Photovoltaics, European Commission Joint Research Centre, Ispra, August 2010

[28] http://www.solarbuzz.com/facts-and-figures/market-facts/regional-pv-markets-europe

Figure 10 also shows that in 2010 silicon solar cells held over 80% of the market, with predictions that this would reduce to less than 70% by 2020[25]. Over the same period it shows that thin film technologies market share will increase to over 20%. However, it is now being considered by industry that the predictions for growth of thin film may be different. It held a 17% share in 2009, but this reduced to 13% in 2010. It is expected that it will grow to over 20% by 2020 but this growth may be unpredictable.

Growth will be dependent on the relative attractiveness, to the investment community, of thin film technologies compared to silicon, which at the moment is considered by industry to be uncertain. The investment risk of silicon is considered much more attractive due to its track record and long term concerns about several materials used in thin film materials. Nevertheless, it is still expected that silicon and thin film materials (CIGS and CdTe) will jointly account for over 95% of the market in 2015 and that emerging technologies, such as OPV will develop 2% and 5% market shares by 2015 and 2020 respectively – building on niche applications. This is discussed further in section 5.3 below.

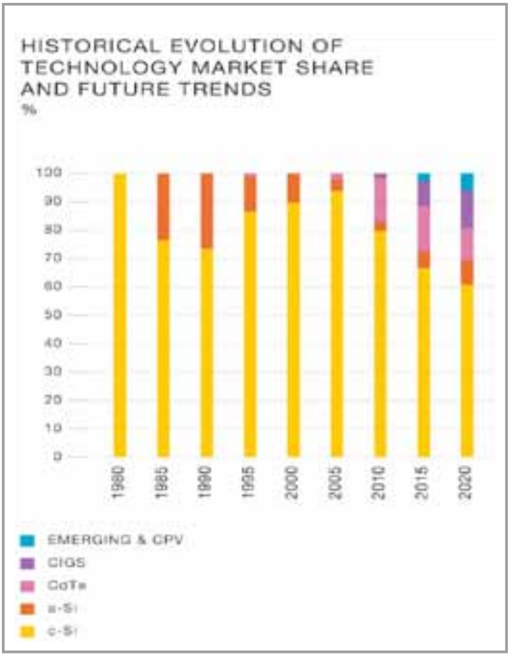

Figure 10: PV Technology Segmentation

2.2.3 Market Players

The position of Europe as a photovoltaics manufacturer is rather different to its status as the dominant user region. Figure 11[27] segments the global photovoltaic production by region, indicating that China is the largest volume manufacturer, with a predicted market share of almost 35% in 2015, compared to a 14.6% share for Europe.

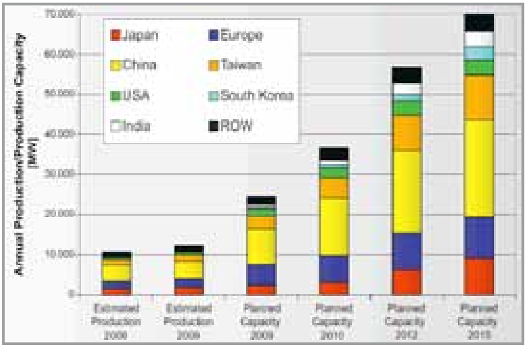

Figure 11: Global Photovoltaic Production Capacity - By Region

The importance of Far East manufacturing is further reinforced if the largest twenty manufacturing companies are analysed[27], as shown in Figure 11.

Company	Nationality	Production Capacity (GW)	Comments
Suntech Power Co. Ltd	China	1,4	
First Solar LLC	USA	1,335	Manufacturing plant in Germany
Sharp Corporation	Japan	1,335	Manufacturing plant in the UK
Q Cells AG	Europe (Germany)	1,1	Manufacturing plant in Malaysia
JingAo Solar Co. Ltd	China	1,1	Partial Australian ownership
Yingii Green Energy Holding Co. Ltd	China	1	
Trina Solar Ltd	China	0,9	
Motech Solar	Taiwan	0,8	
Neo Solar Power Corporation	Taiwan	0,8	
Gintech Energy Corporation	Taiwan	0,75	
Renewable Energy Corp AS	Europe (Norway)	0,75	Manufacturing plant in Singapore
Canadian Solar Inc	Canada/China	0,7	
SunPower Corporation	USA	0,57	
Solar World AG	Europe (Germany)	0,625	Large manufacturing plant in the USA
Kyocera Corporation	Japan	0,6	
Sanyo Electric Company	Japan	0,6	
E-TON Solartech Co. Ltd	Taiwan	0,56	
NingBo Solar Electric Power Ltd	Chine	0,5	
Solarfun Power Holdings Ltd	China	0,5	
Bosch Solar	Europe (Germany)	0,3	
	TOTAL	16.225	

Figure 12: Leading Global Photovoltaic Manufacturing Companies

Focusing on the European company base, there is internationally competitive capability in all major technologies, with the main players including:

- Silicon (e.g. PV Crystallox Solar, Solarworld AG, Centrosolar)
- Thin films (e.g. Q-cells, Sharp Electronics Europe, First Solar, Oerlikon)
- Concentrator technologies (e.g. Concentrix Solar, Isofoton, SolarTec)
- Dye sensitised solar cells (e.g. Dyesol, Greatcell Solar)
- Organic photovoltaics (e.g. Heliatek, Konarka, G24)

However, as indicated above, the dominant technology is silicon based photovoltaics that is increasingly being supplied by Far East companies.

Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

3

3. Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

The current and future challenges for the photovoltaics sector must be analysed to identify promising new photonics technologies. There have been a number of strategic road maps[29] developed for the sector. The International Energy Agency's Technology Roadmap[15] asserts it has been informed by other documents so it can be used to provide an effective overview. It has summarised its analysis of the development timescales for different technologies and has tabulated efficiency targets, manufacturing objectives and R&D requirements for each PV technology over the period to 2030. These are shown in Figure 13 and discussed below.

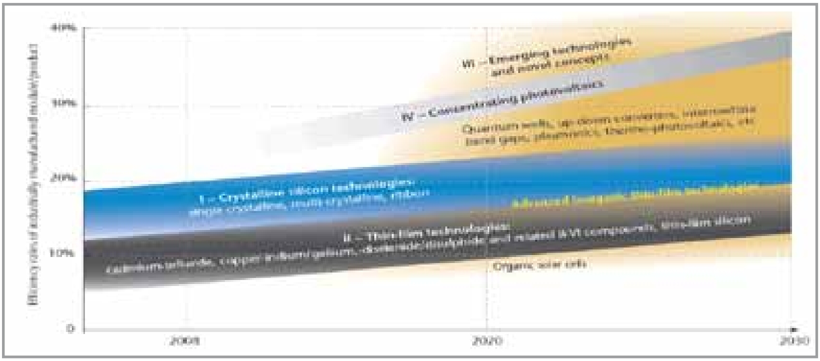

Figure 13: Expected Development of PV Technologies

Firstly, its analysis of key PV technologies underlines that in the timescale defined for this study bulk silicon, thin film technologies and con-

[29] Examples include the International Energy Agency Technology Roadmap, the EU's Strategic Energy Technology (SET) Plan, the Solar Europe Industry Initiative, The European PV Technology Platform Strategic Research Agenda, the Solar America Initiative, Japan's PV Roadmap, China's solar energy development plans, India's Solar Initiative and Australia's Solar flagship initiative

centrating photovoltaics are the technologies that can offer exploitation opportunities for Europe. Other, more novel technologies will offer later opportunities.

The Photovoltaic Technology Platform strategic research agenda is being updated at the moment but it is understood that it will be consistent with these other foresighting documents.

The specific goals and development needs for bulk silicon PV are shown in Figure 14[15] – reflecting the need to enhance cell efficiency and reduce manufacturing costs. Obviously reductions in the volumes of silicon used have significant cost benefits.

Crystalline silicon technologies	2010 – 2015	2015 – 2020	2020 – 2030 / 2050
Efficiency targets in % (commercial modules)	• Single-crystalline: 21% • Multi-crystalline: 17%	• Single-crystalline: 23% • Multi-crystalline: 19%	• Single-crystalline: 25% • Multi-crystalline: 21%
Industry manufacturing aspects	• Si consumption <5 grams / Watt (g/W)	• Si consumption <3 g/W	• Si consumption <2 g/W
Selected R&D areas	• New silicon materials and processing • Cell contacts, emitters and passivation	• Improved device structures • Productivity and cost optimisation in production	• Wafer equivalent technologies • New device structures with novel concepts

Figure 14: Bulk Silicon PV - Targets and Development Needs

This underlines the incremental nature of developments – the future of PV is invested in enhancements to established technologies rather than the introduction of radical approaches.

A similar analysis for thin film technologies defines that the manufacturing needs for the period to 2015 are high rate deposition, (R2R) and packaging and that research and development priorities are large area deposition process development and improved substrates and transparent conductive oxides. In the longer term further improvements to cell structures, development of deposition techniques and enhancement to production processes are highlighted. In comparison, for concentrator PV, low cost, high performance solutions for optical concentration and tracking are identified as key priorities.

These assertions are reinforced by the Solar Europe Industry Initiative[30] which includes the table shown in Figure 15.

		2007	2010	2015	2020
Turn-key price large systems (€/Wp)		5	2,5	2	1,5
PV electricity generation cost in Southern EU (€/kWh)		0.30	0.13	0.10	0.07
Typical PV module efficiency range (%)	Crystalline silicon	13 – 18%	15 – 20%	16 – 21%	18 – 23%
	Thin films	5 – 11%	6 –12%	8 – 14%	10 – 16%
	Concentrators	20%	20 – 25%	25 – 30%	30 – 35%
Inverter lifetime (years)		10	15	20	>25
Cost of PV + small-scale storage (€/kWh) in Southern EU (grid-connected)		–	0.35	0.22	<0.15
Energy pay-back time (years)		2 – 3	1 – 2	1	0.5

Figure 15: Solar Europe Industry Initiative Performance Targets

As indicated in Figures 13 to 15 future developments of photovoltaic technologies will be a continuation and refinement of existing activities, rather than the introduction of radical new technologies.

Key technology developments to enhance current systems and address future requirements have been identified[15,27,31] and include:

Short Term (2011–2015) Technologies

1. Bulk silicon photovoltaics
    a. Materials
        i. Enhanced, low defect, silicon crystal growth
        ii. Thinner wafers and improved, lower loss wafering technologies
        iii. Improved, ow cost encapsulants
        iv. Improved TCOs
    b. Cells and Modules
        i. Improved back-contact cell structures
        ii. Heterojunction solar cells
        iii. Surface passivation
        iv. Novel cell (e.g.tandem) structures
    c. Manufacturing
        i. Roll to roll processing

2. Thinfilm photovoltaics
    a. Materials
        i. Thin film silicon
            1. Large area plasma process for thin layer deposition
            2. Enhanced transparent oxide layers

[30] Solar Europe Industry Initiative (SEII), Summary Implementation Plan 2010 – 2012, EPAI and The Photovoltaic Technology Platform, February 2010

[31] European Commission Photovoltaics and Nanotechnology Workshop, Aix Les Bains, September 2010

- ii. CIGS
  1. Thinner, high quality layers with enhanced efficiency
  2. oven (non-vakuum) deposition methods
- iii. CdTe
  1. Improved control of deposition and doping
  2. Enhanced transparent oxide layers

b. Cells and Modules
- i. Improved cell structures to optimise optical confinement
- ii. Optimised substrate materials and cell structures

c. Manufacturing
- i. Roll to roll processing
- ii. Laser scribing processes

3. Emerging technologies

a. Materials
- i. Dyesensitised solar cells
  1. Improved sensitisers
  2. Encapsulation
- ii. Organics
  1. Photoactive materials with optimised transport and absorption properties
  2. Solution processable materials

b. Cells and Modules
- i. Organics
  1. Develop tandem cell structures

c. Manufacturing- longer term focus

4. Concentrator photovoltaics

a. Enhanced optics (and resultant savings in tracking systems)
b. Improved optical thin films and coatings
c. Optimised alignment of optical systems
d. Development of optics and production processes

These highlight a number of underpinning themes, e.g. optimised materials, encapsulants and TCOs – based on the drive to optimise cell components, cell designs and, ultimately, cell efficiencies.

Longer Term (2015–2020) Technologies

In addition to the continuation and refinement of the photonics technologies listed above, in this period, novel materials and structures will be developed to optimise cell efficiency, including

- Development of further enhanced cell designs using, for example, nanoparticles, nanodots and nanowires
- Utilisation of low cost silicon substrates
- Development of all-silicon tandem solar cells

- Development of photonic and plasmonic structures in all types of photovoltaic cell (e.g. Bragg gratings, stepped surfaces and laser doping)
- Development of laser based optimisation of cell structures
- Development of cells with novel materials (e.g. CuZnSnSe) to substitute for materials (e.g. CIGS) which have toxicity or availability concerns

A number of these concepts are currently being investigated under European Commission R&D funding[31].

Development of these technologies is driven by two over-arching requirements – achieving increased cell efficiency and lower manufacturing cost. If some of these technologies can be successfully developed and implemented then the global adoption of photovoltaics systems will be increased and the European industry will increase in size. This is discussed in more detail in Section 5.

Overview of Major Research Programmes and Deployment Initiatives outside Europe

4

4.1
USA

The USA, is already a leading player in photovoltaic manufacturing and installation, hve major support programmes for both market and technology development. It has offered major incentives for a number of years for the installation of photovoltaics, but these vary significantly from state to state. The funding offered, which is supported by the national State Energy Programme and individual State Programmes, is summarised in DSIRE[32]. Some of the funding packages are dedicated to solar energy and others are generic renewable energy programmes. The leading policy approaches are financial incentives (e.g. feed in tariffs, tax credits, grants, loans and loan guarantees), solar standards, simplified grid connection and net metering[33]. It is estimated that the total funding available for solar energy in current support programmes is €1.23 billion[34],[35].

Government support for the development of solar energy technologies has also been significant with more than €750 million[35] invested over the last ten years[36]. The leverage of private sector investment is also highlighted where there are examples of a DOE investment of €38.5 million[35] in photovoltaic incubator projects leveraging over €920 million[35] of private sector investment. The main source of current funding is the Solar Energy Technology Programme, which is subdivided into four sub-programmes[37]:

- Photovoltaics (inc. new devices and processes, prototype design and pilot production and systems development and manufacturing)
- Concentrating Solar Power (linear concentrator systems, dish engine and power tower systems, thermal storage and advanced components and systems)

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32 The Database of State Incentives for Renewables and Efficiency, www.dsireusa.org
33 US Photovoltaic Markets: PV Policies Leading the Way, Justin Barnes, N.C. Solar Centre at ASES,2009, May 13th 2009
34 Solar in the Stimulus: An Analysis of State Energy Programme Spending, Ty Gorman and Amanda Zidek-Vanega, ASES Annual Conference. 2010
35 Exchange Rate of 1€=$1.3 (http://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-usd.en.html)
36 Fact Sheet: Department of Energy Investment in Solar Energy, http://www.eere.energy.gov /pdfs/fact_sheet_doe_investments_in_solar.pdf
37 http://www1.eere.energy.gov/solar/

- Systems Integration, addressing the technical barriers to large scale deployment of solar technologies
- Market Transformation, which promotes the commercialisation of solar power

Key technologies under development include advanced solar cell materials (thin film cadmium telluride and copper indium gallium diselenide (CIGS)) and ultra-thin nanocrystalline films.

These programmes are complemented[38] by the "Sunshot Initiative" designed to regain America's once-dominant position in the global market for photovoltaic and the Advanced Research Projects Agency-Energy (ARPA-E), which is investing in a range of transformative energy technologies. The Sunshot Initiative is clearly focusing on re-establishing the USA as a leading photovoltaic manufacturing region and has already demonstrated significant leverage of public sector funding.

In total it is estimated that over €150[35] million per annum is currently invested in developing and commercialising photovoltaic technologies.

4.2
Japan

Japan has set long term policy goals for solar power.

The Japanese government introduced an "Action Plan for Achieving a Low-Carbon Society" in 2008, which set long term targets for the development of solar energy generation – namely a ten-fold increase in installation of systems by 2020 and a forty-fold increase by 2030, with a target to halve the current price of solar power within 3 to 5 years.

This is supported by "An Action Plan for Promoting the Introduction of Solar Power Generation" published by the Ministry of Economy, Trade and Industry in November 2008 on behalf of a number of Ministries.

[38] http://www.eere.energy.gov/sunshot/

Japan has also introduced requirements on utility companies to purchase PV generated energy[39] and specified photovoltaics as a "priority area in innovative technology development"[40].

In parallel, Japan has developed a long term roadmap[41] for the development of PV technologies, which sets targets for module efficiency, generation cost, national production and key applications. These are generally similar to other roadmaps, although the targets for Japanese PV manufacturing are notable. Government supported research activities are funded through New Energy and Industrial Technology Development Organisation (NEDO), which is responsible for research programmes for renewable energies. Recent programmes are shown in the table in Figure 16. In addition NEDO has committed to a new five year programme to develop "next generation" solar cells (thin film solar cells), with funding in year one estimated to be €36 million[42].

Programme	Duration	Typical Annual Funding (€M)*
Field Test Project on New Photovoltiacs Power Generation Technology	2007 – 2014	57,55
Development of Technologies to Accelerate the Practical Application of PV Power Generation Systems	2008 – 2009	1,82
Research and Development of Next-Generation PV Generation Systems Technologies	2006 – 2009	10,00
Research and Development on Innovative Solar Cells	2008 – 2014	18,18
Research and Development of Common Fundamental Technologies for PV Generation Systems	2006 – 2009	3,64
** Based on exchange rate of 1€=110 JPY*	TOTAL	91,18

Figure 16: Current Japanese (NEDO) Research Funding for Photovoltaics

[39] The Promotion and Use of Non-Fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers, enacted July 2009 and
[40] The Basic Energy Plan, 2010 review – adopted in June 2010
[41] Overview of PV Roadmap to 2030, New Energy and Industrial Technology Development Organisation, June 2004, Revised in 2010
[42] Currency exchange rates sources from http://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-jpy.en.html

4.3 China

China has developed a strategic plan for photovoltaics in collaboration with SEMI's PV Group. As indicated above, China has become the largest global producer of solar cells. It currently exports 98% of solar cell manufacturing output and it is recognised that a number of companies rely on imported technology and equipment and do not invest significant funds in R&D[43]. Further, it is recognised that there is a lack of capability in the installation and management of PV systems and a significant population, which does not have basic energy services[44]. Therefore, China's strategy focuses on funding demonstration projects to support the adoption of photovoltaics and it has set clear targets for PV installations to 2020 together with support mechanisms to encourage PV investment[27].

A number of Chinese ministries have been jointly funding the "BIPV" and "Golden Sun" Programmes since 2009, the first of which focuses on grid connected rooftop and BIPV systems and the latter on grid connected and, in rural areas, off grid systems. Government funding for the Golden Sun Programme, which has an installation cap of 680mw, offers 50% of the total cost for on grid systems and 70% for off-grid systems while the BIPV programme offers a subsidy per watt generated. In addition in 2010 there have been calls for proposals by the National Energy Administration (with cap of 800mw across eight regions), the Ministry of Finance and the Ministry of Urban and Rural Development for additional demonstration and installation projects[45].

These programmes all underline China's focus on installation of PV capacity rather than development of new technologies.

The supportive investment climate (low cost loans, low energy costs, low labour costs, etc) in China, which has catalysed the development of an extremely large photovoltaics production capacity is seen as key to its

[43] China's Solar Future, A Preliminary Report on a recommended China PV Policy Roadmap, SEMI PV Group, May 2009
[44] http://www.pvgroup.org/events/ctr_031358
[45] Status of China's PV Industry and Market Development, Melody Song, SEMI, Presentation at SEMICON West, July 2010

current position. It now has a number of vertically integrated companies which are establishing international brands and industry evidence suggests that it has the scope to reduce prices further if required, thus establishing a stronger hold on the global market.

4.4 Korea

Korea's activities in photovoltaics are currently rather modest compared to other Far East economies, with an estimated manufacturing capacity of 1gw. However, it does have a long term "Low Carbon, Green Growth" strategy and PV Market Creation Plan[46][47], strong government support[48] and major global players (i.e. Samsung and LG Philips) to increase its activities significantly and become a major global player in the future. The PV Market Creation Plan is targeting 200mw capacity by 2012 although other sources[46] suggest this figure has already been exceeded.

The joint working of government, global industries and the research community is considered to be central to the potential of Korea to develop as a global player in photovoltaics.

Government support for installation of photovoltaics is provided in the form of feed-in tariffs and specific installation programmes (e.g. 100,000 Solar Roof Programme) where incentives of up to 60% are available.

Investment in PV development is also significant (with a cumulative budget of €1.44 billion for the period to 2009[46,49]) covering four themes – R&D, infrastructure establishment and human resource education, international cooperation and dissemination. In 2009 the R&D budget was €47 million and focused on development of silicon, thin film and dye sensitised solar cells.

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46 Photovoltaic Power Systems Programme, Annual Report 2009, International Energy Agency
47 Kenny Kim, DisplaySearch at the 2009 Korea Green Energy Show PV Conference, October 2009
48 Korea PV Industry: A Sleeping Giant?, http://www.semi.org/en/P043116
49 Based on 1€ = 1500 KRW (http://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)

4.5
Taiwan[50]

Taiwan is the fourth largest producer of solar cells with annual revenues of approximately €1.5 billion in 2009 and further significant growth is expected (82% growth in 2010 targeted)[51], which will result in it becoming the second largest producer, behind China . The majority (97%) of this is exported and indigenous investment in photovoltaics is low, similar to China.

The Taiwanese government is driving further development of its photovoltaic industry and has identified supply chain issues (silicon supply) and cell performance as issues to address. A solar cell technologies roadmap has been developed and the Photovoltaics Development Centre at ITRI is leading national research programmes. These are focusing on silicon (bulk, thin film and polycrystalline), thin film (e.g. CIGS) and dye sensitised solar cells, with clear efficiency targets established for each material. These are similar to the targets set in the IEA Roadmap[54].

The government has also set a target of obtaining 1.8% of the country's energy needs from photovoltaics by 2025 (1,000 mw) and the Taiwanese Bureau of Energy does offer subsidies of 50% to householders and businesses investing in solar energy and 100% to public sector photovoltaics projects.

4.6
Analysis of Initiatives and Transferability to Europe

The activities in these countries reflect dual approaches, similar to Europe – development of the solar energy generation capacity through a

[50] Taiwan PV Industry Overview, Dr Joeng-Shein Chen, Taiwan Photovoltaics Industry Association and Photovoltaics Technology Center, ITRI
[51] http://social.cpvtoday.com/industry-insight/taiwan-ramps-pv-production

Programme	Originator	Description	EU Implementable	Explanation	Investment Scale
Solar Energy Technology Programme	US DOE	Technology, manufacturing and market development programme	High	Already the European Commission is investing in the technology development aspects - it needs to extend this to focus on manufacturing technology and market development.	€100's millions
Photovoltaic Development Programmes	Japan NEDO	A range of technology, manufacturing and market development programmes.	High	As above	€100's millions
BIPV Programme	China	Financial support for grid connected rooftop and BIPV systems	Low	These programmes offer grants for the installation of PV facilities - as such these are different support strategies than the European Feed-in tariff approach.	
Golden Sun	China	Financial support for grid connected, and in rural areas off grid systems.	Low		
Demonstration and Installation Projects	China	Financial support of additional facilities up to 800 MW	Low		
Feed-in Tariffs	Korea	Payment for energy supplied to the grid	High	Already in place	
Solar Roof Programme	Korea	Financial support of up to 60% for new installations	Low	Grant based programme - as such a different strategy to Europe	
PV Development Programme	Korea	Technology and infrastructure development and dissemination	High	Already the European Commission is investing in the technology development aspects - it needs to extend this to other areas.	€100's millions
PV Development Programme	ITRI Taiwan	Technology development programme	High	Already in place	€100's millions
Installation Programme	Bureau of Energy Taiwan	Financial support of up to 100% for installation projects	Low	Grant based programme - as such a different strategy to Europe	

Figure 17: Initiatives Elsewhere and Transferability to Europe

number of incentives (underlining the poor cost competitiveness of existing technologies) and, in the developed economies, significant investment in research and development to achieve enhanced cell efficiencies and lower cost energy generation. China however does not follow this model as it is focusing on production of established technologies rather than developing enhanced technologies. This is summarised in the table shown in Figure 17, which also assesses the transferability of these initiatives to Europe.

The Solar Europe Industry Initiative[30] has prepared an action plan for Europe which is similar to initiatives elsewhere. It proposes support of technology development and systems integration and estimates a budget of €1,300 million to fund its programme.

The consistency between the current and proposed initiatives of the developed economies is quite predictable as these nations are regularly contributing to global foresighting and industrial development activities, through for example the International Energy Agency.

The increasing importance of China and Taiwan for photovoltaic systems manufacture (already 50% of global output in 2015 and expected to increase), while their indigenous demand is extremely low, is a notable difference from Europe and other developed economies. The expected increasing dependence on China, Taiwan and other (low cost) Far East countries for photovoltaics manufacturing is a major issue for Europe to consider. It is interesting to note that both the USA and Japan have set objectives or targets for development of their indigenous manufacturing industries. It is logical that a competitive position for Europe in photovoltaics manufacturing is also identified - this is likely to be based on exploitation of new technologies, thus underlining the importance of technology development activities.

Europe's Current and Future Perspectives for Market Positi-oning in Identified Green Photonics Areas and Related Applications

5

5.1 SWOT Analysis – Current Perspectives for Market Positioning

The current competitive position of Europe in the global photovoltaics market is summarised in the SWOT analysis below.

This is a composite analysis covering all current photovoltaics technologies – the potential for different technologies is discussed in Section 5.3.

Strengths	Weaknesses
• Strong policy drivers for renewable energies • Public sector commitment to support renewables • Strong R&D capability in key technologies • Significant R&D programme funding • Established global research and industry players • Expertise in associate materials and electronics technologies • Installation and management capability	• High cost manufacturing base • Reduced dependency on imported solar cells • Fragmented industrial base and supply chain • Lack of investment for commercialisation • Lack of investment for new manufacturing facilities • Variable and unpredictable incentive structure • Weak interaction with building and construction sector • Unsupportive building regulations • Variability in requirements and regulations across Europe
• Continued exploitation of new technologies - in silicon, thin films and emerging systems • Implementation of "breakthrough" technology • Development of customised systems for BIPV • Establishment of stable sustainable incentive regime	• Competition from low cost Far East manufacture • Widespread adoption of basic standardised PV cells • Large investment in R&D elsewhere • Large investment in demonstrator facilities elsewhere • Attractive incentive regimes elsewhere • Unattractive incentive regime in Europe
Opportunities	**Threats**

Figure 18: SWOT Analysis for European Photovoltaic Industry – Current Position

If new technologies can be developed and adopted in Europe to enhance the efficiency of silicon and thin film based solar cells then the current competitive weaknesses in manufacturing and in investment conditions are likely to be overcome, resulting in a stronger competitive position for Europe.

5.2

Market Development

There have been a number of analyses of the potential growth of photovoltaics under different scenarios. Significant growth in the adoption of photovoltaics is projected by a number of commentators. These include EPIA, Greenpeace and the International Energy Agency (IEA) and have been summarised by the EC JRC[52]. Each analysis tends to consider a number of different scenarios. Taking the EPIA/Greenpeace analysis as a representative example, it used three scenarios:

1. **Reference:**
   The reference scenario used in the IEA 2009 World Energy Outlook Analysis
2. **Accelerated**
   This scenario is based on "business as usual" market behaviour when existing support mechanisms continue.
3. **Paradigm Shift**
   Photovoltaics is producing 12% of Europe's (and other regions) energy needs by 2020.
   This scenario follows strengthening of current support levels, strong political support and introduction of a number of administrative and incentive measures

The different projections resulting from these scenarios are shown in Figure 19.

These scenarios underline significant long term growth potential for photovoltaics. They are, however, primarily linked to political and policy drivers and incentives, and the support of the investment community. They are less dependent on the development of improved photovoltaics technologies.

[52] For example see EPIA document "Global Market Outlook for Photovoltaics to 2014, May 2014 update" (see ref. 24), EPIA/Greenpeace report "Solar Generation 6 – Solar Photovoltaic Electricity Empowering the World" (see ref.3), The IEA Technology Roadmap for Solar Photovoltaic Energy (see ref. 15) and the EC JRC PV status report 2010 (see ref.4)

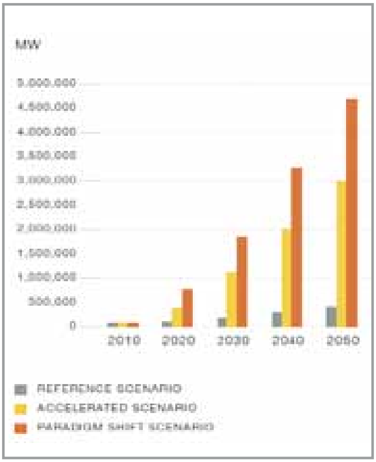

Figure 19:
Scenarios for the Global Growth of PV

So it is important to assess how photovoltaic (and photonics) technology developments are linked to these scenarios.

Firstly there is, underpinning these projections, an assumption that the cost of solar energy generation will continue to decrease – as, for example, presented by EPIA[53], as shown in Figure 20, where the horizontal lines are nominal target costs.

So these future scenarios assume that the improvements in cell efficiencies predicted by industry representative groups are achieved. This is critically dependent on development and implementation of the new and enhanced technologies listed in Section 3.

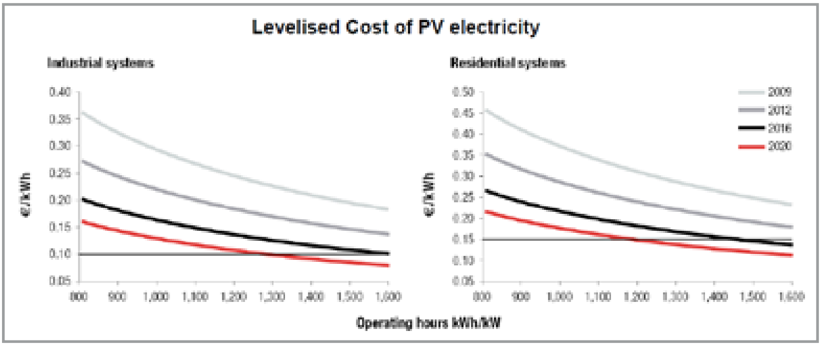

Figure 20: Projected Costs of Photovoltaic Generated Electricity

These cost reductions will be based on enhanced photovoltaic efficiencies and lower cost manufacturing - two aspects, where, as already highlighted, photonics has a major role. It is expected by the industry that 50% of cost reductions will be achieved by enhanced cell designs / lower efficiencies and 50% by economies of scale. These assertions underline the need

[53] SET for 2020: Solar Photovoltaic Electricity Mainstream Energy Source by 2020. EPIA and A. T.Kearney, 2009

to develop, demonstrate and gain investment in large scale processes and develop materials, device and processing capability in parallel.

Further, it is assumed that all key technologies highlighted in Section 2 will co-exist, as each will find its place in the market.

However, as already indicated in Figure 11, it is predicted that China (and other Far East countries) will take a major share of this growing photovoltaics market. So the benefits for Europe will be critically dependent on the performance and cost of new technologies and how they compete with existing competitive solutions. This is discussed further in the SWOT Analysis for Future Market Perspectives in Section 5.5.

The requirement for feed-in tariffs underlines the current uneconomic nature of photovoltaic energy production. The commercial objective for the photovoltaic industry is to achieve competitiveness with electricity grid retail prices (grid parity). The IEA[54] has developed projections on when this will occur, as summarised in Figure 21.

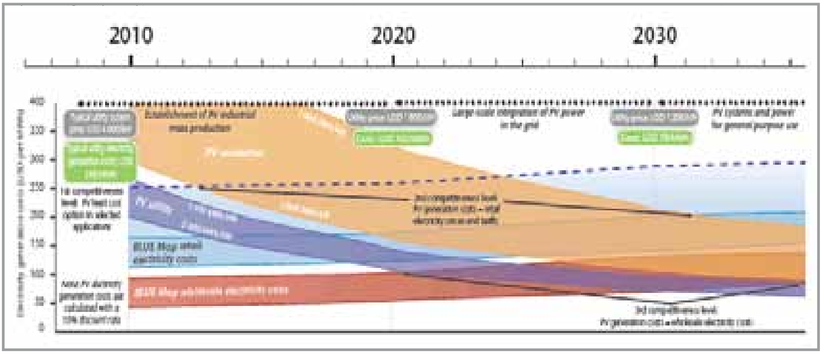

Figure 21: Projections for Competitiveness of Photovoltaic Energy Generation

This shows, based on a number of assumptions, how photovoltaic energy generation will achieve competitiveness in different applications. It is already competitive in selected niche application and is expected to achieve competitiveness with retail electricity prices before 2020 and with wholesale electricity costs before 2030. Therefore, as cost competitiveness is the key challenge and barrier for the photovoltaic industry, this has driven a

[54] Technology Roadmap, Solar Photovoltaic Energy, International Energy Agency, 2010

strong focus on enhancing the cell efficiency (the conversion of light to energy) for all types of photovoltaic cell – typically quantified in €/watt.

5.3
Future Market Potential – Key Technologies

It is fully expected that each of the different photovoltaic technologies described in Section 2 will gain a market share. The significant variations in climate and sun conditions in Europe demand different technologies so it is unrealistic to assume that one approach can be optimum in all conditions. The actual market share will be critically dependent on the technology advances that enable enhanced cell efficiencies to be achieved and the ability to win investment in different technologies. Industry analyses indicates, as already shown in Figure 10, that silicon based cells will remain the dominant photovoltaic system in the period to 2020, at which point a market share in excess of 60% will be retained. It is further assumed that different thin film technologies will achieve a combined market share of over 20% with emerging technologies (concentrator photovoltaics and organics) having the remaining share of the market.

Concentrator technologies are expected to gain a significant market in the Mediterranean countries, with an estimated 4.5 % market share by 2020.

As already indicated, organic photovoltaics is considered a “long-term play” and is expected to develop larger volume markets in the future once performance has been demonstrated in niche applications, as shown in Figure 22:

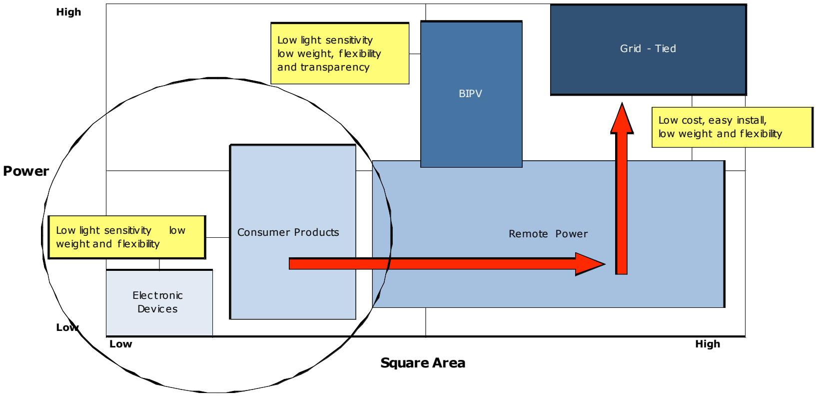

Figure 22: Expected Development in Organic Photovoltaic Technologies[55]

The expected market growth of these novel technologies is presented in the Organic and Large Area Electronics Strategic Road Map[56] as shown in Figure 23. It predicts that OPV global market share will begin to develop in 2013 and will hold a larger market share than any of the other thin film approaches by 2023. These estimates are considered to be optimistic by parts of the industry.

Recently, Lux Research has published a report[57] that asserts that organic photovoltaics will remain a niche technology until 2020 at the earliest, with a market size between €25 million and €360 million depending on the assumptions used.

Figure 23: Expected Growth in Thin Film and Novel PV Technologies

Industry feedback indicates that these predictions are as accurate as can be expected at this stage in the development of these technologies.

[55] Adapted from Konarka data presented by ECN at EC funded workshop on Nanotechnology in Photovoltaics, Aix Les Bains, September 2010
[56] Towards Green Electronics in Europe, Strategic Research Agenda – Organic and Large Area Electronics, Photonics 21, OE-A, EPOSS and Opera, November 2009
[57] Looking for a Future in Organics Photovoltaics, Lux Research, April 2011

5.4
Future Market Share for Europe

It has already been shown in Figure 19 that the global market for photovoltaics is predicted to grow significantly. However, it is also expected that European manufacturers will win a decreasing share of the market as the Far East manufacturing capability continues to develop.

Figure 11 shows how the production capacity in different global regions is expected to develop for the period to 2015 and indicates that by 2015 the Far East is expected to hold a 50% market share, despite the fact that Europe is the major regional market and that there are significant incentives in Europe (i.e. feed-in tariffs) for development of photovoltaics. This is due to feed-in tariffs supporting photovoltaic energy generation, rather than manufacture, and the low cost of supply from the Far East, as already discussed. Furthermore, recent market developments, such as the risk-averse nature of the investment community, has led to growth in the market share won by silicon technology, the major focus of the Chinese photovoltaic manufacturing industry. In addition, recent developments such as the trio of public Chinese companies, have formed a new photovoltaics-focused investment consortium with access to a €7.7 billion credit facility to target the European market[58] simply underlines the increasing growth and market share of the Chinese photovoltaic manufacturing industry.

[58] http://optics.org/news/2/6/20

5.5
SWOT Analysis – Future Perspectives for Market Positioning

The future perspectives for market positioning can be presented as follows:

Strengths

- Renewable energy established in the market
- Strong policy drivers for renewable energies
- Strong R&D capability in key technologies
- Significant R&D and innovation programme funding
- Established global research and industry players
- Strong organic chemistry and electronics sectors
- Developing advanced manufacturing sector
- Expertise in associate materials and electronics technologies
- Installation and management capability

Weaknesses

- High cost manufacturing base
- Ongoing dependency on imported solar cells
- Fragmented industrial base and supply chain
- Lack of investment for commercialisation
- Lack of investment for new manufacturing facilities
- Variability in requirements and regulations across Europe

Opportunities

- Development of novel technologies (e.g. organics)
- Implementation of "breakthrough" technology
- Local manufacture facilities of Far East companies
- Flexible PV for zero carbon devices
- Establishment of stable sustainable incentive regime

Threats

- Competition from low cost Far East manufacture
- Far East investment in emerging technologies
- Widespread adoption of basic standardised PV cells
- Large investment in R&D elsewhere
- Large investment in demonstrator facilities elsewhere
- Attractive incentive regimes elsewhere
- Unattractive incentive regime in Europe

Figure 24: SWOT Analysis - Future Perspectives for Europe

The above comments and analysis suggest that the opportunities for European manufacturing to grow its market share are dependent on a number of factors. These include:

1. Market penetration of new technologies where Europe is currently in a strong competitive position – however, as already highlighted for some key areas (e.g. OPV) this is expected to develop over a longer timescale than that defined for this study.
2. The level of investment in Far East manufacturing capacity and in developing manufacturing capacity for emerging technologies

3. Reduced product (module) cost – which will make manufacture in the Far East for supply to the European market increasingly costly.
   It has been suggested by some commentators[59] that transport costs will become an increasing issue in the future as module costs reduce and this will drive the growth of a European photovoltaics assembly industry, possibly owned or jointly owned by Far East manufacturers.
4. The development of demand for building integrated photovoltaics (BIPV). This is likely to drive the development of country specific requirements, to meet national building regulations, and thus develop a demand for a wide range of photovoltaic panels. It is suggested by the industry that this can only be addressed by regional / national suppliers. However, a revised incentive regime is likely to be required for the BIPV market to grow significantly.

Therefore, two very contrasting scenarios can be presented for the European photovoltaic industry. If Europe is successful in developing, commercialising and investing in newer and emerging technologies and if product costs continue to reduce significantly then development of a strong European industry, based on indigenous development of technology and inward investment of end product market manufacturing facilities, can be envisaged. In contrast, if Europe is unable to develop and introduce new technologies to the market, product cost reductions are minimal and the investment community continues to show a risk-averse nature then a continued dominance of standardised silicon photovoltaic modules and an increased market share for the Far East supply base can be foreseen. The behaviour of the European industry and the investment it can attract will be the key factors influencing which outcome prevails.

[59] Evidence from the industry stakeholder interview programme carried out as part of this study

Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

6

6. Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

The take up of green photonics and the development of a dynamic photovoltaics industry will offer significant socio-economic and environmental impacts, as follows:

6.1 Economic Impacts

It is estimated[25] that thirty full time equivalent jobs are created for each megawatt of solar power modules manufactured and installed. Analysis of European production capacity[27] suggests growth from 5,000 to over 10,000MW between 2009 and 2015. This conservative estimate (as it excludes installation of solar cells manufactured elsewhere) suggests 150,000 additional jobs by 2015. If EPIA's "paradigm shift" scenario to 2020[25] is considered, resulting in an annual global market of 125,000MW and Europe retains its 14.6% share of manufacturing[27] then 397,500 additional jobs will be required in Europe compared to 2009 figures. This is higher employment than the figure of 290,000 for whole photonics industry in 2008[60]. To date no data has been sourced to separate manufacturing (photonics) jobs from those linked to installation.

Published evidence on the potential growth of Gross Domestic Product (GDP) was not available. However, Gross Value Added[61] (GVA) can be used

[60] Photonics In Europe, Economic Impact, Photonics 21 and Optech Consulting, December 2007
[61] Gross Value Added is the difference between the value of goods and services produced and the cost of raw materials and other inputs which are used up in production while Gross Domestic Product is the sum of all the Value Added by all activities which produce goods and services – see http://

as an alternative to indicate the potential benefit to Europe of a dynamic photovoltaics industry. If a figure of €54,165 is assumed for the GVA of each job in photovoltaics manufacture[62], then this leads to an increase in the GVA of the European photonics industry of €21.53 billion. In comparison, the output of the photonics industry was valued at €55 billion in 2008[63].

This, of course, assumes that there are no raw materials or manufacturing issues which inhibit such growth. In terms of raw materials, there are no major issues arising. Silicon availability is expected to be good for the foreseeable future. Furthermore, there are a number of technology development projects[31] which are identifying routes to reduce the consumption of silicon in solar cells, without reducing efficiencies that will effectively extend the capacity.

As already indicated, there are, however, issues with some of the other key materials used in thin film photovoltaics or in solar cell structures (e.g. TCO layers), such as Indium and Tellurium[19]. This source indicates that the supply risk is considered critical or near critical in the short and medium term (less than 15 years). There are further concerns due to China being a key source of these materials. There are also technology development projects underway[31] to identify and assess alternative materials for e.g. Indium and other work underway[59] to identify alternatives to CIGS, such as Copper-Tin-Zinc (CuSnZn).

Currently photovoltaics is not dependent on rare earth metals[19], although some research and development projects are assessing the potential of some rare earth metals in novel solar cell structures[31].

Similarly Europe is in a strong position regarding photovoltaics processing and manufacturing technology, with a number of leading companies which are currently supplying global markets.

www.statistics.gov.uk/about/glossary/economic_terms.asp
[62] Electronics, Photonics and Electrical Systems Strategy, UK Technology Strategy Board, 2008
[63] Photonics – A Key Enabling Technology for Europe, High level strategy Group on Key Enabling Technologies, Final Report, July 2011

6.2
Social Impacts

In terms of social impacts, photovoltaics offers practical low cost options for provision of (off-grid) electricity to those who do not yet have access to the grid, thus providing a basic utility. This is recognised in some of the feed-in tariff structures in other regions (e.g. China) which offer higher support for off-grid systems.

6.3
Environmental Impacts

The adoption of photovoltaic systems will offer a massive environmental benefit.

It is estimated (see Figure 19) that photovoltaics could product 12% of Europe's energy by 2020. This is 60% of the 2020 target for renewable energy. Energy consumption in 2020, assuming the 20% energy savings target, is estimated at 1,574 million tonnes of oil equivalent (Mtoe)[64],[65] so the share for photovoltaics would be 189 Mtoe.

The manufacture of photovoltaic systems produces less than 50g CO_2 equivalent/kWh,[66] showing it to be a very environmentally friendly energy solution, a shown in Figure 25[67]:

[64] Energy Savings 2020, Ecofys and Fraunhofer ISI, September 2010.
[65] The tonne of oil equivalent is a conventional standardised unit for measuring energy, defined on the basis of a tonne of oil with a net calorific value of 41 868 kilojoules/kg.
[66] Harmonisation of LCA Studies, Kim, Fthenakis et al, National Renewable Energy Laboratory, 03/11/2010
[67] Photovoltaic Energy – Electricity from the Sun, EPIA, April 2010

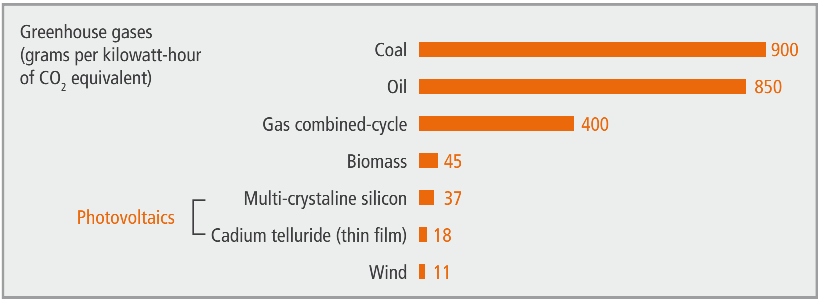

Figure 25: Comparative Environmental Impact of Photovoltaics

EPIA and Greenpeace[25] have developed estimates of the potential CO_2 reduction in each of the three scenarios prepared for photovoltaics market development (see Figure 19). It is estimated, based on the assumptions made on the CO_2 equivalent emissions of the typical mix of electricity generation methods, that photovoltaics could save 540 million tonnes in 2020, over 800 million tonnes of CO_2 equivalent in 2025 and over 4 billions tonnes in 2050. The cumulative impact is 2 billion and 65 billion tonnes of CO_2 equivalent saved over the periods to 2020 and 2050 respectively. These figures are all based on the "paradigm shift" scenario, as defined in Figure 19. It is estimated that the reference and accelerated scenarios shown in the same figure will lead to cumulative CO_2 reductions of around 8 and over 40 billion tonnes respectively.

The potential saving in 2020 is equivalent to 49% of the 2020 target for green house gas emissions.

It is also important to consider the availability, toxicity, recycling of, and legislative pressures on, materials used in photovoltaics systems. The availability of materials has already been discussed in Section 2 (see Figure 5) and activities to develop alternatives systems to CIGS where there are the most significant availability concerns has also been highlighted (see Section 3).

Toxicity is also a concern as one of the key thin film technologies uses cadmium which is recognised to have toxicity issues. Currently the market share of CdTe thin film technology is low and is expected that this market share is unlikely to grow significantly in the future as more cost effective and/or environmentally friendly options will be preferred.

Activities to develop recycling of used photovoltaic panels are already underway with the industry setting up PV Cycle to implement its commitment to establish a voluntary take back and recycling programme for end of life modules and PV modules in the supply chain. PV Cycle will use established processes for the recycling and reuse of a number of the components of silicon and thin film photovoltaic panels, such as silicon, glass, aluminium and a variety of semiconductor materials[68].

There have been significant recent legislative pressures as the historic exemption of photovoltaics from the EU Restriction of Hazardous Substances (RoHS) Directive has been reviewed. This was a major issue for the manufacture of CdTe panels. However the EU Parliament decided to retain the status quo in 2010[69] so the established exemption continues.

[68] http://www.pvcycle.org/index.php?id=3

[69] "Cadmium won't be banned under RoHS, as lobbyists battle it out", PV Magazine, 24/11/2010

Contribution to 2020 Low Carbon Energy Targets

7

7. Contribution to 2020 Low Carbon Energy Targets

The low carbon economy targets set for Europe[70] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

Photovoltaics has a major contribution to make in achieving a 20% share of renewable energies in EU energy consumption by 2020. EPIA asserts[39] that by 2020 ***"a 12% market share for PV is a demanding, but achievable and desirable objective"*** (60% of the 2020 target) while the European Commission SET Plan[71] defines a 15% target for photovoltaics.

Further, EPIA calculates that a cumulative saving of 2 billion tonnes of CO_2 will be achieved by 2020 compared to generation of electricity using the current generation mix if the 12% market share is achieved. The 2020 saving of 540 million tonnes of CO_2 equates to 49% of the 2020 target for green house gas emission reduction.

[70] EUROPE 2020, A European strategy for smart, sustainable and inclusive growth, European Commission, March 2010
[71] Investing in the Development of Low Carbon Technologies (SET Plan) – A Technology Roadmap, SEC (2009), 1295, 07/10/2009

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

8

8.

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

The key driver of the photovoltaic industry, as already stated, is lower cost energy generation and the development needs to achieve these are discussed above. New technologies are under development, are becoming available and are being adopted where practicable. The investment by the European Commission and national governments in R&D programmes has catalysed significant development activities. However, there are a number of issues affecting uptake, including:

- **Cost of Photovoltaic Energy Generation**
  This is based on a combination of current device performance, manufacturing efficiency and resultant product cost. Companies are investing in product, process and automation technologies, but the development of the photovoltaics market remains dependent on incentives. This is expected to change in the 2013 – 2017 period with Italy expected to be the first country in Europe to achieve grid parity, with other countries following soon after[72]. This will be achieved by reductions in the costs of photovoltaics combined with increasing costs of energy generated by other technologies (these are already high in Italy and expected to double in the UK by 2017). However, achieving the "holy grail" of grid parity addresses only one issue – the major issue of investment risk remains, as discussed below.

- **Competition**
  As shown in Figure 11, the Far East has already become the major manufacturing region for photovoltaics, a situation which reflects many other more established sectors (e.g. displays, LEDs and electronics in

[72] Solar Photovoltaics Competing in the Energy Sector –On the Road to Competitiveness, EPAI, September 2011

general). This trend is expected to continue in the foreseeable future due to the significant investment in photovoltaic manufacturing capacity, as already described.

Industry highlights the generous support infrastructure in China (e.g. €billion loan and credit facilities, sometimes provided at 0% interest[73]) and scale of financial and manpower resources available which enables the Chinese photovoltaics industry to grow at significant rates.

However, the logic of continuing to transport photovoltaic modules from China to Europe is being openly questioned, especially as transport is becoming an increasingly significant cost as module costs reduce.

- **Investment Risk**

Development of the scale of Europe's photovoltaics industry is critically dependent on the investment community – for investment in manufacturing facilities and in generation capacity. The investment community is currently taking a short term low risk approach, leading to a preference in proven technology (i.e. silicon). According to industry players[74] there is an unwillingness to invest in other technologies as there is a lack of trust due to a lack of evidence of reliability and lifetime performance and Chinese companies have had to take out third party guarantees of performance to ensure investment.

Further, according to industry stakeholders, there is anecdotal evidence in Europe of investment in manufacturing capability but a subsequent reluctance to invest in generation capacity. This has led to the viability of some manufacturing facilities being undermined

This issue also extends to upscaling laboratory scale technology to production capacities. If investment in established technology is difficult to obtain, the support of technology commercialisation is even more difficult.

Thus there is a major question about how to overcome the risk of investment in new technology.

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[73] Survey of Photovoltaic Industry and Policy in Germany and China, Grau, Huo and Neuhoff, Climate Policy Initiative, March 2011

[74] Participants in stakeholder interview programme

- **A Stable Financial / Incentive Regime**
  The development of photovoltaics remains critically dependent on the incentives available. But these tend to vary significantly from country to country, by type of installation and over time. The impact in investment in PV has already been demonstrated. This is a major issue for investors due to the timescales required to achieve pay-back from investment in photovoltaics. A clear, guaranteed, long term incentive system would offer significant benefits to investors. There is currently a fear that there will be future changes in public policy, driven by current economic conditions, which is reducing the appetite in investment.

- **Lack of Awareness**
  It is claimed that there is a lack of awareness of the potential of photovoltaics, despite the activities of organisation such as EPIA and the PVTP. It has been asserted by the industry that photovoltaics offer the optimum short term option to increase generation capacity but this is not recognised by the wider community. Further the potential of photovoltaics is not recognised by those who can catalyse its increased adoption, such as architects and others involved in the building industry. Some photovoltaics companies have taken independent steps to overcome this issue – for example the UK company, Romag has developed a training course on photovoltaics for architects which offers continued professional development credits. An industry wide initiative may however offer wider benefits.

- **Current and Potential Supply Chain Gaps**
  As already indicated there are concerns about the long term availability of some key materials. In addition, a number of new manufacturing technologies (e.g. R2R processing where there is a limited European company base) are required to optimise the potential of photovoltaics. Integration to the "Grid"

  Typically for renewable energies there have been connection and administrative difficulties in linking to the electricity grid (and thus generating income).

- **Regulation, Standards and Certification**
  For example it has been identified that certification can be a particular problem with building integrated photovoltaics (BIPV) should certification requirements not be revised, so it becomes an encouragement rather than a barrier.

Analysis / Ranking of Barriers

The barriers discussed above can be tabulated as follows:

Barrier Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
PV Generation Costs	Technical and Financial	High	Immediate	High	The current costs of PV electricity generation are uncompetitive with other generation technologies.
Competition	Industrial	High	Immediate	Very High	The PV manufacturing industry is migrating to the Far East. Despite Europe being the major market for PV, product supply is increasing coming from the Far East. Feed-in tariffs are currently supporting Far Eastern rather than European industrial development.
Investment Risk	Financial	Medium	Immediate	High	There is a reluctance for the investment community to support anything other than proven technology - thus inhibiting developing PV technologies and exploitation of R&D
Incentive Regime	Financial	High	Immediate	High	Incentives are available but they vary from country to country and are likely to change at any time. This leads to uncertainty in the market which inhibits investment.
Awareness	Information	Medium	Immediate	Low	Potential users and investors are unaware of the potential of photovoltaics.
Supply Chain Gaps	Industrial	High/ Medium	Mid-term	High	Development of manufacturing capability for implementation of novel technologies is required - placing demands on the RTD and investment communities.
Grid Integration	Market	High	Mid-term	Unknown	Development of effective gird connectivity is required for PV (and other renewables). This could have a fundamental impact on the current grid system and requires significant attention.
Regulations, Standards and Certification	Standards	Medium	Mid-term	Low	It is recognised, particularly for BIPV that different products are required in each country - to fit with building regulations

Figure 26: Classification of Barriers

The fundamental barrier to the development of markets for photovoltaics is the comparatively high cost of energy generation – the €/watt data. The focus of the majority of development activities is to reduce these costs.

There have already been great improvements in both device and manufacturing efficiency - evidence from the industry underlines that efficiency has systematically increased as photovoltaics output has grown – but a combination of more efficiency improvements and cost reductions are required to achieve grid parity. A significant investment in new capacity would, based on this evidence, have a concomitant impact on photovoltaics efficiency, leading to further opportunities – essentially creating a virtuous circle. The investment required to address this challenge is already significant and is expected to continue, as defined by the Solar Industry Initiative. This highlights a key barrier – the investment community's attitude to risk, especially when linked to newer technologies. The industry has indicated that this factor has already significantly affected the potential of photovoltaics.

Thus, in the interim financial incentives and market development mechanisms are critical to the adoption of photovoltaics. The impact of such incentives to date in Europe is well established, although support to date has been variable and, in some cases, short lived. Obviously these national incentive schemes have addressed the cost competitiveness of photovoltaics and catalysed investment, but as highlighted above, these could be significantly improved. The development of a stable, long term, transparent, pan-European incentive structure would provide clarity that the financial and business communities would welcome when making investment decisions.

Potential Intervention Options

9

9.
Potential Intervention Options

The major barriers to development of the photovoltaics industry, as shown in Figure 26 above, have been assessed and the following actions to address these barriers have been identified:

1. **PV Generation Costs** are currently not competitive with other electricity generation technologies, although this situation is likely to change over the period from 2013 to 2020. These improvements will only be achieved through developments in product and process technology that will result in cell efficiency and electricity generation cost improvements. Therefore key initiatives to overcome these barriers are
   a. **Research, development and innovation programmes,** focusing on materials, device and manufacturing development. These programmes should support all PV technologies (including longer term emerging technologies where Europe is currently in a strong R&D position), effectively continuing the type of support currently provided by the European Commission and national programmes.
   b. **Near market product development programmes,** such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe. In the short term these programmes should focus on technologies (see Section 3, above) that will enhance the performance and manufacturing of silicon, thin film and concentrator technologies

2. **Competition,** as the Far East becomes the dominant manufacturing region for photovoltaic systems. To quantify the situation, the recently published PV Status Report 2011[75] estimates that by 2015 the Far East will be responsible for over 70% of world-wide PV manufacturing capacity.
   It is important that Europe responds to this situation by encouraging development of its indigenous manufacturing capacity. This can be achieved by
   a. **Capital Grant Programme,** focusing on materials and device manufacturing equipment to develop European manufacturing capacity. This should be a long term programme that supports all PV technolo-

[75] PV Status Report, 2011, European Commission JRC, 2011

gies. In the short term the focus should be on silicon, thin film and concentrator technologies while in the longer term it should support development of manufacturing capability for newer technologies where Europe is currently in a strong R&D position (e.g. organic photovoltaics and roll to roll processing technologies).

b. **Development of novel incentive schemes,** which would encourage development of European manufacturing capacity. For example it has been highlighted[76] that BIPV is dependent on the building specifications and regulations in different countries and thus requires customised approaches rather than standard panels. These national regulations are listed as a barrier in figure 26, but if incentive schemes were developed to encourage BIPV they would encourage national activity to address national markets, so this intervention transforms the issues of national regulations into an advantage for indigenous suppliers of customised products.

3. **Incentive Regimes** that are different from country to country and tend to be changed without warning depending on the political priorities in each country. This leads to uncertainty, which inhibits investment.
   A coherent Europe wide incentive regime that is guaranteed for an agreed period, linked to the achievement of grid parity, should be implemented. The incentive regime should be designed to reflect the different market conditions in different countries (e.g. weather conditions, gap to grid parity, etc).

4. **Supply Chain Gaps** in the European photovoltaics industry that relate, for example, to the availability of some key materials (e.g. III-V materials and organics) and to the need for new manufacturing technologies (e.g. high volume production techniques, roll to roll processing) to support emerging technologies.
   This barrier can be overcome by
   a. Research, development and innovation programmes, focusing on materials, device and manufacturing development. These programmes, similar to 1), above should support all PV technologies, including longer term emerging technologies where Europe is currently in a strong R&D position

[76] Interview programme completed as part of this study

b. Near market product development programmes, such as proof of concept and prototype development programmes to support commercialisation of technologies under development in Europe.
c. Capital Grant Programme, focusing on materials and device manufacturing equipment to develop European manufacturing capacity.

These interventions have already been highlighted above, showing that some interventions can effectively address more than one of the identified barriers.

Grid Integration, although a high priority barrier is not assessed further in this study as it is considered to be beyond the scope of photonics technologies.

It is also worth noting that the potential interventions to address barriers 1, 3 and 4 above would also address the investment risk barrier highlighted in Figure 26.

These intervention options can be summarised as follows:

		Intervention Options						
		R&D and Commercialisation Programmes				Subsidised Market Development Programmes		Market Reengineering
		RD&I Programmes	Near Market R&D Programmes	Proof of Concept Programmes	Prototype Programmes	Novel Incentive Schemes	Capital Grant Programmes	Revised Incentive Regimes
Key Barriers to Market Development	PV Generation Costs	●	●	●	●			
	Competition				●	●	●	●
	Incentive Regime							●
	Supply Chain Gaps	●	●	●	●	●	●	
	Investment Risk	●	●	●		●	●	●

Figure 27: Potential Interventions to Address Major Barriers to Uptake

PHOTONICS TECHNOLOGIES
and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Annex 2:

Energy Efficient Lighting and Displays Technologies and Applications

1st October 2011

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Executive Summary

Executive Summary

Energy efficient lighting and displays are rapidly developing applications for green photonics technologies. Some energy efficient lighting technologies are already well proven, are competitive with established technologies and are winning an increasing share of the lighting market. New technologies are also under development. Displays have become ubiquitous with wide ranging applications in industry, medicine and consumer products. Flat panel displays have become the standard with Liquid Crystal Display (LCD) technologies dominating, although a number of Organic Light Emitting Diode (OLED) and e-paper technologies are beginning to win a small share of the market.

In this study we have focused on Light Emitting Diodes (LEDs) and OLEDs as the key energy efficient lighting technologies. LEDs are rapidly maturing in terms of technology and current developments are focusing on product design and lifetime optimisation. For displays we have considered LCD technology and the wide range of emerging new display technologies, such as OLEDs and e-paper technologies. OLEDs are an emerging technology that will address lighting and display applications. Current development activities are addressing performance, lifetime, manufacturing and application issues. E-paper technologies (such as electrophoretic displays and cholesteric liquid crystal displays) are also emerging with current developments focusing on demonstrating the potential performance of the technology.

The current global market for light bulbs is estimated at over €11 billion per annum[1]. LEDs currently hold a small share of this market, but it is expected that this will grow to around 95% market share by 2020[1]. LEDs will find applications in signs, displays and automotive applications as well as in illumination. In comparison, the LCD dominated global display market was valued at over €90 billion in 2011[2]. The current market for OLED technologies is around €1 billion but this is expected to increase significantly over the next 5 to 10 years[3]. Market values of over €6 billion are estimated

[1] J.P. Morgan Cazenove, "Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED", March 2010
[2] Global TV Trends in the Flat Panel Display Market, DisplaySearch, November 2010
[3] OLED Display and OLED Lighting Technology and Market Forecast, DisplaySearch, September 2010

for 2017[3]. Similarly the market for e-paper technologies is expected to grow to over €3 billion by 2016[4].

Europe has traditionally been strong in the lighting industry. Philips and Osram are currently leading global players and have diverse product portfolios covering traditional, LED and OLED developments. Osram was the world's third largest producer of LEDs in 2010 and Philips fourth. In addition, there are over 1,000 other companies in the industry in Europe[5]. The position in displays is not so positive with display manufacturing being well established in the Far East. However, Europe has a strong position in the OLED market space through the activities of major global materials/ chemicals companies and smaller device development and manufacturing companies. This is supported by a strong academic research and development capability.

A number of new technologies are being developed at all stages of the LED supply chain – such as improved sapphire and silicon substrates, novel down convertor materials and enhanced technologies for die and light engine performance. A number of technology developments are also being addressed for OLEDs covering materials, device, system, standardisation and manufacturing challenges. These activities are detailed in the relevant technology and industry roadmaps published.

There are major initiatives to support research and development and deployment of energy efficient lighting in the USA, Japan, Korea, Taiwan and China. In the USA these initiatives support R&D, manufacturing capacity and market development. Similarly, Japan is supporting R&D and industrial development and the government expects 100% market penetration for (O)LED lighting equipment by 2020[6]. China has made a major commitment to the development of a LED manufacturing industry and has invested billions of dollars to achieve this aim. As a result it is expected that China will become a major player in the global LED market by 2015. A key feature in all these regions is the co-ordinated approaches developed, which is in contrast to the currently fragmented position in Europe.

[4] E-Paper Opportunities 2009, NanoMarkets

[5] European Lamp Companies Federation(ELC) and the Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires (CELMA)

[6] Japanese Government, Basic Energy Plan, 2010

The European SWOT analysis for energy efficient lighting shows strong policy drivers for low carbon solutions, a strong base of leading materials, lighting and production equipment companies and an internationally recognised research and development capability. However, the fragmented, uncoordinated approach in Europe, comparatively low investments and the high cost manufacturing base in Europe means that the Far East is likely to dominate future manufacturing. As with photovoltaics, Europe's major opportunity in energy efficient lighting (EEL) is to develop new technologies and highly functional lighting systems.

Significant growth in the market demand for LEDs is expected over the next 5 to 10 years, by product substitution rather than overall market growth. It is expected that architectural markets will initially be penetrated followed by retail display and consumer markets. Predictions indicate that volume OLED based devices will only begin to emerge around 2020.

The strengths of the European display industry are its capabilities in the development of new OLED technologies, although the dominance of SMEs and the lack of a strong global brand are likely to affect Europe's ability to access large volume global markets. In a similar way to energy efficient lighting, OLED based products are expected to emerge in volumes in the 2015 to 2020 period.

It is estimated[7] that the turnover of the lighting industry in Europe will increase by over €3 billion by 2019 and that employment will increase by over 115,000 in the same period. This growth is expected to be due to new LED and OLED technologies, especially in the design, manufacturing and sales of lighting fixtures.

Energy efficient lighting and displays will offer a number of social benefits. These include improved visual comfort and light quality, improved safety, reduced light pollution and improved health.

There are clear and significant environmental benefits from adopting energy efficient lighting technologies. It is estimated that a 40% energy saving can be achieved using energy efficient lighting rather than current technologies[8]. This would lead to a saving of over 640 million tonnes of CO_2 per annum.

[7] World Lighting Fixtures to 2014, Freedonia Group Market Report, 2010
[8] "Energy efficient lighting - a summary of "Green Switch" facts", Philips, December 2007

There are a number of barriers to the development of energy efficient lighting technologies. These include high capital costs, low light / colour quality, low market awareness, financial support to competing technologies and a lack of standards. The development and adoption of new display technologies are also inhibited by technology, market and financial barriers, although technology barriers dominate, as expected for an emerging technology.

These barriers can be addressed by interventions focusing on research, development and innovation (RDI) and commercialisation programmes, subsidised market development programmes, standards development programmes and revised subsidy regimes.

In summary, it is expected that solid state lighting will hold a significant market share by 2020, based on further developments of existing technologies, driven mainly by legislative requirements. There are significant opportunities for Europe to exploit this market growth through development of its existing industry.

OLED technologies will be further developed to address opportunities in both lighting and displays, competing with other technology solutions. It is expected that display applications will be the first to develop, where OLED technologies will compete with a number of other novel technologies, some of which offer the distinct benefit of being reflective rather than emissive. Initially the focus will be on small scale displays but in the longer term large scale (e.g. signage) will also be a target for OLED and other novel display technologies.

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Notes

Exchange rates of €1.55 = £1 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source

Glossary

Acronym	Description
µm	Micrometre
µS	Microsecond
2D	Two Dimensional
3D	Three Dimensional
AlN	Aluminium Nitride
AMOLED	Active Matrix Organic Light Emitting Diode
AMEPD	Active-Matrix Electrophoretic Display
AMS	Automated Measuring System
APD	Avalanche Photodiode
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act (2009)
a-Si	Amorphous Silicon
ASP	Average Selling Price
AWG	Arrayed Waveguide Grating
BAT	Best Available Technology
BIPV	Building Integrated Photovoltaics
CAGR	Compound Annual Growth Rate
CALiPER	US Department of Energy Commercially Available LED Product Evaluation and Reporting Programme
CCS	Carbon Capture and Storage
CCT	Correlated Colour Temperature
CD/M^2	Candela per Meter Squared
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformité Européenne
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires
CEM	Continuous Emissions Monitors
CEMS	Continuous Emissions Monitoring Systems
CEN	European Committee for Standardisation
CEN TC 264	CEN Standards Committee

CFL	Compact Fluorescent Light
CFP	C-Form Factor Pluggable
CIE	International Commission on Illumination
CIGS	Copper Indium Gallium Diselenide
CIP	Centre of Integrated Photonics
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPV	Concentrator Photovoltaics
CQS	Colour Quality Scale
CRI	Colour Rendering Index
CRT	Cathode Ray Tube
CSM	Sustainable Manufacturing
CuZnSnSe	Copper Zinc Tin Selenide
CVD	Chemical Vapour Deposition
CW	Continuous Wave
DCICC	Dynamic Coalition on Internet and Climate Change
DFB	Distributed Feedback
DG ENV	Environment Directorate, European Commission
DIAL	Differential Absorption Lidar
DLP	Digital Light Projection
DMD	Digital Micro-mirror Device
DOE	Department of Energy
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electroabsorption Modulator
EBM	Environmentally Benign Manufacturing
EC	European Commission
EC JRC	European Commission Joint Research Centres
EDFA	Erbium Doped Fibre Amplifier
e-ink	Electronic Ink
EISA	Energy Independence and Security Act
EL	Electroluminescent
ELC	European Lamp Companies Federation
EML	Electroabsorption Modulated Laser
EMS	Environmental Management System
EN 15267	European Standard for Instrument Type Approval
EN 1911	Standard method for monitoring HCl
e-paper	Electronic Paper
EPA (US)	Environment Protection Agency
EPI	Epitaxy
EPIA	European Photovoltaic Industry Association

ESL	Electronic Shelf Label
ETV	Environmental Technologies Verification Scheme
EU	European Union
EU-ETS	European Emissions Trading Scheme
FBG	Fibre Bragg Grating
FEC	Forward Error Correction
FED	Field Emission Display
FP	Fabry Perot
FP8	Framework Programme 8
FPD	Flat Panel Displays
fs	Femtosecond
FTIR	Fourier Transform Infra red
FTTC	Fibre to the Kerb or Building
FTTH	Fibre to the Home
GaN	Gallium Nitride
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GDP	Gross Domestic Product
GE	General Electric
GEPON	Gigabit Ethernet Passive Optical Network
GHG	Greenhouse gas
GLS	General Lighting Service
GPON	Gigabit-Capable Passive Optical Network
gw	Gigawatt
HB-LED	High Brightness Light Emitting Diode
HCl	Hydrogen Chloride
HDTV	High Definition Television
HTPS	High Temperature PolySilicon
IALD	International Association of Lighting Designers
ICT	Information and Communications Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ILS	Industrial Laser Solutions for Manufacturing
InAsSb	Indium Arsenic Antimonide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infra Red
ISO	International Standards Organisation

ISO 14001	International environmental quality standard
ITO	Indium Tin Oxide
ITRI	Industrial Technologies Research Institute, Taiwan
ITU	International Telecommunications Union
JRCM	Japan R&D Centre of Metals
kg	Kilogramme
KOPTI	Korean Photonics Technology Institute
KTN	Knowledge Transfer Network
kW	Kilo Watt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LED	Light Emitting Diode
LEP	Light Emitting Polymer
LIDAR	Light detection and Ranging
lm/W	Lumens per Watt
LTE	Long Term Evolution
LTPS	Low Temperature PolySIlicon
MACT	Maximum Achievable Control Technology
MCERTS	UK Product Certification Scheme
MEMS	Microelectromechanical Systems
MIIT	Ministry of Industry and Information Technology
MOVCD	Metal-Organic Chemical Vapour Deposition
MP3	Media Player
Mtoe	Million tonnes oil equivalent
MW	Megawatt
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
NEDO	New Energy and Industrial Technology Development Organisation
NER 300	Support Programme for Installations of Innovative Renewable Energy Technology and CCS in the EU
NGLI	Next Generation Lighting Initiative
NGLIA	Next Generation Lighting Industry Association
NGO	Non Governmental Organisation
NGPON	Next Generation Passive Optical Network
NMP	Nanotechnology, Materials and Production Technologies
nm	Nanometre
NO_x	Nitrous Oxide
NPL	National Physical Laboratory
NREL	National Renewable Energy Laboratories

NRZ	Non Return to Zero
ns	Nanosecond
OEM	Original Equipment Manufacturer
OIML	International Organisation of Legal Metrology
OLED	Organic Light Emitting Diode
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPV	Organic Photovoltaics
OVPD	Organic Vapour Phase Deposition
OXC	Optical Cross Connect
PDA	Personal Digital Assistant
PDP	Plasma Display Panels
PIC	Photonic Integrated Circuit
PLED	Polymer Light Emitting Diode
PM	Particulate Monitoring
PMEPD	Passive Matrix Electrophoretic Display
PMLCD	Passive Matrix Liquid Crystal Display
PMOLED	Passive Matrix Organic Light Emitting Diode
PMP	Portable Media Player
PON	Passive Optical Network
POP	Point of Presence
POS	Point of Sale
PPE KTN	Photonics and Plastic Electronics Knowledge Transfer Network
ps	Picosecond
PSD	Power Spectral Density
p-Si	Polycrystalline Silicon
PV	Photovoltaics
PVI	Photovoltaic International
PVTP	Photovoltaic Technology Platform
QC / QCL	Quantum Cascade (laser)
QPSK	Quadrature Phase Shifting Keying
R&D	Research and Development
RDI	Research, development and Innovation
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RGB	Red, Green Blue
RMB	Chinese currency
ROADM	Reconfigurable Optical Add Drop Multiplexer

R2R	Roll to Roll
RoI	Return on Investment
SCR	Selective Catalytic Reduction
SED	Surface-conduction Electron-emitter Display
SEMI	Global Industry Association Serving the Manufacturing Supply Chain for the Micro- and Nano-electronics Industries
SERDES	Serilaiser/Deserialiser
Si	Silicon
SiC	Silicon Carbide
SME	Small and Medium Enterprise
SMOLED	Small Molecule Organic Light Emitting Diode
SOA	Semiconductor Optical Amplifier
SONET/SDH	Synchronous Optical Network/ Synchronous Digital Hierarchy
SSL	Solid-State Lighting
STN	Super-Twisted Nematic
SWOT	Strengths, Weaknesses, Opportunities and Threats
Tb	Terabyte
TCO	Transparent Conducting Oxide
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing Passive Optical Networks
TEC	Thermo-Electric Cooler
TFT	Thin Film Transistor
TDL	Tunable Diode Laser
TN	Twisted Nematic
TV	Television
TWh	Terra Watt Hour
TWI	The Welding Institute
UBA	German Type Approval Scheme
USD	United States Dollar
USP	Unique Selling Proposition
UV	Ultra Violet
VCSEL	Vertical Cavity Surface Emitting Laser
VDSL	Very-High-Bit-Rate Digital Subscriber Line
VFD	Vacuum Fluorescent Display
VOC	Volatile Organic Compound
WDM	Wave Division Multiplexing
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
WOLED	White Organic Light Emitting Diode

Introduction

1

1.
Introduction

This document, which reviews energy efficient lighting and displays, is one of a series of five reports that summarises a specific green photonics technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity. It has been prepared to address the following specific objectives and to underpin a summary report on the potential of green photonics technologies in Europe:

1. Overview of existing green photonics technologies and today's related markets and market players
2. Identification and analysis of promising new green photonics technology developments for market deployment in the period 2011-2015
3. Overview of major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
4. Analysis of Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
5. Assessment of the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
6. Assessment of how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
7. Identification and analysis of the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
8. Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries.

Each of these objectives is addressed in turn in the following eight sections of this report.

1.1 Overview – Energy Efficient Lighting and Displays

1.1.1 Energy Efficient Lighting

Energy Efficient Lighting, also known as Solid State Lighting (SSL), is perhaps the most significant advancement in illumination since the invention of the electric light bulb by Joseph Swann more than a century ago. Solid State Lighting[9] may be defined as a type of lighting that uses semiconductor light-emitting diodes (LED), organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) as sources of illumination rather than electrical filaments, plasma (used in arc lamps such as fluorescent lamps), or gas. The energy efficient lighting supply chain is shown in Figure 1[10]:

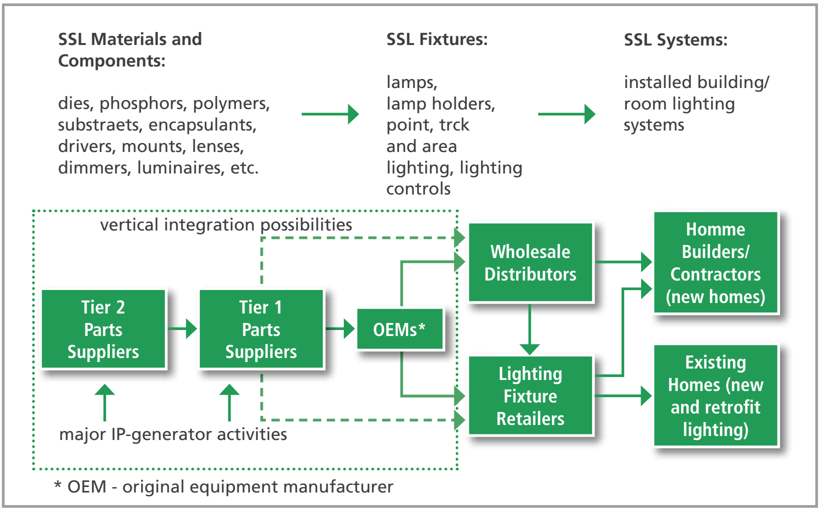


Figure 1: High Level SSL Supply Chain

9 Wikipedia - http://en.wikipedia.org/wiki/Solid-state_lighting

10 Ashdown, Barabara, "Assessing Consumer Values and Supply-Chain Relationships for Solid-State Lighting Technologies", OAK RIDGE NATIONAL LABORATORY, June 2004

Modern society relies heavily on lighting, whether at home, in the office, in hospitals, schools and universities, in other public buildings, in urban spaces or on streets and motorways. It is a vital component for productivity growth in future economies. General lighting accounts for a significant share of worldwide energy consumption at over 2600 TWh or 19% of electricity production and contributes 1900 million tonnes of carbon dioxide per year (equivalent to 70% of the emissions from the world's light passenger vehicles in 2006)[11]. The annual cost of lighting was estimated to be €275 billion[11] including energy, lighting equipment and employment, which was roughly 1% of global GDP in 2006 (with energy contributing approximately two thirds of the cost). It has been predicted that if all electrical lighting is converted to SSL by 2050 the forecast savings in global energy consumption would be 1300 TWh in 2030 and 3000 TWh by 2050, enabling a reinvestment of between €190 and €450 billion per year in economic growth rather than on fuel bills[12]. European office buildings use 50% of their total electricity consumption for lighting, while the share of electricity for lighting is 20-30% in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings[13]. Furthermore, the heat produced by lighting represents a significant fraction of the cooling load in many offices contributing to the further consumption of electricity indirectly[14].

Within the last decade the underlying technologies needed to construct high performance LED and OLED lighting systems have developed at a rapid pace leading to a disruptive position in a once mature but traditional lighting market. Initially, LEDs were used for signalling, signage or to illuminate mobile phone keypads but due to ever-increasing brightness, efficiency and quality of light, LEDs are now appearing in far more demanding applications such as street lighting and automotive headlamps.

For lighting purposes, SSL offers outstanding properties and during 2011 will outperform the majority of traditional light sources used within general lighting applications in terms of efficiency, colour quality and controllability. SSL products offer very long lifetimes, robustness, no hazardous materials (such as mercury or lead), rapid-on times, digital control

[11] International Energy Agency, "Light's Labour Lost, Policies for Energy Efficient Lighting", 2006
[12] Photonics 21, Second Strategic Research Agenda, "Lighting the way ahead", 2010
[13] http://www.ec.europa.eu/comm/energy_transport/atlas/html/buildings.html
[14] Lisa Halonen et al., "GUIDEBOOK ON ENERGY EFFICIENT ELECTRIC LIGHTING FOR BUILDINGS", Aalto University, 2010

with 100% dimming, no harmful IR or UV wavelengths, vivid saturated colours, wide operating temperature range and a significant choice of solutions for lighting applications. Despite this, approximately two thirds of all lighting currently installed worldwide is based on older, less energy efficient technology (developed before 1970) according to Philips[15].

1.1.2 Displays

In modern societies, display technologies play a prominent role in communication, education and entertainment and in recent years flat panel displays (FPDs) have dominated the market, displacing cathode ray tube (CRT) based displays. Europe is currently the largest end-user market for FPDs with demanding applications from desktop, laptop displays and TVs to a vast number of non-consumer applications such as displays for the automotive sector, health care and mechanical engineering industries.

Previously, Europe was a dominant manufacturer of CRTs, but due to the substantial capital investments required for FPD production facilities the majority of FPDs are produced in Asia. Europe still has a presence within the displays market for materials and production equipment. There is a range of interesting new display technologies at early stages such as flexible displays based on OLEDs, printed organic backplanes, pico projectors and emerging technologies such as electro-wetting displays. OLEDs are playing an increasingly prominent role in FPDs due to their increased flexibility, extremely thin and transparent surface, high colour gamuts, pixel switching speed, high contrast ratios and improved energy efficiency. Consumer based demand for ever higher quality displays and new functionality is driving FPDs to new heights and in 2010, 3D display technology reached the market, illuminated through the use of LED back light units. The scope of the display section within this report will be limited to OLED and LED backlit LCD displays. The typical displays supply chain is presented in Figure 2[16]:

[15] Philips - Energy Efficient Lighting - A summary of "Green Switch" Facts - December 2008
[16] Global TV Trends in the Flat Panel Display Market, Paul a Gagnon, DisplaySearch, 2010, www.displaysearch.com

Figure 2: Typical Displays Supply Chain

This section will identify the opportunities that exist for the European lighting and displays sector, highlighting the current market position for both technologies and incorporating the non-technical market drivers such as legislation, consumer appetite and global political focus on energy security, that are accelerating the market adoption of SSL and FPD technologies. An overview of current and promising technologies within the timeframe of 2011-2015 and 2016-2020, along with their relevant importance, will enable robust roadmaps to be clearly identified. Further focus on the barriers to the uptake of new SSL and FPD technologies will be identified along with a discussion of how global initiatives elsewhere are helping to overcome barriers to accelerate market adoption. It is important to differentiate OLED technologies for displays and for lighting as their manufacturing, application and cost requirements are substantially different for both applications. OLED technologies and processes for displays can be considered a current technology whereas OLED technologies and processes for lighting must be considered as embryonic at this time.

Overview of Existing Green Photonics Technologies and Today's Related Markets and Players

2

2.1
Existing Technologies

2.1.1 Inorganic LED lighting

Since high-powered LEDs (>1W) were introduced by Philips Lumileds in 1999, it has become increasingly necessary to dissipate the heat generated by the semiconductor, so LED packages have become more complex and adapted for heat dissipation. Packages for state-of-the-art high-power single-chip LEDs bear little resemblance to early LEDs as shown in Figure 3.

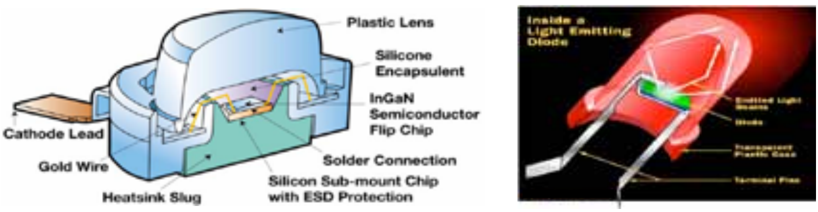


Figure 3: The different high power (left) and low power (right) LED packages
(Philips & www.ledsinside.com)

The high power LEDs usually contain a large (1mm²) semiconductor die and are placed upon a heat sink that dissipates the heat away from the chip.

In addition to Philips Lumileds, an increasingly large number of companies including OSRAM, CREE, Nichia, Sharp, Optodiode, Epitex, Edison Opto, Seoul Semiconductor, Toyoda Gosei, Citizen, Enfis, Samsung, LG and Bridgelux have developed novel power LED packages, which enable the multiple semiconductor LED dies to be operated in series-parallel strings to provide significant light output power densities. Indeed, today's white light power LED arrays have lumen efficiencies in excess of 100 lumens/watt and up to 12,000 lumens per LED package.

A number of approaches have been developed for LED applications and it is important to note that each LED emitter approach has relative advantages and disadvantages based upon thermal management criteria, required price/performance ratios and optical output density power as shown in Figure 4.

SSL Lighting Categories	Lumen Output	Optical Power Density
Entertainment	Medium-High	Medium – High
Exterior architectural	Low – High	Low – High
Interior functional	Low	Medium – High
Interior decorative	Low	Low
Feature Lighting	Medium	Medium
Art Installation	Low	Low

Figure 4: SSL lighting category lumen and optical power density requirements

LED emitter technology is rapidly maturing and many of the technical barriers have been overcome. Those remaining include:

- The price of an LED emitter package is comparatively costly
- LEDs are fabricated on small area substrates reducing potential manufacturing yields
- LED emitters suffer from a loss in performance with temperature increase so system design can be more complicated
- The performance of a LED reduces as the forward current increases, which reduces system scalability.
- Several rare-earth materials are used in the phosphor materials so long term reliance is a risk. New materials will need to be found that provide the same or better performance to convert photons in various wavelengths.
- The lifetimes of LED systems are compromised due to short-life electronic power controllers and components

2.1.2 Light Emitting Diodes

An Organic Light Emitting Diode (OLED) is an electroluminescence or light emitting device based on organic compounds. OLEDs are similar to electroluminescent lighting, in which a sheet of material is excited using electrical energy so that it emits light. Depending on the organic material used within an OLED the colour of light emitted can change and today virtually any colour within the visible spectrum can be reproduced, including white as shown in Figure 5.

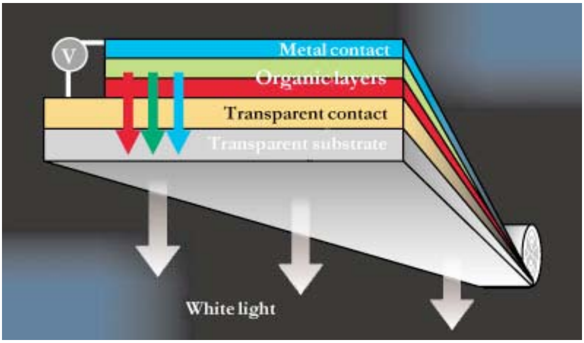


Figure 5: A schematic diagram of an OLED device producing white light

OLEDs essentially exist in two forms - small molecule (SMOLED) and polymer (PLEDS)s.

The production of small-molecule OLED devices requires specialist vacuum deposition manufacturing capabilities which makes the production process more expensive than other processing techniques. Since SMOLEDs are typically produced by evaporating layers of low molecular weight materials on glass substrates, they are generally not flexible. However, "long chain" polymer-based OLEDs use a thin film for full-spectrum colour lighting and require a relatively small amount of power for the light produced. PLEDs do not require a vacuum in order to be produced and the emissive materials can be applied directly on the substrate by techniques derived from commercial inkjet printing. This offers the potential for PLEDs to be produced inexpensively and on flexible substrates offering exciting lighting design opportunities.

There are several advantages that OLEDs possess in terms of being used as a light source, including:

- Since OLEDs can be printed onto any suitable substrate using inkjet printing or screen printing technologies, they can theoretically have a significantly lower cost
- Printing OLEDs on flexible substrates opens the door to new applications such as roll-up lighting and lighting embedded into textiles
- OLEDs enable a greater range of colours, brightness, and viewing angle
- OLED pixel colours appear correct and unshifted, even as the viewing angle approaches 90 degrees from normal

- OLEDs have large beam angles and can emit light over large areas providing diffuse and low glare lighting
- OLEDs have the long-term potential to be energy efficient compared to traditional white light sources
- They are low-voltage devices (typically 2V - 10V)
- Lightweight
- They offer a diffuse light source
- They are rugged and vibration resistant
- Offer the lighting designer a new degree of freedom to develop novel lighting effects

OLEDs are now being commercialised in small-size displays used in devices such as mobile phones, PDAs, MP3 players and TVs. Although OLEDs had offered significant advantages over TFT displays which require backlighting, the technology has taken time to mature and provide stable polymer materials with sufficient light output and lifetimes. Currently, investment in worldwide OLED research is attempting to create high-brightness, high efficiency and long life white OLEDs for lighting and signage. White light OLEDs can be generated by several approaches including:

- The down-conversion of a blue emitting OLED by organic or inorganic phosphors. Similar to a white LED that uses a blue LED with a phosphor
- The use of a stack of blue, green and red emitting layers to create a white output
- The use of intrinsically white emitting layers. Superior light quality with very high Colour Rendering Index (CRI>90) can be realised

As OLEDs are still an emerging technology there are significant challenges that will need to be resolved in order to ensure their future success across the lighting industry. The following are a few of the current disadvantages of OLED lighting:

- Low device efficiency (compared to traditional and LED lamps)
- Uniformity of light emitting layers over large areas
- Difficulty of high electrical currents evenly required over large areas
- Low Luminance outputs not yet suitable for lighting
- Poor operational lifetimes for various emitter materials
- Poor storage life due to degradation on moisture and oxygen
- Complexity of design due to limited material selections for electrodes
- Low cost manufacturing technology for large OLED devices not established

- Degradation if exposed to UV
- A new lighting infrastructure is required

Several companies are working towards white OLED light products. GE has launched OLED products and OSRAM launched in 2010 the ORBEOS OLED panel that can be used by designers to build up lighting systems. Philips has also launched its Lumiblade OLED lighting (see www.lumiblade.com) and further commercial products will arrive by 2012 from other companies involved in white OLED lighting, such as Konica Minolta (plans to have products in 2011), Mitsubishi Chemicals, Universal Display (WOLED technology), and Kodak. The expected timescales for market introduction of these products are shown in Figure 6.

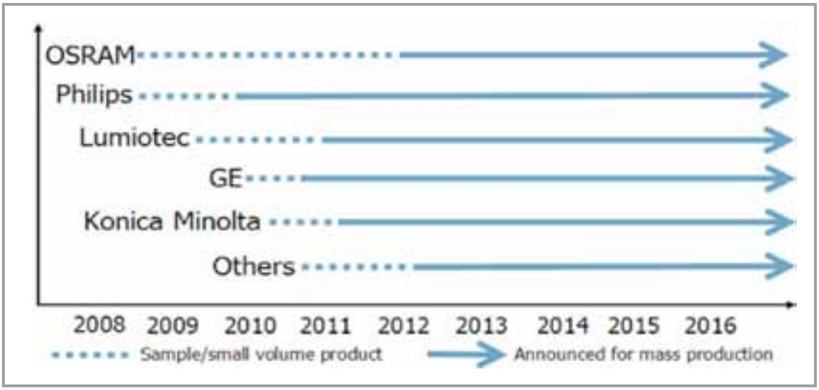


Figure 6: OLED Industry Market Development Plans

2.1.3 Compact Fluorescent Lamps (CFL)

Compact Fluorescent Lamps is an established lighting technology that has seen market growth recently despite poor user market acceptance due to significant Government market incentive programmes. China has dominated CFL production for more than a decade. Over 80% of CFLs are produced in mainland China and 10% in Chinese Taipei. Production also takes place in Europe, Japan and Korea, with new production centres emerging in countries such as India, Indonesia, the Philippines, Egypt, Dubai and South Africa. Global CFL production output increased by 70% from 2005 to 2007 and reached approximately 4 billion lamps in 2009. Figure 7 demonstrates the efficiency of CFLs compared to Incandescent and early LED lamps.[17]

[17] US Department of Energy report "Energy Star CFL Market Profile: Data Trends and Market Insights", Sept, 2010

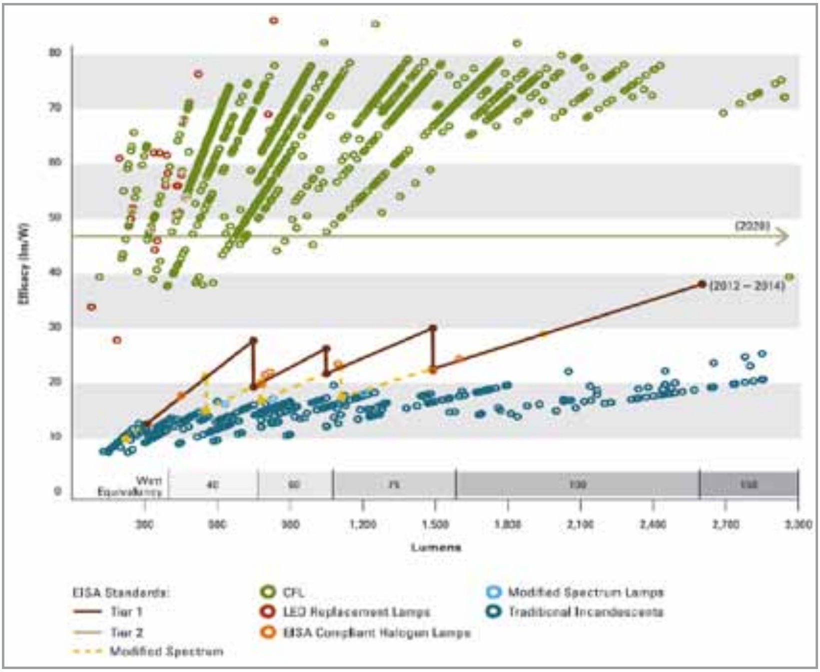


Figure 7: CFL, LED and Incandescent efficacy Vs Lumens

2.2
Current Market

2.2.1 Global Lighting Fixture Market

The global market size for electric lighting fixtures, also known as luminaires, was estimated to be worth €74 billion in 2009,[18] which increased by approximately 5.5% per year through 2009. The market is forecast to grow to approximately €127 billion by 2019 achieving a compound annual growth rate of 5.8%.

Two of the most significant growth drivers in the market are the predicted growth of the world's population from approximately 5.8 billion people

[18] World Lighting Fixtures to 2014, Freedonia Group Market Report, 2010

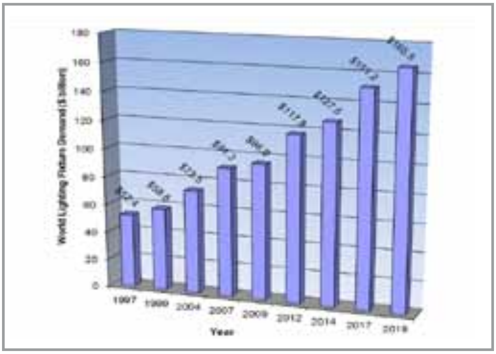


Figure 8: World Lighting Fixture Demand 1997-2019

in 1997 to more than 7.6 billion people by 2020 and the lighting needs of developing nations[19]. Global lighting fixture demand value as a proportion of population increase is likely to increase proportionally from €7 per person in 1997 to €16 by 2019 or by a factor of two in 10 years, as shown in Figure 8.

The most rapid growth in demand is expected in developing areas such as Eastern Europe, the African/Middle-East and the Asia/Pacific regions, where building construction activity and greater industrialisation will generate more opportunities for lighting equipment[20].

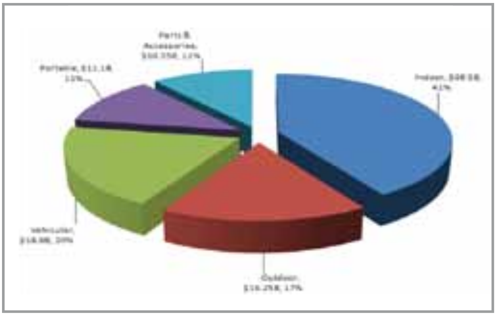


Figure 9: Lighting Revenue by Product Type in 2009

As shown in Figure 9, during 2009, the indoor lighting market represented 41% and the outdoor lighting market represented 17% of the total worldwide lighting demand. Parts and accessories as well as portable fixtures such as lamps represent €8.5 billion or 11% of the market.

The global lighting market can be further refined into three distinct categories of Lamps, Lighting Electronics including ballasts, controllers and sensors and luminaire fixtures.

Figure 10, created by Philips Lighting shows the relative market share for each application.

The lifetime potential of SSL light sources is changing the standard re-

[19] World Development Indicators Report, World Bank, December 2010
[20] Phillips, Energy Efficient Lighting – a Summary of "Green Switch" Facts, December 2008

placement lamp business model as it is expected that the annual volume of replacement bulbs will fall as LED lamps become dominant. This is shown by data from JP Morgan[21] below where the number of global light bulb sales (Figure 11) could halve between 2009 and 2020. However, the equivalent sales forecast shown in Figure 12, sees an increase in sales revenue implying that the cost of light bulbs will increase over the next decade as global volumes decrease and light bulbs offer longer lifetimes. Importantly in Figure 11 we see that LED bulbs will represent over 80% of the market penetration by annual volume in 2020.

Furthermore, it is predicted that LED lamps will become the majority installed light bulb source by 2020 (Figure 12).

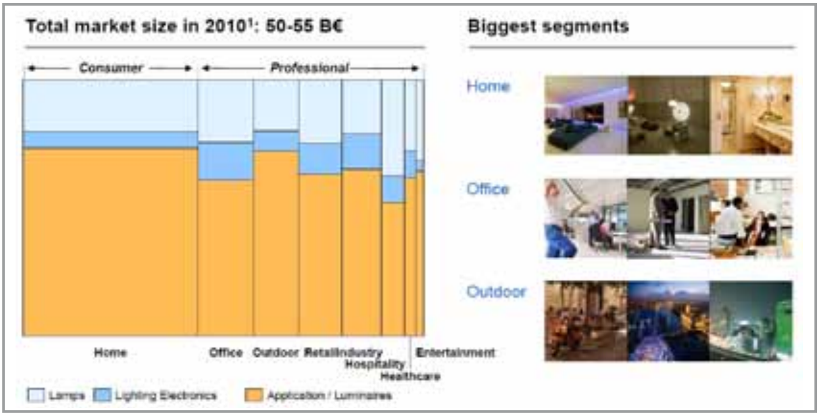
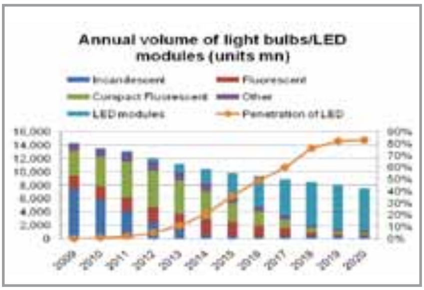


Figure 10: Segmentation of Global Lighting Market by Application and Lighting Category



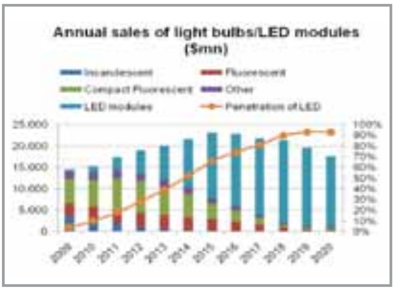


Figure 11: Annual Volume of Light Bulbs

Figure 12: Annual Sales Forecasts of Light Bulbs

[21] J.P. Morgan Cazenove, "Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED", March 2010

2.2.2 European Lighting Fixture Market

Within Europe the professional lighting market (that which covers commercial, industrial, public and domestic lighting) is significant. It was worth approximately €12 billion in 1997 and is expected to grow to approximately €29 billion in 2019[18] as shown in Figure 13 opposite. The lighting market is expected to grow in excess of 3.5% CAGR in Western European member states with Eastern European States having a faster CAGR of 6.2% due to the shift in European Commission infrastructure investment in new member states.

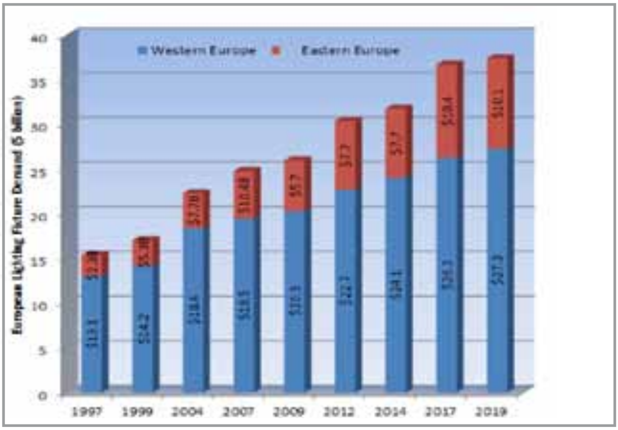


Figure 13: European Lighting Fixture Demand 1997 – 2019

The previously buoyant construction market and strong consumer spending have had a positive impact on the European lighting market over the 5 years to 2008. However, the global financial crisis along with intense price competition and increased life span of lamps has hindered stronger market growth since 2008. Product innovation in the area of energy efficiency along with changes in national building regulations are likely to further boost the lighting market.

The major lighting fixture markets are construction (including residential buildings, non-residential buildings and non-residential applications) and manufactured goods (vehicular equipment and other durable goods). In Western Europe the largest market in 2014 will be lighting for Non-residential buildings at €7 billion followed by vehicular equipment achieving €5.5 billion in 2014.

2.2.3 Global and European Lighting Market

The global lighting market is expected to grow to a value of €80 billion by 2015, based on 7-9% CAGR, as shown in Figure 14[22]. This figure also shows the market for conventional lighting (light blue) and LED lighting (darker blue) – indicating that conventional lighting will retain a significant market share for the foreseeable future. The segmentation of the lighting market by application for the US[23] is shown in Figure 15, to give an indication of the relative importance of different end use markets.

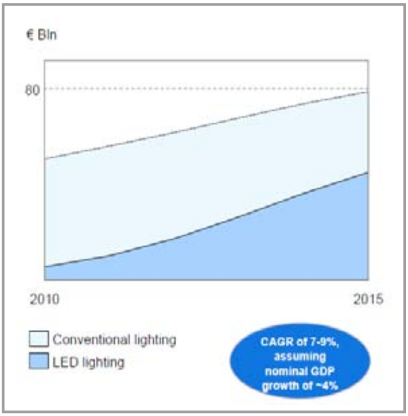


Figure 14: Global Lighting Market

The 2007 European market volume and segmentation for lighting (lamps) can be segmented as shown in Figure 16[24]:

	Market Demand (€M)	
	2008	2013
Buildings	2481	3108
Consumer Products	619	592
Motor Vehicles	404	469
Outdoor Lighting and Other	846	1092
TOTAL	4350	5262

Figure 15: Lighting Market Segmentation

	Market Volume	Market Share (%)	Share of Light Output (%)
Incandescent Lamps	1.9 billion	57	20
Fluorescent Lamps	470 million	14	41
Tungsten Halogen Lamps	470 million	14	14
Compact Fluorescent Lamps	450 million	14	5
High Intensity Discharge Lamps	58 million	2	23

Figure 16: European Lighting (Lamp) Market Segmentation

22 Philips Lighting Global Market Study 2009, updated for 2010
23 Freedonia Focus on Lamps to 2013, September 2009
24 European Lamp Companies Federation, http://www.elcfed.org/2_lighting_applications.html, 2007

2.2.4 Global LED Market

The market for high-brightness LEDs was forecast to reach €7 billion in 2010 with a CAGR of 52% in 2009/10 and is expected to grow to €14 billion in 2014[25]. In recent years much of this growth has been driven by the increasing use of high-brightness LEDs in display applications such as LED backlights for LCD TVs and monitors, though this is expected to stabilise. Meanwhile, the penetration of LEDs into the lighting market has achieved substantial momentum with outdoor lighting and replacement lamps being the fastest-growing segments.

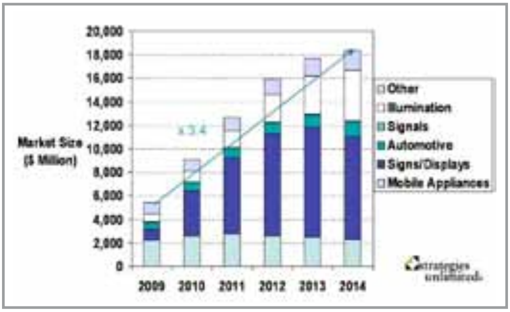


Figure 17: Global LED Market Forecasts 2009 - 2014

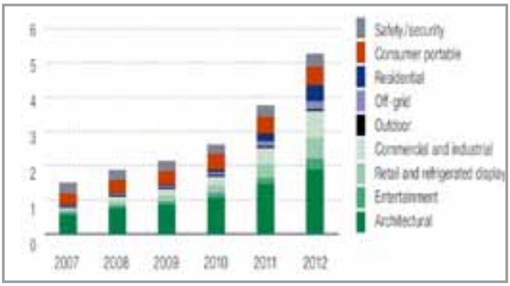


Figure 18: LED Fixture Application Forecast

The longer-term outlook continues to be highly positive, with a 5-year CAGR forecast of 48%. The transition to LEDs will start relatively slowly but will then rise rapidly to reach a total market of €4 billion in 2012 with a high CAGR of 28.5% as shown in Figure 18. Residential and outdoor lighting will show the highest growth rates.

According to LEDinside, during 2010, Europe held a 12% worldwide LED market share and was ranked the 4th largest producer of LEDs globally after Japan (27%), Korea (23%) and Taiwan (18%)[26].

2.2.5 Global Display Market

The global flat panel display market passed the milestone €77 billion ($100 billion) revenue mark in 2007. However, the market is entering a slower growth period and is expected to reduce to less than 5% per year from 2012 as shown in Figure 19.

[25] Strategies Unlimited, "High-Brightness LED Market Review and Forecast 2009", 2009
[26] LEDinside, "Outlook of LED Industry Trend in 2011", Jan 2011

Figure 19: Global Display Market – Market Size and Growth

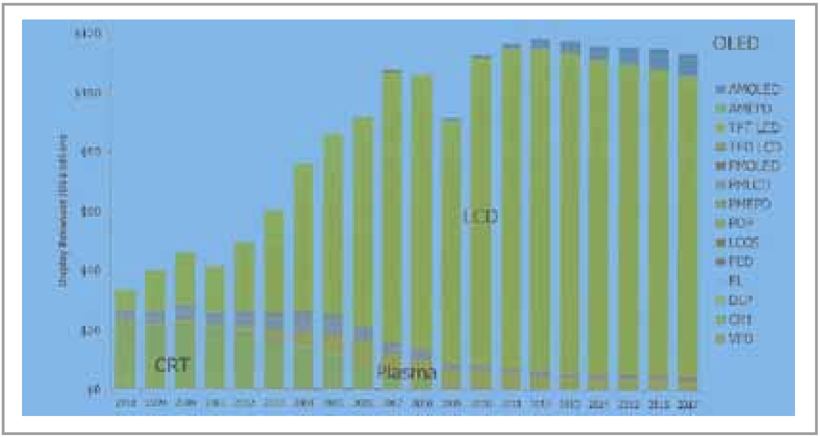


Figure 20: Display Market Trends (1998 – 2017)

The global display market is dominated by LCD technology as shown in Figure 20[27]:

The chart also shows the introduction of new (e.g. OLED) technologies over the period to 2017.

OLED technology (the markets for which are summarised below) is only one of a number of novel display technologies being developed.

[27] Global TV Trends in the Flat Panel Display Market, DisplaySearch, November 2010

A number of "e-paper" technologies are under development, as summarised in Figure 21, which shows the underpinning technologies and those involved in development. These are already being commercialised and some products are achieving significant market volumes (e.g. Amazon Kindle).

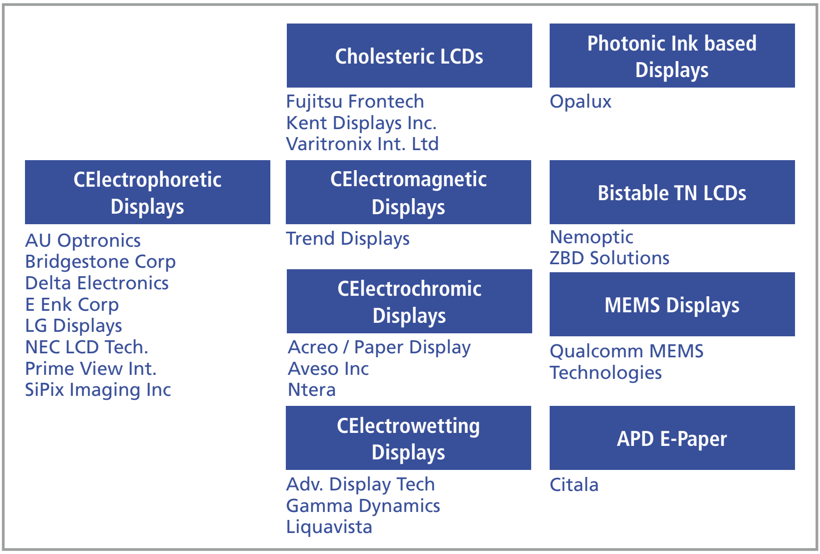


Figure 21: Overview of Developers of Novel Display Technologies

However, the majority of these new technologies are being developed by American and Far East companies.

2.2.6 OLED Market

It is predicted by NanoMarkets[28] that the OLED lighting market will reach almost €3.5 billion by 2013 and grow to €4.5 billion by 2015.

As described by the Optoelectronics Industry Development Association (OIDA), OLED lighting can be segmented into four categories: backlighting, automotive, signage and lighting, as shown in Figure 22 which shows the market revenue of OLED technologies by application from 2008 to 2020 with the largest segment relating to backlighting of flat panel displays followed by general lighting.

[28] NanoMarkets, "OLED Lighting, An Eight-Year Market Forecast", 2010

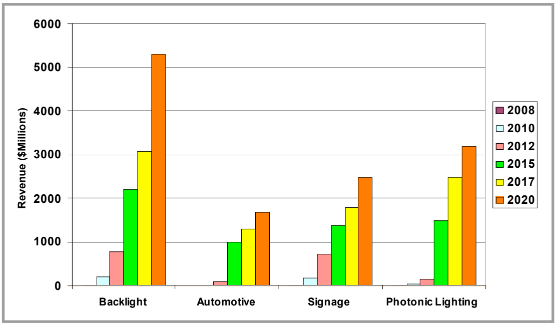


Figure 22: OLED Lighting by Application to 2020

It is widely expected that many more OLED based products will be commercialised from 2011 onwards, targeting demonstration and special niche markets which are less sensitive to price. From this starting point, the OLED market will gradually spread into general illumination, with stronger growth once the efficacy and cost levels become comparable with fluorescent lamps. A more detailed segmentation of current and expected applications for OLEDs is shown in Figure 23[29], indicating a market in excess of €6 billion by 2017 with mobile phones and televisions being the main market applications.

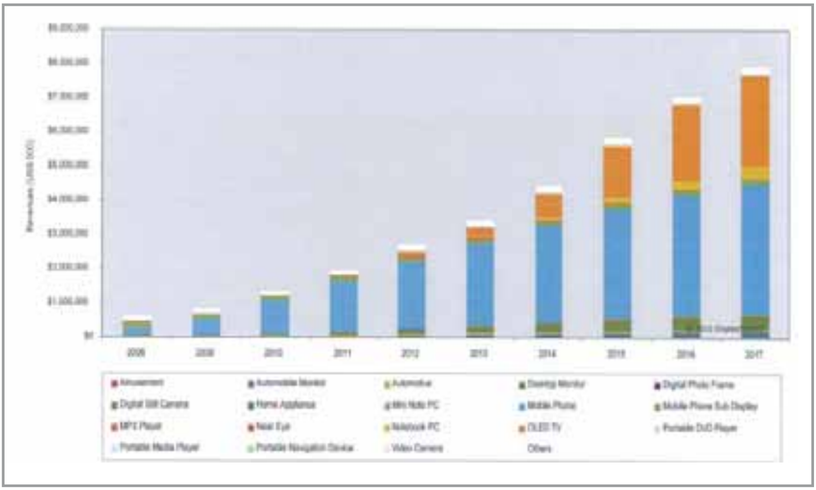


Figure 23: Predicted OLED Market Growth

[29] OLED Display and OLED Lighting Technology and Market Forecast, DisplaySearch, September 2010

2.2.7 E-Paper Technologies

There has been widespread diffusion of e-paper technologies in a range of applications, as shown in Figure 24[30]:

Application segment	Applications	Rate of emergence
Signage	Outdoor displays Indoor information and advertising displays Smart shelves – electronic shelf labelling and POS displays	Rapid emergence, already happening for smart shelving (e.g. from Fujitsu)
ICT components	E-books or e-readers (consumer and military) Mobile handsets Other handheld devices Laptops Desktop PCs Computer and telecommunications peripherals Wearable electronics (consumer and military)	Still just emerging – e-readers leading and market expected to expand in 2009/2010, especially as content widens, Other applications are further away
Disposable electronics	Smartcards Smart packaging	Slowly emerging
Consumer electronics	Clocks and watches White and brown FMCG	Imminent in low cost applications
Cars and other transport	Instrument dashboards Navigation screens Avionic displays	Slow emergence and various problems of robustness in harsh environments to be overcome

Figure 24: E-Paper Application Segments

There is already a significant market for novel display technologies dominated by small scale, black and white devices (e.g. Amazon Kindle), as shown in Figure 25[31]. This indicates a predicted market of €3.4billion by 2016 with disposable electronics, cell phones, computers and peripherals and e-book readers being the main applications.

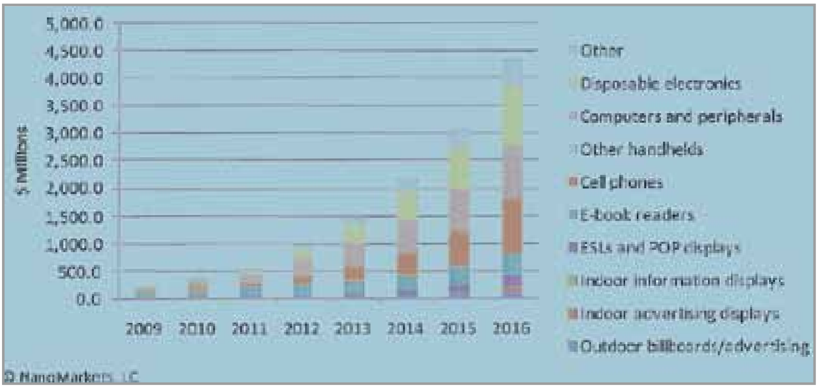


Figure 25: Predicted Market Growth for "E-Paper" Technologies

[30] OLEDs and E-Paper: Their Disruptive Potential for the European Display Industry, Simon Forge and Colin Blackman, JRC Institute for Prospective Technological Studies, 2009
[31] E-Paper Opportunities 2009, NanoMarkets

2.3

Important Market Drivers and Challenges – Solid State Lighting

Several key global trends are changing the way people use light. They demand that lighting solutions can deliver enhanced functionality without affecting the environment, as concerns increase about the effects of climate change and rising energy costs. In many countries a substantial body of "green" legislation is in place or imminent – much of which has a direct impact on the lighting industry. For example, 2009 saw the start of the phase-out of incandescent lamps within the European Union.

In Europe, an ageing, electricity generation and distribution network has placed emphasis on developing "green" policies to improve energy security moving into the next decade. The reduction in energy consumption through solid state lighting and the use of advanced lighting controls ensure improved security of energy supply in the mid-term.

A key driver for the lighting market is the transition to higher value products (from bulbs and components to complete lighting products as the point of value creation) and this enables significant economic growth opportunities.

A further key development is the trend toward custom solutions. Increasingly aware of the possibilities beyond standard solutions, consumers, businesses, national and metropolitan authorities demand highly adaptable lighting solutions which they can use to customise their indoor and outdoor environments as and when they desire. Other solid state lighting market drivers include:

- The increased need for more security and safety within society through the use of efficient lighting that can cost- effectively power outdoor applications such as street, park and amenity lighting
- The need to reduce light pollution by using of more directed lighting that can be easily achieved with LEDs

2.4

Important Market Drivers and Challenges – Displays

There are several market drivers for the display industry which enable its continued growth including:

- Price reduction (applicable across all LCD and new driver technologies)
- Increased display size (mainly OLED display technologies)
- Improved energy efficiency (mainly driven by government legislation)
- Improved colour quality (wide colour gamuts)
- Reduced display thickness (driven mainly by portable applications and large screen TVs)
- Faster refresh times (driven by high definition and 3D TV applications)
- Three dimension TV (driven by content providers)

There are a number of challenges that the display industry has to overcome that are specific to individual technologies, however, price and Industry profitability remain vital to the long term health of the sector. The three main challenges for OLED displays to enter the TV and display market are defined as[32]:

- Display pricing (material costs, production yields and backplane challenges)
- Scaling display sizes (OLED displays and OLED TV size)
- Lifetime - the OLED materials especially blue have a lower lifetime

Further barriers include quality, yields, reliability, power and large scale production.

[32] OLED Display and OLED Lighting Technology and Market Forecast, Jennifer Colegrove, DisplaySearch at OLEDs World Summit, September 2010

Flexible displays have further specific challenges such as reliability due to degradation from Oxygen and other gases as well as water ingress making it particularly difficult to create robust systems in market applications.

The final challenge is how to maintain a healthy supply chain as the average selling price (ASP) for small and medium flat panel displays has seen a rapid decrease in prices up until 2010. It is anticipated that the rapid decrease in average selling price (ASP) cannot continue and the ASP is predicted to level off enabling manufacturers to recoup their investments.

Of course, the major investments required in LCD production assets will be a significant barrier for OLED technology market penetration as prices are low and the current manufacturers will need to leverage their current asset base.

2.5 Market Players

2.5.1 Lighting

Europe has historically been a strong player on the global stage with numerous organisations taking their place within a dynamic supply chain from LED manufacturers to makers of luminaires and suppliers of materials, production equipment and power electronics. The European lighting industry has established a strong position with a share of about 40% of the world lamp market. OSRAM and Philips hold equal shares and General Electric (GE) in the U.S. occupies third place, however, Toshiba, Samsung and Panasonic have targeted this market over the last 12 months. Worldwide, Philips Lighting is the number one player in both professional and consumer luminaires with over 51,653 employees and global sales of €6.5 billion with €2.3 billion of that within Europe during 2009. The SME-dominated luminaire market is quite scattered across Europe[33] with the main players in Italy, Germany, the United Kingdom, Spain and France.

The ELC (European Lamp Companies Federation) and CELMA (Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires) represent over 1000 producers that di-

[33] CSIL study, "The European Market for Lighting Fixtures", 2007

Positon	Company	Country	Turnover ($000)	Sales Growth (%)	Profit/Loss ($000)	Employees
1	ZUMTOBEL AG	Austria	1998876	3.5	136570	7708
2	PHILIPS LIGHTING POLAND S.A.	Poland	1543689	18.3	149822	3800
3	HAVELLS SYLVANIA EUROPE LTD	United Kingdom	505657	16.2	-381	59
4	GEWISS SPA	Italy	486944	7	64159	1777
5	SAS OSRAM	France	363891	-10.1	17152	835
6	MASSIVE	Belgium	357920	10.3	11280	347
7	FAGERHULT AB	Sweden	356631	9.6	33262	1978
8	OY LIVAL AB	Finland	322684	-6	51811	359
9	LAMPLAST FINANZIARIA S.P.A.	Italy	315612	5.6	68528	645
10	GLAMOX ASA	Norway	294604	17.8	24869	467
11	IGUZZINI ILLUMINAZIONE S.P.A.	Italy	262753	20.5	35319	783
12	SITECO BELEUCHTUNGSTECHNIK GMBH	Germany	261441	0	10642	936
13	BEGHELLI S.P.A.	Italy	257894	28.8	10701	
14	THORN EUROPHANE	France	251474	3.7	626	581
15	ERCO GMBH	Germany	243119	7.1	30276	1090
16	DISANO ILLUMINAZIONE S.P.A.	Italy	241819	5	40955	86
17	THORN LIGHTING LIMITED	United Kingdom	236638	1.6	12287	826
18	TARGETTI SANKEY S.P.A.	Italy	235003	12	14782	
19	MARTIN PROFESSIONAL A/S	Denmark	197766	-10.9	988	1073
20	FAGERHULTS BELYSNING AB	Sweden	195417	11.3	10165	795
21	FLOS SOCIETA´ PER AZIONI	Italy	182429	14.6	26778	369
22	LUIS POULSEN LIGHTING A/S	Denmark	162493	-0.4	19565	578
23	DAMBACH-WERKE GMBH	Germany	154575	2.4	676	607
24	LUXTEN LIGHTING COMPANY SA	Romania	137675	-2.7	21105	1594
25	J FELIU DE LA PENYA S.L.	Spain	127496	39.1	14692	1040
26	OSRAM SLOVAKIA, A.S.	Slovakia	122756	18.7	-1228	1500
27	OSRAM LIMITED	United Kingdom	120515	9.9	5980	105
28	CML INNOVATIVE TECHNOLOGIES	France	112598	11.5	9442	311
29	SOCIETE FRANCAISE CONSTRUCTION MATERIEL EL…	France	111111	15.5	32707	206
30	SLI LICHTSYSTEME GMBH	Germany	110501	-3	1259	565
31	PAULMANN LICHT GMBH	Germany	106857	5.4	8811	194
32	EGLO MAGYARORSZAG TERMELO KORLATOLT FELE…	Hungary	103910	2.6	7705	339
33	F.W. THORPE PUBLIC LIMITED COMPANY	United Kingdom	103130	13.3	23343	545
34	HAVELLS SYLVANIA LIGHTING FRANCE	France	102856	-7.1	-8660	338
35	ARTEMIDE S.P.A.	Italy	97578	8.4	11274	266
36	RIDI-LEUCHTEN GMBH	Germany	97308	14.7	7147	278
37	THORN LIGHTING NORDIC AB	Sweden	97035	-1.8	1902	287
38	OSM, S.R.O.	Slovakia	96889	-1.7	15115	750
39	SLV ELEKTRONIK GMBH	Germany	96651	26.8	32888	154
40	SEMPERLUX AKTIENGESELLSCHAFT- LICHTTECHNI…	Germany	93948	0	6461	415
41	OSRAM CESKA REPUBIKA S.R.O.	Czech Republic	93019	-17.4	315	1250
42	HAVELLS SYLVANIA LIGHTING BELGIUM	Belgium	91796	4.8	9114	419
43	3F FILIPPI S.P.A.	Italy	89509	8.4	14417	327
44	DEXTRA GROUP PLC	United Kingdom	89509	15.3	2033	456
45	DELTA LIGHT	Belgium	88255	16.6	24634	168
		Totals	**11719809**	**6,9**	**1011288**	**37206**

Figure 26: Top 45 European Companies by Market Share (Plimsoll 2009)

rectly employ more than 107,000 people and generate more than €15 billion annually. A further study[34] of the European lighting market estimates over 102,000 employees from 1000 companies generated more than €17.9 billion revenue within 2009.

However, the top 45 European lighting companies by market share in 2009/10 are shown in Figure 26 along with their respective sales growth. In 2009/10, there were 34 separate companies or divisions that had revenue turnovers in excess of €77 million.

Currently, an average company in this industry has sales increasing by 6.9% per annum. Almost one in four of the European companies recorded a fall in sales with an average fall of 11%. Three quarters of the companies recorded an increase in sales, with an average increase of 16%. In general, the larger companies are growing at 11.3% growth, compared to the smaller companies who are growing at 10.9%. The top 45 companies generated revenues close to €9.2 billion in 2009/10, employed approximately 37,206 and generated over €0.77 billion in profits.

In 2010, OSRAM Opto Semiconductors was the world's third largest manufacturer of LEDs by revenue whilst Philips LED manufacturer, Philips Lumileds, was equal fourth largest as shown in Figure 27. Their main competition comes from Japan (Nichia), Korea (Samsung, Seoul Semiconductor & LG) and the U.S (Cree). Many new LED factories are currently under construction in China due to the Chinese Government's encouragement of metal-organic chemical vapour deposition (MOVCD) production with tool subsidies of up to €0.9 to €1.15 million each[35].

2010 Ranking	Company Name	2010 Ranking	Company Name
1	Nichia (Japan)	6=	Cree (USA)
2	Samsung LED (Korea)	6=	LG Innotek (Korea)
3	Osram Opto Semiconductors (Europe)	8	Sharp (Japan)
4=	Philips Lumileds Lighting (Europe)	9=	Everlight (Taiwan)
4=	Seoul Semiconductor (Korea)	9=	Toyoda Gosei (Japan)

Figure 27: Leading Global LED Companies

[34] Plimsoll, "1000 Europe Lighting Manufacturers Industry Analysis", 2009
[35] Semiconductor Today, "Chinese burn into LED market driving MOVCD", Vol. 5, Issue 7, September 2010

Europe also has a strong position in the OLED market space through major chemicals companies such as BASF, Bayer and Merck investing in materials development and companies such as Novaled, Cambridge Display Technology, OLED-T and Ormecon which are focusing on device development.

In summary, Europe has an outstanding position in the global lighting market due to its long-standing emphasis on energy-saving solutions. It has gained this position based on incumbent technologies such as fluorescent and high-intensity gas discharge technology. It was the first large economic region in the world to reach an agreement on banning incandescent lamps. This provides an excellent opportunity to tackle the challenges of transitioning to LED and OLED technology and strengthening the European position as the global leader in lighting.

2.5.2 Displays

Europe offers strong intellectual property for display devices, manufacturing processes and material supply/verification. This is particularly applicable to OLED and E-display technologies with established companies within the supply chain.

There are a significant number of European-based companies within the displays supply chain. However, the majority reside in the materials and process equipment area with virtually no major international panel or OEM manufacturers. In general the displays sector can be characterised as small and fragmented with the largest European player, Philips, transferring its last remaining displays related division to TPV of China in April 2011.

Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

3

3.1
Light Emitting Diodes

There are many stages to the development of Solid State Lighting systems based on LED technology (as shown in Figure 28 for GaN LEDs[36]) and at each stage of the supply chain improvements can be made with current technologies and processes or there are opportunities to develop new techniques that address many of the barriers currently understood today.

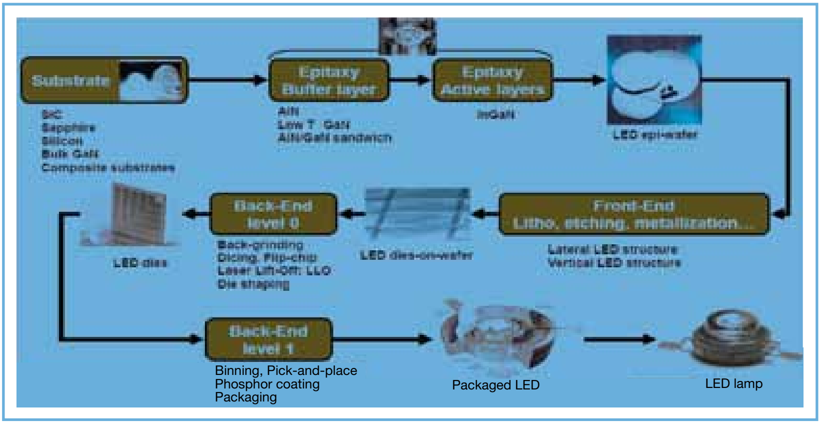


Figure 28: Main Manufacturing Steps for LED Lighting

There are many promising technologies being developed that enable the LED industry to meet its roadmap for LED cost, efficiency and performance including:

- Substrate development (e.g. larger sapphire wafers and silicon substrates)
- Down-convertor materials (e.g. phosphors and quantum dots)
- Die performance (e.g. led droop, photonic crystals and surface enhancement)
- Light engine performance (e.g. remote phosphor, multiple wavelength)

[36] LED Manufacturing Technologies and Costs, Jeff Perkins, Yole Developpements, Presentation at SEMICON WEST, July 2009

- Thermal Performance using thermally conductive polymers
- Smart network enabled lighting controls
- Low cost colour and intensity sensors for real-time feedback
- High efficiency, low cost, flexible and reliable driver technologies
- Visual light communication technology

3.2
Organic Light Emitting Diode Technologies

OLEDs promise novel lighting systems with functionalities that go beyond what is achievable with LEDs. Their broad emission spectrum makes OLEDs a very pleasant source of light. OLEDs offer new options for design and open the way for large-surface-area lighting built in to walls and ceilings. OLEDs can be manufactured on plastic, glass and metal substrates so conformable and flexible light sources are expected to be available before 2015. There are tremendous opportunities to use transparent OLEDs within windows and facades to allow a room to have a single source of light, natural light during the day and electrical light after sunset.

Much research on OLEDs has been performed around the world since the early 1990s. One main finding is that the efficiency, lifetime, brightness and size of the active areas are hard to reconcile with each other. It has been possible to achieve record values for efficiency, brightness and lifetime, and thus to demonstrate the potential offered by OLED technology, but not all at the same time. The challenge now is to combine all these properties into high quality devices with high flux, high efficiency and lifetimes exceeding several thousands of hours and all at costs comparable to traditional or LED lighting.

Philips and OSRAM launched OLED devices during 2010 and this is considered the first wave of products. These light sources are being integrated by manufacturers into lighting fixtures. The second wave of OLED lighting products will enter the market during 2013 with the introduction of function lighting products in niche applications such as automotive, healthcare, electrical goods and signage markets. The third wave of OLED lighting will start in 2014/15 with OLEDs starting to penetrate general illumination and backlighting markets.

There are three main factors driving OLED lighting development currently:

1. OLED Performance	– Power and Efficiency (20–40lm/W in 2010) – Light extraction coupling (1000–3000 Cd/M^2 in 2010
2. OLED Lifetime	– OLED reliability (5000–20000 hours at $1000Cd/M^2$ in 2010) – Encapsulation
3. OLED Price (above €1500 per m^2 in 2010)	– Material, substrate, encapsulation and production cost – Material and device yield

The Organic and Large Area Electronics strategic research agenda[37] details the short medium and long term technology development needs for OLED based lighting and displays. These technology developments, as shown in Figure 29[37], highlight the importance of device performance, reliability and cost competitiveness for lighting applications and colour output, video rate responsiveness and operational performance for displays.

[37] Towards Green Electronics in Europe, Strategic Research Agenda – Organic and Large Area Electronics, Photonics 21, OE-A, EPOSS and Opera, November 2009

Research Topic	Technical Objectives	Short term	Mid term	Long term
OLED Materials	• Highly efficient emitter materials and materials for charge transport and injection; Materials suitable for high process operation temperatures • Improved electrode materials • Encapsulation enabling high shelf-life time; better pachaging materials for perfect light out-coupling • Material screening	• Suitable for gas phase processing • Printed ITO • Stable under ambient conditions • Analytical tool development	• Suitable for solution processing • Suitable for high speed deposition • ITO alternatives • Also stable under high temperature conditions (e.g. automotive) • Analytical tool	• Air stable and materials with high conductivity (R&D) High temperature stable materials (automotive) • >20years stable for fixed integration (e.g. in architecture)
OLED Devices with combined performance properties	• Device efficiency • Reability (at higher temperature, less differential ageing) • Less short circuits • High operating and shelf life-time • High quality white (CRI, Color over angle, homogenelty) • Transparent devices • Conformal/flexible devices • Drivers (high efficient, new concepts (integrated design, miniaturized) • Simulation tools for modelling devices	• >100lm/W (in R&D) • 25°C • Stack development • >100y/ >5yT_{50} • >80 CRI • 60-70% • rigid • Miniaturized high efficient • Tool development	• >100lm/W (in production) @high lifetime & high lumen • 50°C • Stack development • >15y/ >10yT_{20} • >90 CRI • 75% • conformal • Integrated design • advanced tools	• >120lm/W (in production) • 80°C • >20y/l >15y • >95 CRI • >80% • Also flexible • Organic drivers • Advanced tools with good predictive power
OLED luminaires	• High system efficiency • Tiling concepts • Luminaire design • Acceptance studies (well-being)	• Connecting • Simulation studies	• Seamless • Demonstration studies	
OLED Standardization	• Standardization of OLED devices and drivers	• Measurement metrics	• ‚Standardization	
OLED Production	• Novel low cost & high throughput production processes • OLED technologies development • Equipment development, in line diagnostics & up scaling • Cost decrease	• Low-cost vacuum deposition • CVD OVPD • Development for production • Decrease	• Fabrication via laminating of printing • Also lamintating & printing options • Development for mass production • <100 €/m²	• R2R manufacturing • Also R2R • >70€/m²

Figure 29: OLED – Key Technology Development Needs

3.2.1 High Efficiency OLED Materials

To reach high luminous efficacy performance, new techniques will be needed to target breakthrough materials such as highly efficient emitters (especially deep blue), charge transport and injection materials, and materials especially suited for processing at high speed or optimised for high-temperature vapour phase deposition. Such new materials will shorten manufacturing throughput times. Materials with higher electrical conductivity are also desirable since they can be used in thicker layers to make more robust designs

Special attention should be given to cost-effective alternatives to indium tin oxides (ITO), transparent electrode materials and low-cost substrates for OLED lighting. These are needed if OLEDs are to be used in flexible and transparent light sources. Three low cost alternatives to ITO that could find their way to market between 2014 and 2020 are (a) transparent conducting oxides (TCOs), (b) conductive polymers and (c) nanomaterials.

Alternative TCOs and polymers have a lot in common. They are technologically mature, very low cost materials, and they are used wherever possible as an ITO substitute. The problem is that, as a practical matter, these materials can seldom offer the performance in terms of transparency and/or conductivity that ITO can offer.

An emerging alternative to ITO may come in the form of nanomaterials either based on carbon nanotubes or some nanoparticulate preparation. Although early in development the basic materials from which the nanomaterials are created, may be less subject to the price fluctuations associated with indium.

The development of novel, high-performance materials suitable for high-speed vapour phase processing, as well as similar materials suitable for R2R processing are also required. Materials need to be stable and optimised for the high temperatures used during vapour phase deposition.

3.2.2 Light Extraction and OLED Structure

Efficient and cost-effective light extraction for flat light sources could be tackled by exploring 2-D and 3-D nano-structured materials, or by including suitable plasmonic structures within the OLED structure. Theoretical studies show that this approach gives a large boost in external quantum efficiency but it needs to be evaluated in practice. Nanostructures could include enhanced surface roughening or the use of photonics crystals structure as light guides both of which are techniques understood from inorganic LED production.

Currently, light extraction efficiency has achieved 45% in laboratories[38], however, it is important for cost and performance reasons to increase this to a target figure of 75% by 2020.

The type and number of OLED structures for white OLED emitters still requires considerable research in order develop high performing and reliable white OLEDs.

[38] US DOE, "Round table discussions of the solid-state lighting R&D Task Priorities", Jan 2011

There are four areas of OLED structure research that will have an impact on performance including bottom or top emission, transparent OLEDs, stacked OLEDs and inverted OLED.

3.2.3 OLED Substrates and Fabrication Technology

While OLEDs have been produced on the back of display manufacturing capabilities, there has been little direct investment by manufacturers in the infrastructure needed to develop commercial OLED lighting products. A breakthrough is necessary to produce low-cost OLEDs for general illumination. Lack of process uniformity is an important issue for LEDs and is a barrier to reduced costs as well as a problem for uniform quality of light. Most OLED manufacturing strategies can be separated into three stages - preparation of the manufacturing substrate, deposition of the active organic layers and second electrode and encapsulation and panel formation.

The development of R2R processes and novel OLED and barrier materials will have a significant effect on the market deployment of OLED lighting between 2011 and 2020. The adoption of R2R processing should enable capital expenditure and labour costs of OLED production to reduce by a factor of 60 between 2011 and 2015[39].

Europe has strong opportunities within the supply chain with companies such as Cambridge Display Technologies, NovaLEDs, Philips, OSRAM, BASF and MERCK amongst many others providing the materials required for White OLED production.

3.2.4 Long Life, High Efficiency, Flexible Power Electronics for SSL Systems

A vitally important aspect of SSL systems revolves around the power electronics or drivers employed within such systems. There is currently a high demand for drivers with improved design for manufacturing, integration and flexibility within the SSL luminaire. New approaches for the development of flexible, high efficiency, long life, and low cost drivers need to be developed to enable advanced, smart controlled luminaires.
A LED driver may be defined as a complete subsystem enabling a user to attach a primary energy source and is capable of driving an array of (O) LEDs on one or more output channels using a variety of control protocol techniques to obtain a desired lighting effect.

[39] US DOE, "Solid-State Lighting Research and Development: Manufacturing Roadmap", July 2010

3.3
Display Technologies

The number of display technologies developed over the last few decades is significant as shown in Figure 30[40], however, LCD displays are currently the dominant technology within the displays market.

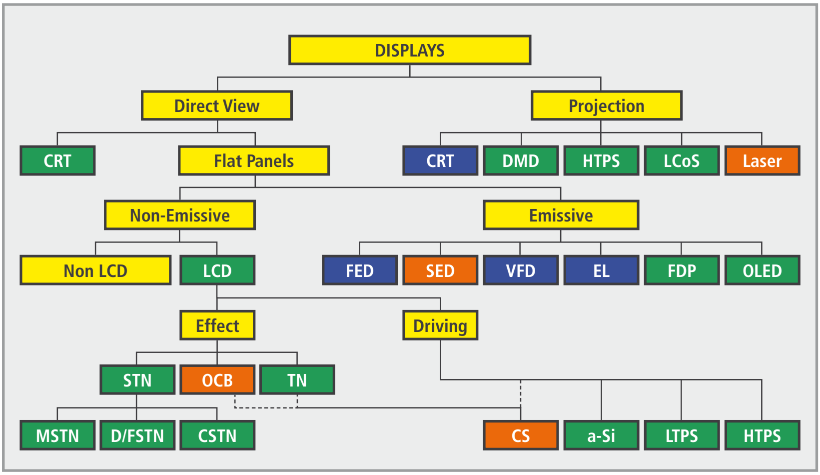


Figure 30: Overview of Display Technologies

A number of new display technologies have already been highlighted together with their expected market growth throughout Section 2. The global display market is dominated by LCD technology as shown in Figure 20: in Figure 31[37]. Currently the main display technologies being considered as important are e-paper technologies including electrophoretic, electrochromic, electrowetting, cholesteric liquid crystal as well as some other novel display technologies and OLED displays.

The most successful e-paper technology to date is used in electrophoretic displays. In general, electrophoretic displays suffer from limitations associated with motion video and full colour rendering although all of the manufacturers are developing solutions to address both of these limitations.

[40] A.J.S.M. de Vaan, Philips Consumer Electronics, CIC 14 Conference Scottsdale, 10-11-2006

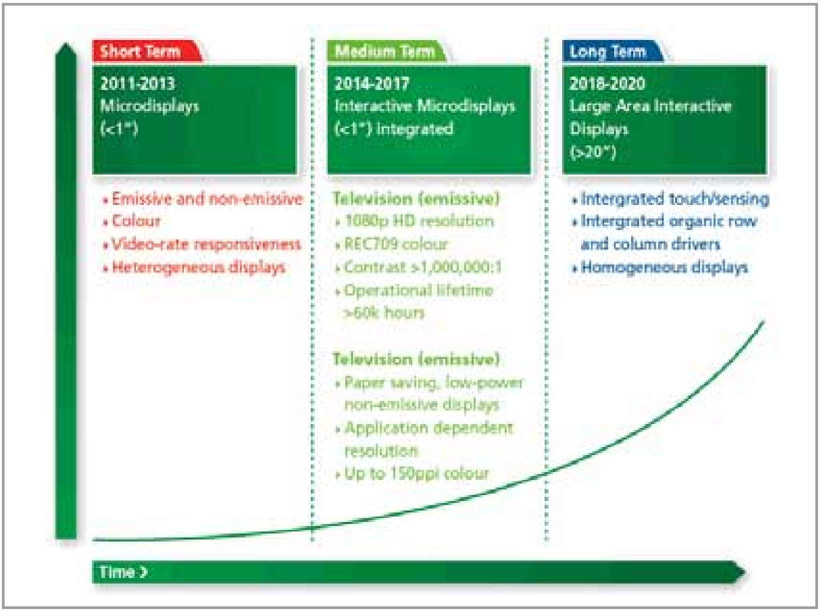


Figure 31: Short, Medium and Long Term Display Technology Development Needs

For example, E-ink[41] has developed the Triton electrophoretic display, which offers 16 levels of grey and 4096 levels of colour displays which offer 20% faster switching speeds than its first generation of displays.

There are at least three different e-paper technologies developed on the concept of electrochromism, which is a chemical reaction whereby colours are changed reversibly when a charge is applied. One example of an electrochromism material is Polyaniline, which can be formed either by the electrochemical or chemical oxidation of aniline. Other electrochromism materials include Tungsten Oxide, which is the main chemical used in the production of smart windows. Several companies such as Ntera, Acreo, Siemens and Aveso have developed electrochromic displays which are focussed on small monochrome applications such as smart cards and similar devices.

Electrowetting technology is a new technology, which allows much faster switching speeds than most other types of electronic paper technologies,

[41] http://www.eink.com/sell_sheets/triton%20sell%20sheet.pdf

enabled by the use of selectively charging hydrophobic and hydrophilic materials. The technology is particularly useful for use in flexible substrates because there are no moisture or gas permeation issues, peak fabrication temperatures are only 9°C, only four main process steps are required, images are bistable and lambertian even on a curved surface and they can show ultra-high brightness. Several organisations are known to be working on electrowetting displays including LiquaVista, PVI and adt amongst others.

An interesting area of display technology is the development of laser projection that matches the laser architecture with micro-mirrors of a digital light projection (DLP) light engine to replace the more conventional lamp solutions used in projection TVs. These mirrors switch on and off thousands of times per second and the lasers shine on the mirrors in varying intensity enabling the fundamental red, green and blue lasers to achieve a high colour gamut and contrast ratios. The challenges for such a display technology is high efficiency green lasers, cost, perceived eye safety issues and the fact that projection displays have not seen high levels of market penetration previously.

The recent launch of 3D displays into the market demonstrates the excellent potential for such technologies, however, these displays have been based mainly on stereoscopic technologies. Other 3D display technologies include volumetric displays that emit, redirect, diffuse or re-image light from a localised true volume as integrated over the systems refresh rate as well as autostereoscopic displays that create multiple viewpoints so a viewer does not have to wear special glasses. Recently, Nintendo has launched a portable games console with a 3D autostereoscopic display that has captured the imagination of game players as they do not require the usual 3D glasses in order to play 3D games. The console also includes two cameras that enable users to capture 3D pictures that will drive 3D content in the future.

Other display technologies include holographic displays, cholesteric liquid crystal displays, polymer dispersed liquid crystals, blue phase liquid crystals, optically compensated bend LCDs and MEMs based displays. All of these display technologies have attracted serious research and development activities over the last decade, however, they are not expected to make significant impacts within the market over the next decade.

Overview of Major Research Programmes and Deployment Initiatives outside Europe

4

4. Overview of Major Research Programmes and Deployment Initiatives outside Europe

The disruptive Solid State Lighting market is seen as a coveted prize by industry and governments alike. The barriers to such a new market are relatively low, compared for example, to the significant capital investment required for the latest flat panel display manufacturing lines. This, along with the huge economic market potential and significant carbon reduction benefits, has created a rush to establish comprehensive supply chains in Japan, Korea, Taiwan and the USA through a variety of Government stimuli and support mechanisms. In order for Europe to maintain and extend its global position within general lighting, it will need to monitor and assess the impact of government policies, research programmes and economic incentives on solid state lighting activities worldwide.

The following sections will outline government interventions within the solid-state lighting markets.

4.1 North American Initiatives

The USA is already a leading player in photonics research, development and manufacturing and has a range of major support programmes for both technology and market development. For EEL and Displays Technology, these are described below.

The Legislative Directive, Energy Policy Act, enacted on August 8, 2005, issued a directive to the Secretary of Energy to carry out a "Next Generation Lighting Initiative" (NGLI) to support the R&D of SSL. The legislation directs the Secretary of Energy to support research, development, demonstration, and commercial application activities related to advanced SSL technologies. Section 911 of Energy Policy Act of 2005, enacted on August 8, 2005, authorised €38 million for each fiscal year 2007 through 2009 to the NGLI, with extended authorisation for the Secretary to allocate €38 million for each of the fiscal years 2010 to 2013. In total, Congress proposed €270 million for R&D investment in SSL

The Energy Independence and Security Act (EISA) was enacted on December 19, 2007. EISA instituted the "Bright Tomorrow Lighting Prizes." The "Bright Tomorrow Lighting Prizes" established prizes for an SSL product with an efficacy of 90 lm/W to replace an incandescent 60W lamp, an SSL product with an efficacy of 123 lm/W to replace halogen PAR 38 lamps, and an SSL product with an efficacy of 150 lm/W. EISA 2007 also authorised a lighting R&D programme of €7.7 million per year for fiscal years 2008-2013, to terminate by September 30, 2015. The Energy and Water Development and Related Agencies Appropriations Act 2010, enacted on October 28, 2009, authorised €20.8 million to the Department of Energy (DOE) for SSL R&D.

The DOE has made a long-term commitment to advance the development and market introduction of energy-efficient white-light sources for general illumination. Figure 32 shows the DOE funding sources and level of support contributed to the SSL project portfolio in Feb 2010.

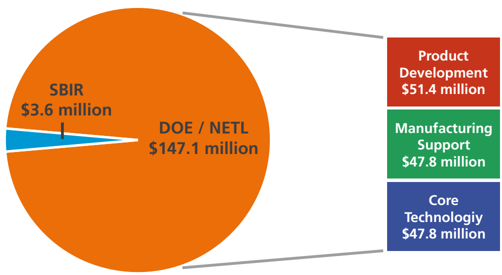


Figure 32: Cumulative US Funding Sources for SSL R&D Portfolio

The DOE has developed a comprehensive national strategy that encompasses basic energy science, core technology research, product development, manufacturing research and development, commercialisation support, partnership development and standards development.

The current US SSL portfolio[42] identifies that industry participants received approximately 58% of portfolio funding, with €68 million in R&D activities followed by small businesses who received 20%, or €23 million, in research funds. Finally, universities and national laboratories received 12% and 10% of the R&D portfolio funding respectively, and received €14 million and €11 million, respectively.

In 2010, the DOE added a further pathway to its R&D portfolio: a new SSL manufacturing initiative to accelerate SSL technology adoption through manufacturing improvements that reduce costs and enhance quality. As part of this initiative, DOE and industry partners have developed a "Solid-State Lighting Manufacturing R&D Roadmap"[43], which represents industry consensus on the expected evolution of SSL manufacturing, best practices, and opportunities for improvement and collaboration. As an extension of the multi-year programme, the roadmap is updated annually with input from industry partners and workshop attendees, and guides the development of annual SSL manufacturing R&D solicitations.

To facilitate successful market introduction of high-quality, energy-efficient SSL products for general illumination, the DOE has also developed a Five-Year "SSL Commercialization Support Plan"[44]. The plan draws on key partnerships with the SSL industry, research community, standards setting organisations, energy efficiency groups, utilities, and others, as well as lessons learned from the past. The plan focuses DOE resources on strategic areas that foster the market for high-performance SSL products, including buyer and specification guidance, design competitions, gateway technology demonstrations and procurements, the Commercially Available LED Product Evaluation and Reporting Programme (CALiPER), technical information, standards and test procedures support and coordination/leadership.

From a fiscal perspective, the American Recovery and Reinvestment Act (ARRA) authorised the Secretary of the Treasury, in consultation with the Secretary of Energy, to award tax credits for qualified investments in new, expanded or re-equipped domestic manufacturing facilities for clean energy technologies. The goal of the Advanced Energy Manufacturing Tax

[42] DOE Report, "Solid-State Lighting Research and Development: Multi-Year Program Plan", March 2010
[43] US DOE, "Solid-State Lighting Research and Development: Manufacturing Roadmap", July 2010
[44] US DOE, "5-Year SSL Commercialisation Support Plan FY09 through FY13", May 2009

Credit—codified in Section 48c of the Internal Revenue Code—is to expand the domestic manufacturing industry for clean energy.

Tax credits have been issued to manufacturers in a number of relevant energy technology areas including LED lighting[45].

4.2 Japanese Initiatives

Japan was an early supporter of Solid State Lighting with the Government providing an estimated €5.4 million a year from 1998 to 2008[46].

The "Light for the 21st Century" programme, funded by the New Energy and Industrial Technology Development Organisation (NEDO), was started with Phase 1 covering the period from 1998 through 2002 to develop GaN based LED technology for lighting applications. It provided funding of €40 million to the Japan R&D Centre of Metals (JRCM) and 13 other companies and Universities. The objectives of the programme were to produce 120 lm/W and 80% efficient LEDs.

The Ministry of Education, Culture, Science & Technology developed a support programme for medical equipment and therapeutic techniques based on LEDs in 2004 with funding of €3.1 million each year until 2008. The programme established the Yamaguchi-Ube Medical innovation Centre and supported several universities and more than 20 companies. The key areas of focus included:

- LED production, lighting systems (near UV and Green-White LEDs) and applications
- LED sterilisation equipment, endoscopes and light therapy devices
- Cell separation equipment
- Arteriosclerosis Diagnostic Systems
- Cellular and Information Analysis Systems
- Diagnosis System of Liver Cancer

[45] US DOE, "Critical Materials Strategy", December 2010, p. 57
[46] Rensselaer Polytechnic Institute, "Lighting Industry: Structure and Technology in the Transition to Solid State", 2008

Japan has an Energy Basic Plan (2010)[47] in place which plans to reduce 50% Carbon by 2050 with a baseline of 1990. The policy objectives set out in the Energy Basic Plan will focus on implementation, through research and development, the further enhancement of LED light emitting efficiency to 200lm / W; high efficiency OLED lighting with enhanced luminous efficiency of 130lm / W, and to reduce the production costs in order to achieve the market penetration.

From an LED and OLED perspective, the Japanese government expects sales of all (O)LED lighting equipment to reach 100% by 2020 and by 2030, the use of all installed lighting equipment will be high efficiency (O)LED replacement lighting, which stood at only 2% market penetration in 2010. In addition, the Japanese government will make policy incentives to encourage business and the public to adopt LED lighting products. National policy in Japan, proposes energy tax breaks and forcing large companies through legislation to switch to energy-saving products. Many local governments also provide local-level energy-saving LED lighting products and subsidies.

Various Japanese cities and counties offer grants/subsidies and have introduced relevant regulations to expedite the adoption of energy-saving LED products. For example, Chiyoda-ku, Tokyo offer 20% installation subsidies for LED lighting products that meet certain performance standards.

There is federal funding of €3.75 million set aside for energy efficient lighting.

In the displays sector, Japan is taking a lead with a €199 million ministry funded collaborative project between Sony, Toshiba, Panasonic, Sharp and others to develop 40-inch and larger OLED television panels.

4.3 Korean Initiatives

The Korean government has actively supported EEL since 2005, when it created a semiconductor-lighting national programme[48] and backed the

[47] Japanese Government, Basic Energy Plan, 2010
[48] Richard Stevenson, Compound Semiconductor, April 2005

Korean Photonics Technology Institute (KOPTI) with €45.7 million per year (from 2001 to 2008). KOPTI's costs were shared by the Government - 73.1%; Gwanju City of Light (see below) - 16.5% and industry - 10.4%. In addition KOPTI received an equipment budget in 2000 of €50 million. The Korean government's main aim was to adhere to environmental pollution agreements by reducing Korea's energy requirements to help decrease carbon dioxide emissions and allow the country to meet targets set by the Kyoto Protocol. In addition, an increased dependence on LED-based lighting would reduce the use of glass, phosphors and heavy metals widely found in traditional light sources.

In Gwangju, which is also known as the "city of light", the so-called LED Valley project received €77 million between 2005 and 2008 towards a high-brightness (HB) LED development initiative and involved the construction of 310,000 m2 of building space, while a solid-state lighting and display centre with research and development support has been established. Gwangju also received a further €330 million between 2005 and 2010 split between the second phase of a photonics industry project investigating HB-LEDs and a venture to deploy fibre-to-the-home networks to 20,000 households.

In 2006 Korea stated its intention that the proportion of LED lighting by 2015 will reach 30% of the overall development of lighting and proposed some major policies to promote LED lighting to achieve the target. These are described below:

- Firstly, to create the initial market demand for LED lighting, the Korean Government announced In Feb 2009, the "12/30 Project for LED Lighting". This project targets replacing 30% of existing conventional lamps with LED lamps in all government buildings by the year 2012; expanding the scope of application of LED lighting to public street lighting, tunnel lighting, and in the construction of a new city with active use of LED lighting, to ensure outcome driven benefits of investment of the LED lighting-related companies. The Korea Government will invest 540 billion Korean Won (~€355 million) over the next five years to accelerate eco-friendly segments like SSL.
- Secondly, in order to achieve a world-class LED lighting supply chain that could exploit the global LED lighting market, Korea enhanced support for increasing LED luminous efficiency and extend the average life and other related technologies.

- Thirdly, to solve the existing gap of quality on LED lighting products, Korea established standards for LED lighting, which helps accelerate the pace of development of LED lighting certification standards. Korea established LED-based lighting certification standards to replace incandescent, halogen lamps, fluorescent lamps between 2008 and 2009 and plans to promote LED lighting-based certification standards to replace the various existing technologies between 2010 and 2012.

OLED lighting manufacturing in South Korea was enhanced in 2010 with a KRW30 billion (€20.5 million) investment from the Ministry of Knowledge Economy. The investment will deliver fourth-generation processes that will produce OLED panels almost twice the size of products coming off current pilot lines worldwide. Technology produced will enter the market in 2015 for direct lighting[49].

For display technology, Korea is already significant in scale for both manufacturing capability and Government policy.

Samsung Mobile Display (SMD) raised €2.3 billion from its parent companies (Samsung Electronics and Samsung SDI) in March 2011. The money will be used to boost AMOLED production capacity. This investment is part of Samsung's massive €3.7 billion OLED budget for 2011.

In November 2007, the Government established a development project comprising "15 strategic technologies" focused on LCDs, OLEDs, 3-D and flexible displays, as part of its efforts to develop them into next-generation industries.

As a follow-up measure to the new growth engine strategy[50] announced in May 2010, the Korean government established comprehensive measures to cultivate the display industry. From 2010 to 2017, the Ministry of Knowledge Economy will invest €0.32 billion in the development of next-generation display equipment, and parts and materials, and in the reinforcement of the industrial basis.

Major display policies include:

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49 http://joongangdaily.joins.com/article/view.asp?aid=2920060
50 http://www.korea.net/detail.do?guid=54515

- "Council for the development of LCD equipment and materials" set up in 2010
- Planned to initiate the development of equipment and materials for 11th-generation LCDs and 8th-generation
- AMOLEDs from 2011
- Established the patent support centre' and the'eco-display research centre' to promote the development of environment-friendly assembly and equipment
- Planned to initiate the development of flexible plates and production equipment for plastic displays in 2011

Major Display Policy Goals include:

- To consolidate Korea's position as global leader of the display industry by actively encouraging panel makers to invest in 11th-generation LCDs and AMOLEDs
- To release AMOLED TVs around 2013
- To concentrate efforts on cultivating the equipment and parts sectors, which are lagging behind Japan in relative terms, by standardising 11th-generation equipment and materials (in terms of size and detail processing), and establishing a collaborative development system

4.4 Taiwanese Initiatives

The Taiwanese Government has provided much in the way of support and niche policies for the local LED industry and up to 2003 it invested €35 million on a five-year "White LED Project", with a further €9.2 million between 2003 and 2005 on the "Next Generation Lighting" project involving a consortium of 11 companies to achieve 50 lm/W output products and 100 lm/W laboratory devices.

In December 2007, the Taiwanese government announced the "Energy Saving Promotion Project for Lighting", with objectives to replace all incandescent light bulbs with energy-saving light bulbs within a short period of time and, in the long run, to replace traditional lighting with

LED lights for better energy-saving performance. The first phase of this project was to replace incandescent light bulbs with their energy-saving counterparts. The Government took the lead by ensuring compliance in all central and local government offices with a target of completion by the end of 2008.

Also in 2008, the government provided guidance to hotels, hostels, homes, farms, and markets for carrying out voluntary light bulb replacements.

It was estimated that once LED lights were popularised[51] that lighting-related electricity consumption in Taiwan will decrease substantially by 40%, or approximately 10.7 billion kW. Total savings in electricity expenditures by the government and the general public is estimated at €0.64 billion.

In 2008, specific regions in Taiwan were selected for the implementation of the "LED Road Lights Demonstration Project."

Moreover, the Ministry of the Interior has revised the Fire Safety Act to encourage the use of LED products for exit and escape lights in residential areas and office buildings. A "Minimum Energy Efficiency Standards for Light Source" has also been established in compliance with the Energy Management Act. Its provisions include that after 2012, the production and sales of low-efficiency light sources such as incandescent lights will be prohibited. This is targeted at specific users such as department stores and hotels and mandatory measures will be taken to prohibit the use of low-efficiency light sources like incandescent lights.

4.5 Chinese Initiatives

Since June, 2003, China's National Ministry of Science and Technology has associated with the National Ministry of Information Industry and the National Ministry of Construction to launch a "National Solid State Lighting (SSL) Program".

[51] The Status of LED Industry Development in Taiwan, Taiwan Department of Investment Services, http://sourcing.taiwantrade.com.tw/db/IndustryOverview/18.LED_Industry.pdf

The successful completion of the Program during China's 10th Five Year Plan, has seen the SSL industry in China establish a relatively complete R&D system from processing of epi-wafers, fabrication of chips and packaging of devices to integrated applications. China State Council released the "National Medium and Long-Term Program for Scientific and Technological Development (2006-2020)" strategy in 2006 and "energy-efficient and long lifetime SSL products" have been listed as priority topics in the "most important energy" field.

In February 2006, China formally inaugurated its national solid-state lighting program as part of its 11th Five Year Plan. The high tech sector growth has been highlighted by the Chinese Government as key to China's future development, and LEDs are seen as an indispensable part of that sector. Currently, only 10% of China's GDP comes from high-technology and 88% of that, results from foreign companies located in China or from joint ventures with Chinese companies. Therefore, one goal of the national SSL program is to stimulate domestic production through the use of public-private partnerships.

To address the R&D needs for SSL, China budgeted €33.8 million during the 11th Five Year Plan. Participation will include more than 15 research institutions and university research labs, as well as more than 2500 companies involved in LED wafers, chips, packaging and applications. Protection of IP is a significant concern and a major element of the SSL program, although China also believes that no single enterprise should be able to monopolise the technology or markets.

Additionally, Chinese companies receive extensive funding from government sources enabling them to capture a major share of soaring domestic demand. For example, local governments in China subsidise at least 70% of the cost, €1.15 million on average, for each purchase of a machine that performs Metal-Organic Chemical Vapour Deposition (MOCVD), a process used in the manufacturing of LEDs[52]. Such equipment subsidies represent 50% of the capital costs and have driven current orders for equipment up to 1600 machines that will deliver huge output quantities of LED from 2011 onwards, helping to reduce costs of LEDs significantly.

[52] Semiconductor today, "Chinese Burn into LED market driving MOVCD", Vol 5, Issue 7, Sept 2010

Local authorities also offer tax and utility payment benefits to Chinese LED suppliers, which is estimated to spur €2.7 billion in spending for each year from 2010 to 2012 on LED-related manufacturing equipment among Chinese LED suppliers.

According to the Chinese Solid State Lighting Alliance, China already has a complete SSL industrial supply chain, with more than 4000 enterprises, and 2009 sales of €9.1 billion. China has a Municipal Showcase Project involving 21 cities that had already installed over 1.7 million LED fixtures (including 200k roadway lights, and 720k in architectural applications).

The Chinese Government has supported four LED industrial areas and seven national LED industrial parks. China's National Development and Reform Commission has set industrial targets for 2015, of sales in excess of €57.7 billion annual electricity savings of 100 billion kWh, and the creation of 1 million jobs. By this stage, China aims to have 2-3 large-scale LED chip companies and 3-5 leading SSL application companies.

On the 7 September 2010, the Ministry of Science and Technology of the People's Republic of China published a feasibility report[53] of the implementation of a new programme to create efficient semiconductor lighting in key materials technology research and development. The report sets out the investment in the National High Tech R&D Programme of the Twelfth Five Year Programme. The project has determined key technologies and research assignments, including an emphasis on increasing the size of silicon substrates for white light LEDs, a target 150lm/W white light capable LED engineering research, a focus on highly reliability and low cost white light LED industrial production technologies and on white light OLED illumination.

The project focuses in promoting the international core competitiveness and independent innovation ability of China's semiconductor illumination industry that is outlined in "the National Medium and Long-term Science and the Technological Development Plan Summary (2006-2020 Years)".

In 2010, Chinese LED suppliers captured 2% of the market. While Chinese HB-LED technologies are currently three years behind the rest of the world it is expected that huge investment in the SSL industry by 2015 will

[53] http://www.most.gov.cn/eng/programmes1/200610/t20061009_36225.htm

help close the gap. Investments of €13.4 billion have been announced for 2010-2015, and government subsidies and policies are helping to drive initial adoption, for example in street lights. The aim of Chinese interventions is to increase Chinese exports of SSL to €23 billion and to create an additional 1 million jobs.

Chinese market research firm Gaogong LED has identified 46 companies that announced investments in epiwafer and chip production during 2009-2010. The total of the announced investments during this period was €12.8 billion), for an average of RMB2.46 billion (€282 million) per company. Approximately 62 percent of this investment is for epiwafer production (i.e. MOCVD reactors).

It is important to realise that the investments described above do not all take place all at once, but rather are planned for the period 2010-2015. If all of these announced plans are carried out, approximately 2,000 multi-wafer MOCVD machines will be installed in China in 2011-2015, compared to a total of 130 in operation at the end of 2009, and 327 in operation at the end of 2010. Figure 33[54] demonstrates how subsidies have helped China become the biggest market for MOVCD shipments between 2010 and 2011.

In 2009, the "Plans for Adjustment and Promotion of the Electronic Information Industry", approved by the State Council of the People's Republic of China, announced support for sixth-generation and above LCD panel projects.

Key support will be given to key enterprises to construct several production lines of large-sized TFT-LCD and PDP panels and form large-scale panel production capability.

Additionally, policies such as a scheme for providing household appliances to the countryside, old-for-new service and HDTV broadcast, stimulate both the rural and urban consumer markets and further the development of China's LCD panel industry.

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[54] MOCVD and LED Supply/Demand Outlook, Ross Young, IMS Research, July 19th 2010, Semicon West

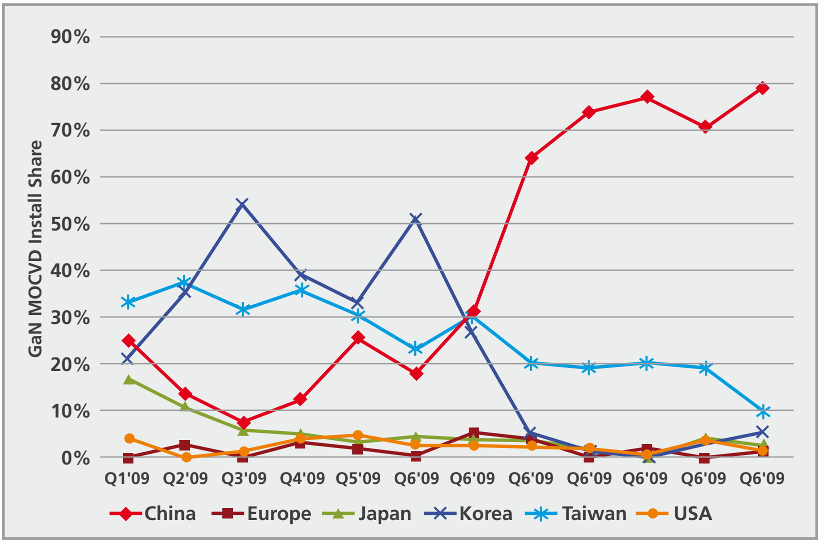

Figure 33: MOCVD Worldwide Installation Share

Under an initiative aimed at sourcing 50% or more LCD TV panels within the country, the Chinese government will support the construction of manufacturing lines that are 6th-generation or beyond for Chinese manufacturers currently focusing on the production of small and mid-size LCDs under the 5th-generation.

The Chinese government also imposes a 3% tariff on imports of FPDs below 26 inches to protect domestic panel makers who have relatively small-scale 5th-generation manufacturing capacities (there is no tax for panels above 26 inches). However, with more domestic high generation capacity being developed, import taxes on larger panels are likely to materialise in the future, furthering the incentive to locate display fabs in China.

The Chinese government continues its support for the OLED industry, including special funds from the Ministry of Industry and Information Technology (MIIT) and import taxes on new display materials. In 2010, Chinese companies shipped 1.35 million OLED displays, up 38.2% over 2009. OLED makers in China include Visionox, Shanwei Truly, Sichuan CCO and Irico. Both Shanghai Tianme and Irico are in the process of building 4.5-generation AMOLED fabs, with mass production planned to start in 2011. BOE Display and Sichuan CCO are also engaged with AMOLED R&D.

These extensive and continual support programmes have resulted in more than 4,200 companies in China being identified as participating in the LED industry, including upstream, midstream and downstream (i.e. epitaxial wafers and chips, packaging, and systems) companies.

4.6 Analysis of Initiatives and their Transferability to Europe

As described above, the support for Solid State Lighting initiatives elsewhere is extensive. Governments are placing huge commitments on the implementation of industrial policies to support supply chain development and encourage uptake of lighting by end-users. It seems clear, therefore, that global initiatives, where successful, are due to Government leadership and leadership from specific SSL industry pioneers and that similar initiatives across Europe are less developed due to internal market and government fragmentation.

Figure 34 and Figure 35 review and rank the initiatives in terms of scale of support needed for successful implementation in Europe as well as the level of successful transferability. It is clear that the majority of the initiatives can be easily transferred to a European context, however, Europe could leverage some of the work already undertaken such as standards development and market appraisal, as well as targeting areas that are not being addressed elsewhere.

Programme	Originator	Description	EU Implementable	Explanation	Investment Scale
Basic Energy Science	US DOE	Basic research programme to provide understanding of materials behaviour to impact future directions in applied research and technology development	High	The European Commission could provide a programme across workstreams dedicated to Basic Material Science of LED and OLED Lighting.	€10's millions
Core Technology Research	US DOE	Core Technology Research involves applied research efforts to seek more comprehensive knowledge by filling technology gaps, provide enabling knowledge or data and represents an advance in knowledge base.	High	This programme could be replicated within Europe and be focussed on step change research including production tools for large size substrates, new substrate materials such as silicon or GaN and Quantum Dots amongst a variety of other topics.	€100's millions
Product Development	US DOE	Technical activities are focussed on a targeted market application with fully defined technical, commercial and performance parameters necessary for the success of the proposed project.	High	This programme could be replicated within Europe and support to develop innovative, high quality, high performance lighting products. Significant support for near market product innovation would accelerate the adoption of high quality, high performing SSL luminaires	€100's millions
Manufacturing R&D Initiatives	US DOE	Manufacturing projects focus on achieving significant cost reductions through improvements in manufacturing equipment, processes or monitoring techniques	High	The European supply chain strength would be actively increased through the support of the equipment and measurement techniques used in the manufacture of LED and OLED technologies.	€100's millions
Commerciali-sation Support	US DOE	To ensure that the R&D investments lead to SSL commercialisation the DOE has developed a national strategy to guide market introduction of SSL for general illumination.	High	There is a need to support the market entry into Europe and the majority of US programmes should be implemented.	€10's millions
Standards Development	US DOE	The development of national standards and rating systems for new products enbles consumers to compare products.	Medium	The development of standards could be supported by the European Commission however it is recommended that the support is used to ensure that standards are developed in a non-competitive manner.	€ millions
SSL Partnerships	US DOE	This programme helps support activities within expert partners such as NGLIA, IES and IALD to help define standards, guides and promotes lighting to stakeholders.	Medium	Support of partners is more difficult throughout Europe as the market contains a significant number of individual stakeholders in various countries. Although there is CELMA and ELC they only represent a fraction of the SSL community.	€ millions
Patents and Publications	US DOE	All IPR generated as a result of funding by the DOE would be available to participants for exploitation.	High	The European commission could implement an IPR agreement throughout all its support programmes which enable EU based SME companies access to the IPR which would stimulate growth and economic activity.	€ millions
Buyer and Specification Guidance	US DOE	Support for Energy Star, SSL Quality Advocates, Retailer outreach and Lighting Design Guidance	High	Priority support should be given to an Energy Star equivalent that actually engages with industry and procurers to set performance levels. Less emphasis needs to be given on Lighting Design Guidance as this has already been covered internationally.	€ millions
Design Competitions	US DOE	This programme supports high profile design competitions such as the Lighting for Tomorrow (Residential) and Next Generation Luminaires (Commercial)	High	Europe should support similar high profile competitions for both Residential and Commercial applications however Europe should focus on integrated systems and higher value solutions such as high spectral content lighting, system efficacy rather than fixture efficacy and user interface quality metrics which will provide differentiation from the US programmes.	€10 millions

Programme	Originator	Description	EU Implementable	Explanation	Investment Scale
Gateway Technology Demonstrations and Procurement	US DOE	This programme supports demonstrations to test field performance and market readiness, Technology Demonstration Consortia and Procurement	High	The European Commission has begun to implement procurement strategies and technology demonstrator projects however the implementation isnt significant and a considerable amount of additional matched funding should be put in place to accelerate commercial SSL deployment across Europe.	€100's millions
CALiPER	US DOE	This programme supports the market testing of SSL and traditional light fixtures and provides important trend information on quarterly basis. The programme encourages the improvement of high quality designs to various stakeholders	High	There is a desperate need for a market testing and performance programme across Europe. Such a programme will provide vital information and real data on the quality and performance improvement of SSL products. This programme will help monitor, maintain and increase the quality metrics for the European SSL industry and enable stakeholders to review product performance.	€ millions
Energy Star	US EPA	Energy Star is an international standard for energy efficient consumer products operate by the Environmental Protection Agency which now includes SSL products.	High	Either Europe could adopt the SSL Energy Star criteria or develop its own equivalent of Energy Star. An important factor for success of these types of labelling endorsements is the brand recognition they have with end users.	€ millions
Federal Green Grants and Tax Deductions	US DOE	The US Recovery Act has enable the support of incentives for stimulus grants for large infrastructure developments	High	Europe could support large infrastructure projects that demonstrate energy efficiency technologies on a large scale. This could be implemented by leveraging the Regional Structural Funds already in place and putting restrictions on bids that mean they must include SSL technologies as a priority.	€ billions
Energy Policy Programmes	Japan/ Korea	There are several Asian countries which have implemented Energy Policies to support LED lighting.	High	Europe needs to coordinate Energy Policy with Technology Development policies to provide an economic environment for the private sector to fluorish and increase sovereign Energy security.	€ millions
Street Lighting Support	China/ Taiwan	China and Taiwan have supported the active roll out of LED streetlighting within selected Cities.	High	Europe could easily implement a support programme for deploying outdoor lighting across 20 cities in Europe for implementation by 2020. The support programme could support capital expenditure only with the host cities contributing to commissioning and operating expenses.	€100's millions
Supply Chain Development	China/ Taiwan/ Korea	China, Taiwan and Korean Governments have significant programmes in creating, enhancing and investing in their respective supply chain industries. Subsidies include capital equipment contributions, reduced corporation and income tax as well as export credits.	High	Europe could develop a Capital investment support policy that would enable companies to obtain contribution funding support to create production lines in Europe. This support could be focused on LED and OLED emitter technology manufacturing so that both downstream (Modules and Fixtures) and upstream (materials and equipment suppliers) suppliers can be created or developed further.	€ billions
Investment Funding	Russia	Russia through various state-owned investment vehicles are investing in technology companies.	High	Europe needs to create a community-owned investment vehicle that is specifically focussed on energy efficiency technologies and high growth SME organisations. The EU investment vehicle can be used to leverage private market investments but its immediate use is to address the current financial market failure of technology investments.	€ billions

Figure 34: Evaluation of Major Research and Market Activities for Energy Efficient Lighting

Programme	Originator	Description	EU Implementable	Explanation	Investment Scale
Basic Energy Science	US DOE	Basic research programme to provide understanding of materials behaviour to impact future directions in applied research and technology development	High	The European Commission could provide a programme across workstreams dedicated to Basic Material Science of OLED displays Lighting.	€10's millions
Core Technology Research	US DOE	Core Technology Research involves applied research efforts to seek more comprehensive knowledge by filling technology gaps, provide enabling knowledge or data and represents an advance in knowledge base.	High	This programme could be replicated within Europe and be focussed on step change research including production tools for large size OLED and e-paper displays.	€100's millions
Manufacturing R&D Initiatives	US DOE	Manufacturing projects focus on achieving significant cost reductions through improvements in manufacturing equipment, processes or monitoring techniques	High	The European supply chain strength would be actively increased through the support of the equipment and measurement techniques used in the manufacture of OLED and e-paper display technologies.	€100's millions
Patents and Publications	US DOE	All IPR generated as a result of funding by the DOE would be available to participants for exploitation.	High	The European commission could implement an IPR agreement throughout all its support programmes which enable EU based SME companies access to the IPR which would stimulate growth and economic activity.	€ millions
Energy Star	US EPA	Energy Star is an international standard for energy efficient consumer products operate by the Environmental Protection Agency.	High	Either Europe could adopt the Energy Star criteria or develop its own equivalent of Energy Star for energy consumption of displays. An important factor for success of these types of labelling endorsements is the brand recognition they have with end users.	€ millions
Supply Chain Development	China/ Taiwan/ Korea	China, Taiwan and Korean Governments have significant programmes in creating, enhancing and investing in their respective supply chain industries. Subsidies include capital equipment contributions, reduced corporation and income tax as well as export credits.	High	Europe could develop a Capital investment support policy that would enable companies to obtain contribution funding support to create production lines in Europe. This support could be focused on OLED and e-paper manufacturing so that both downstream (displays) and upstream (materials and equipment suppliers) suppliers can be created or developed further.	€ billions
Investment Funding	Russia	Russia through various state-owned investment vehicles are investing in technology companies.	High	Europe needs to create a community-owned investment vehicle that is specifically focussed on energy efficiency technologies and high growth SME organisations. The EU investment vehicle can be used to leverage private market investments but its immediate use is to address the current financial market failure of technology investments.	€ billions

Figure 35: Evaluation of Major Research and Market Activities for Displays

Europe's Current and Future Perspectives for Market Positioning in Identified Green Photonics Areas and Related Applications

5

5.1
Energy Efficient Lighting

5.1.1 SWOT Analysis – Current Perspectives and Market Positioning

The current competitive position of energy efficient lighting in Europe, including current and emerging technologies is summarised in the following SWOT analysis.

Strengths

- Europe is a world leader in OLED lighting fixtures
- A strong R&D science base in key LED & OLED material technologies
- Large leaders have substantial IP portfolio
- Strong European industry in high power semiconductor /modules
- European networks to provide good platform for discussion, cooperation and joint research
- Expertise in associate materials and electronics technologies.
- Well respected lighting design community
- Installation and management capability
- Good relationships throughout the value chain in the professional market
- Public sector commitment to supporting energy efficiency
- European Union has invested heavily in OLED technologies

Weaknesses

- Fragmented/uncoordinated approach to research and markets compared to Asia and the USA
- SME sector lacking global scale and capability
- Limited participation of SMEs in R&D programmes; limited access to state-of-the-art knowledge and infrastructures
- Poor Investment in sector for growth (No innovative VC and Seed funds)
- Lack of automated manufacturing capability. Production volume of LED chips is small in EU.
- Fragmented market and supply chain. LEDs are packaged in Asia.
- SME manufacturers lack scale to command global market and no support for growth
- Next generation of engineers – shortage of students specialising in Lighting technologies
- Limited user/market awareness of economic & ecological benefits of SSL (Lack of large scale demo projects). Outside perception of SSL as unproven
- Cost: devices, installation (retrofitting), maintenance
- Poor market surveillance/quality awareness
- Lifetime, quality of Light and cost are not mature
- Lack of full building models incorporating lighting
- Lack of standardisation (source, connectors, control protocols, performance evaluation etc.)

Opportunities

- World energy situation – energy efficiency, cost savings and energy security
- Meeting EU CO2 emission targets
- Capture fast growing world market for SSL solutions
- Energy efficiency: cost reduction potential and drive industry in Europe via regulatory targets – Phase out of incandescent lamps
- Large Innovation potential: S&T knowledge, SMEs, intelligent lighting, ageing society, health effects
- EC Public-Private Partnership (PPPs) "Energy- Efficient Buildings"
- Market opportunities - Wireless sensor networks, data gathering and processing, intelligent control, power electronics for actuation and control.
- Development of effective exploitation infrastructure
- Develop significant European supply chain - (O)LED Manufacturing in EU
- SMEs can act as diffusion of technology
- Implement lower VAT on efficient products, higher VAT on products with old technology
- Large public procurement sector - Realize benchmark projects in large cities and government buildings
- Create pricing structure based on lowest cost over lifetime
- Higher future demand for quality energy efficient lighting
- Reduce Carbon Footprint by manufacturing of (O)LEDs in Eastern EU
- Focus on higher end & specification markets e.g. hotels, hospitals etc.

Threats

- Insufficient long-range planning and coordination of technology policy
- Slowness of end-users to adopt to new technology
- Public focus on ICT only, limited awareness of SSL
- Key European industries could be taken over by competitors from Asia providing low quality products.
- Strong engineers resources in emerging countries in Asia (China, Taiwan, India)
- Falling numbers of EU based graduates in technical courses
- High European sovereign debt, lack of Finance and investment
- Slow responsiveness by universities to rapidly-evolving technologies and poor articulation of industry research needs.
- Low cost incumbent Lighting Technologies
- Loss of sustainable industrial infrastructure due to imports from Asia
- Dominance of Asian LED and OLED production
- Rising oil prices effecting supply chain especially OLEDs
- Non-EU Governments strongly supporting or subsidising an SSL ecosystem
- Attractive incentive regimes elsewhere
- Reliance on rare-earth elements for LED Phosphors – China main product

Figure 36: SWOT Analysis for European Energy Efficient Lighting Industry – Current Position

The SWOT analysis (Figure 36) indicates that although Europe has been historically strong in lighting, it is now threatened by low cost and poor quality imports from Asian competition most notably China, Korea, Japan and Taiwan. Increased competition is now challenging the European leadership in lighting through substantial and coordinated Government interventions outside of Europe. Such interventions are creating new supply chains in disruptive LED and OLED lighting technologies which will dominate the global lighting market over the next two decades.

The key points in the above SWOT can be discussed in more detail as follows:

- Strengths

  - The European energy efficiency lighting market offers a strong platform to compete globally with leading lighting brands including Philips, OSRAM, Schneider and Zumtobel combined with an excellent science base covering materials (CDT, NOVALED, Nanoco, IQE), processes and production tool development (Aixtron, Oxford Instruments).
  - Europe is currently seen as a world leader in OLED lighting fixtures which has occurred through the substantial support of public sector funding (between €300 and €500 million over the last 5 years or so) along with a very well respected research and development science base in both OLED and LED materials technology.
  - A further European strength is in the global brands of Philips and OSRAM that have accumulated substantial vertically integrated IP across both the LED and OLED value chain. The size and strength of the IP is significant and will enable Europe to operate globally. The IP portfolios of Europe's leading organisations are also a threat as it could be used for negative gain by creating barriers for innovative European SME's which may need to be monitored by the European Commission.
  - Europe is also host to a large, vibrant and well respected lighting design and architect community with considerable expertise in lighting. There are many lighting designers that have been used on prestigious landmark buildings around the world. In general, the European lighting design community will specify lighting systems from European lighting manufacturers enabling an excellent opportunity for European exports.

- The European commitment to reducing greenhouse gas emissions is a strength as it ensures that energy efficient lighting including LED and OLED technologies will be very high on the agenda of public sector organisations initially and subsequently the residential community (when energy price increases escalate towards 2020). The impending European energy security issues are a key opportunity for LED and OLED technologies as this will be a key driver of market penetration from the period between 2015 and 2020 and enable Europe a chance to meet its CO_2 commitments.

Support for LED and OLED value and vertically integrated supply chains could enable Europe to capture a significant part of a fast and disruptive global market. These disruptive technologies offer Europe a large innovation potential that offers energy efficiencies, societal benefits such as improving health and well-being through quality lighting.

- Weakness

  - Europe has so far had a fragmented and uncoordinated approach to energy efficient lighting unlike its global counterparts in the USA, China, Korea, Taiwan, Japan and Russia. All of the global competitors have understood the advantages of LED and OLED technologies and believe that there is an excellent opportunity to enter the market and challenge Europe's leadership position. The European SME lighting sector is highly innovative but highly fragmented and therefore SME's do not have the scale and international capability to grow without substantial support.
  - The financial crisis and sovereign debt issues within Europe have made it extremely difficult for the SME sector to raise investment capital to grow and this is a significant weakness as the transition of the lighting sector is occurring at speed and thus European companies are disadvantaged.
  - Many of the current lighting supply chain actors require education regarding the new lighting technologies in order to understand high quality from low quality products, how best to specify and utilise the (O)LED products and how to best utilise the new functionality of these products in applications.
  - The lack of standards relevant for the new lighting technologies is also providing an opportunity for low quality products to enter the supply chain. It is however important that standards are not

developed exclusively by industry as this will act as a barrier for the innovative SME sector. The European Commission should act as a leader in orchestrating the formation of standards that could affect future market competitiveness.

- One weakness is the reduction of engineers and scientists capable of developing lighting systems due to the ageing population and other factors that divert the highest level undergraduates from taking scientific and engineering studies. For example, there is now a distinct shortage of power electronic engineers that are capable of designing AC to DC power supplies not only for lighting products but any other types of electronic devices.
- Europe and individual member states do not exercise the long range planning and coordination of technology support that their colleagues in Asia demonstrate. Although Europe provides long term strategic research planning this is not sufficient to capture the wealth generated from innovation and this is where Asian countries excel by creating a complete supply chain which creates market demand by pulling through R&D capabilities. Europe will need to respond with a long term market demand and supply chain strategy for new disruptive technologies.

- Opportunities

  - The opportunity for Europe is to concentrate on two segments of the market. The first being the sole domain of the large global brands such as Philips and OSRAM that could partner to create LED retrofit bulbs for the residential market in order to remain competitive against Asian manufacturers with large scale manufacturing capabilities. The second opportunity exists for the higher end and specification lighting market which requires more innovation, systems design and quality lighting products that may be serviced by both the SME and global players. Further opportunities exist by changing public sector procurement practices to enable energy efficient lighting to be adopted.

- Threats

  - A significant threat to Europe is the acquisition of innovative lighting technologies from competitor nations enabling them to gain substantial IP positions in key technologies. This threat is currently being executed with Samsung recently acquiring Liquavista, Cooper Industries acquiring a variety of European lighting companies and Sumitomo Chemical acquiring Cambridge Display Technologies. The lack of finance and investment will force innovative SMEs that need investment to either sell the business before they obtain a dominant market position or fail to reach critical mass.

- China and Korea have heavily invested in the next generation of energy efficient lighting with large scale LED and OLED production lines being developed over the next 5 years that will dominate global manufacture. This is a significant threat to Europe which needs to be acknowledged and countered in order for Europe to remain a dominant player in energy efficient lighting. The import of low cost lighting products could create an unsustainable industrial supply chain infrastructure across Europe which could manifest in the lack of high level market pricing control and inflationary pressure.
- Additionally low cost incumbent technology, which has been heavily subsidised previously, does not offer the same energy saving potential as LED and OLED lighting. For example, low energy halogen and Compact Fluorescent Lamps have significantly less efficiency that current LED technologies yet their upfront capital cost is inhibiting market penetration against the more costly LED equivalents. Europe should consider legislation that makes current incumbent technologies less cost effective through whole life or supports the introduction of LED and OLED technology within the market. According to McKinsey & Co[55] the average CFL price is USD2 to 3 without government subsidies, and government subsidies in China for residential use are 50% of the price at present which limits LED penetration worldwide.

A lack of standards has been highlighted in the weaknesses above. Key areas where new/enhanced standards are required include:

- LED fixture lifetime: There currently is no metric for LED/OLED system lifetime or standard methods for evaluating/predicting LED fixture lifetimes. Currently, the industry is using “incorrectly” the LM-80 lumen maintenance standard to state lifetimes of LED fixtures but this standard only predicts single LED emitter lumen depreciation and this is only one factor in a complex lifetime issue. This standard should also

[55] McKinsey & Co, “Lighting the way: Perspectives on the global lighting market” 2011

look to define the actual end of life of LED fixtures as there are no definitions (or if there is e.g. L70 then this can be overcome with constant lumen electronic systems which reduce overall system efficacy).

- Standards for LED/SSL flicker and stroboscopic effects: The majority of SSL lighting systems required high frequency switching electronics for efficient control however there are some serious potential health and usage issues such as the switching frequency, current ripple magnitude and stroboscopic effects. Recent studies in the USA show that humans are able to view ripple current effects up and stroboscopic effects up to 10,000 Hz. One or more standards need to be developed to make sure the health and safety effects are monitored. Currently, the market has implemented very poor low cost LED driver solutions that have low frequencies e.g. 100Hz with ripple currents up to 80% that could cause health or safety aspects at home or work.

- Enhanced quality of light metric definitions: Currently the lighting industry uses colour rendering index as a means of quality but this is not appropriate for all light sources and although the Colour Quality Scale (CQS) initiative is being reviewed by the International Commission on Illumination (CIE) it has not become a standard. Therefore, a new standard needs to be developed which also discusses how lighting can be addressed for different environments such as outdoor lighting and can be compared with older lamp technologies. For example, LED lighting has been shown in some US studies to offer the potential to reduce the actual lumens for street lighting by up to 40% of some high pressure sodium and metal halide lamp solutions due to the favourable power spectral densities of LEDs. Current standards will not allow the reduction of illumination on the road therefore it is not possible to take the advantages of using LEDs with more favourable power spectral density (PSD).

- There is no standard definition for acceptable colour shift or power consumption over the lifetime of an LED fixture which means that when a consumer purchases an LED product they do not know what variances should be expected over the lifetime of the product. This was less of an issue with traditional lamps such as CFL as most of them only last a few thousand hours and as such can be replaced, however, with LEDs offering the potential for up to 10-20x the lifetime, there needs to be metrics to define changes in acceptable characteristics.

The standards needs examples identified above are just as appropriate for OLEDs as for LEDs.

5.1.2 Market Development

Energy efficient lighting (in particular LEDs) has already penetrated certain lighting market segments, six of these are shown in Figure 37. For example, signage or channel lettering used to be delivered almost entirely by neon tubes but within the last three years the majority of installed signage illumination has been LED based.

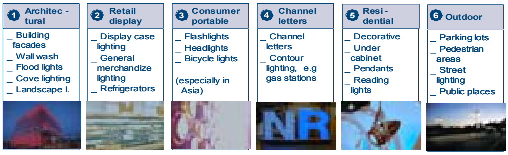

Figure 37: Lighting Market Segments where LEDs have Already Made an Impact (OSRAM)

It is difficult to estimate precisely how and when certain aspects of energy efficient lighting will significantly penetrate the general lighting industry due to the uncertainty of key trigger points being achieved in both cost and light output. Figure 38 attempts to provide an indication of the application areas penetrated by certain timescales[56].

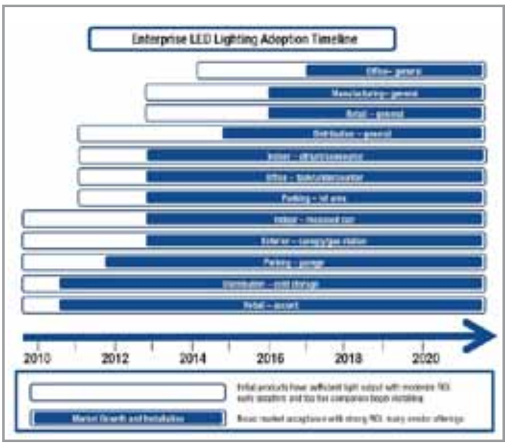

Figure 38: LED Lighting Adoption Timeline

[56] Groom Energy LED Report from GTM Research

However, it is expected that the rapid increase in white LED output per package and lumens per watt efficacy is enabling the period of 2010 – 2015 to witnesses the rapid growth of white LED penetration into high lumen exterior lighting applications.

Current estimates by the US Department of Energy expect energy efficient lighting technologies to have achieved 90% penetration of the annual lighting market by 2020 as shown in Figure 39, representing a worldwide market value of approximately €119 billion. The majority of the energy efficient lighting products within this timeframe will be based upon inorganic LED technology as volume OLED based devices will only begin to emerge.

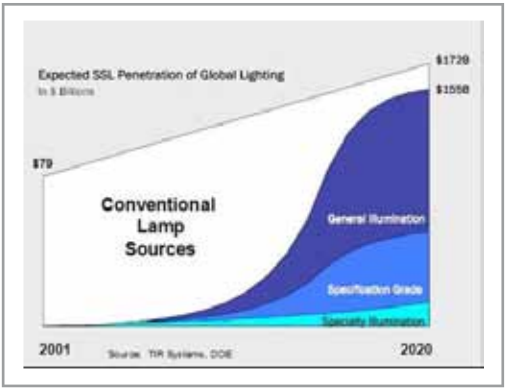

Figure 39: The Expected SSL Penetration of Global Lighting by 2020

The categorisation used in this figure can be described as follows:

- General illumination - mainly residential lighting applications and other aspects of lighting where lower quality of light is accepted such as in residential, channel lighting, consumer lighting and outdoor lighting.
- Specification Grade illumination - higher specified lighting which requires excellent colour and light properties such as high colour rendering index lighting for use in offices, retail and hospitals amongst other high end lighting applications. The quality of light also includes consistency of light between fixtures and therefore meets specifiers' requirements. This is usually commercial lighting for offices etc.
- Speciality illumination – entertainment lighting such as colour changing LED fixtures for stage, TV and theatre as well as for example UV LEDs for back lighting etc

The largest product group by market size will be general illumination. In the medium term this product group will require very little control, exhibit low profit margins and will be heavily commoditised. In the medium to long term the General illumination product group will be dominated by manufacturers from low labour cost countries such as China and India. However, in the short term there is an opportunity to supply early adopters with this product group whilst creating value.

It is predicted that the start of LED penetration in residential lighting or interior functional lighting, that replaces either incandescent or CFL light bulbs, will be commonplace by 2012-2015.

5.1.3 Future Market Potential – Key Technologies

The future market potential has already been presented for both LEDs and OLEDs as follows:

- Figure 12 show the annual sales forecast for light bulbs indicating a 90% market penetration for LEDs by 2020
- Figure 17 details the expected market growth of the LED die and emitter market for each market segment. This market forecast does not relate to the part- or finished- products within the market sector but how much revenue is generated by the LED emitters sold into these products
- Figure 18 shows the market forecast in US$ billions for LED fixtures within a variety of lighting applications. The reason the figures are lower than in figure 46 is because it relates to LED general lighting fixtures whereas figure 46 looks at wider LED emitter sales which are dominated by mobile phone back/flash lights, automotive lighting and other sectors not deemed as general lighting.
- Figure 22 indicates the potential market for OLED in 4 key applications (backlighting, photonic lighting, automotive and signage) and how the markets will develop – achieving a market value of around €5 billion and €10 billion in 2015 and 2020 respectively. This 2020 figure is less than 10% of the total market
- Figure 39 shows one prediction of how solid state lighting (LEDs and OLEDs) will capture €119 billion of the total lighting market

All of this data underlines the significant market penetration expected for LEDs by 2020 and more limited growth in the OLED market demand.

5.1.4 Future Market Share for Europe

The future market perspectives for Europe depend on which part of the supply chain being considered. For LED die and emitter packages it is expected that the European market share will diminish quite rapidly without significant investment in the equipment to manufacture LED emitter products. Figure 40 shows the installed capacity in LED wafers per month based on 4 inch wafer size equivalents in the first quarter of 2011 – with Europe and the Middle East being 10% of the size of Japan and Taiwan. Furthermore European expenditure on LED manufacturing equipment[57] over the 2010 to 2012 period will be much less than other regions simply exacerbating the current position.

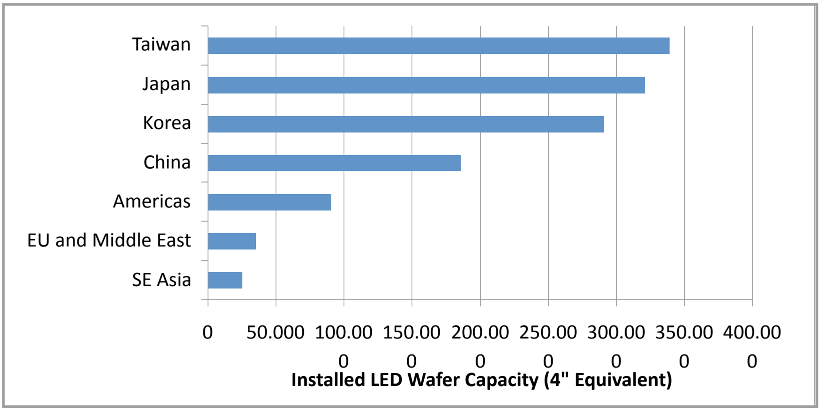

Figure 40: Installed Global LED Wafer Capacity

If, however, the manufacture and supply of lighting fixtures is considered, a stronger European position is foreseen with the main opportunity to 2020 being retrofitting of existing systems.

5.1.5 SWOT Analysis – Future Perspectives for Market Positioning

The future perspectives for market positioning can therefore be presented as follows:

[57] SEMI Opto/LED Fab Watch, 2011

Strengths

- Europe extends it's world leadership of SSL Lighting solutions.
- Science base remains strong but focussed on providing solutions to SSL technology challenges.
- SSL actively helping to meet the EU 2020 CO2 emission targets
- European Lighting Companies focussed on exporting SSL solutions
- European companies enlarge IP portfolios with latest innovations
- Growing internal market is increasingly catered for by European manufacturers with advanced lighting solutions (not just low cost fixtures)
- Healthy & diverse European SSL supply chain with a robust European industry for high power semiconductors / OLED lighting and Light engines.
- Highly educated supply chain and end users enabling strong procurement decisions to be made.
- Enhanced technologies embedded with the supply chain (solid state lighting, energy harvesting, power electronics and integrated sensors)
- Lighting design community operating in international stage with SSL
- Economic environment to support high growth SME business
- Strong EU policies that drive the adoption of SSL technologies and restrain expansion of lower efficiency or toxic lighting

Weaknesses

- Lighting Investment often based on CAPEX rather than OPEX which may slow down the adoption of energy efficient lighting
- Fragmented market and supply chain with only a handful of global players
- Next generation of engineers - shortage of students specialising in Lighting and AC power electronics technologies
- OLED technology performance and cost will lag that of inorganic LEDs
- Full building investment models incorporating lighting still embryonic
- Lack of private or financial funding prevents growth opportunities being secured
- Standardisation will be new to industry
- Light sources
- Connectors/Communication
- Control Protocols

Opportunities

- Support European Energy Security through substantial - energy efficiency and savings
- Strengthen the export development of the lighting market opportunities
- Wireless communication networks
- Data gathering and processing
- Intelligent control
- Power electronics for actuation and control
- Creation of significant European supply chain for OLED and LED technologies
- Strengthen European Lighting Industry against foreign competition
- Realize benchmark projects in large cities and government buildings
- Create pricing structure based on lowest cost over lifetime
- Increasing energy costs will help reduce SSL return on investment and increase market penetration
- EU lighting companies provide trade surplus of lighting equipment based on SSL

Threats

- Insufficient long-range planning and coordination of technology policy
- Public/Government focus on ICT only, limited awareness of SSL
- Key European industries could be over taken by competitors from Japan, China, India and Russia
- Lack of engineering skills restrict the expansion profile of the EU market
- High European sovereign debt and lack of Finance inhibits high growth potential of the SME sector
- Economic slowdown
- Rising oil prices effecting supply chain especially OLEDs
- Rising investment in SSL production capacity throughout Asia
- World Governments supporting or subsidising their SSL ecosystem
- Lower cost base countries developing SSL capability through significant infrastructure investment;

Figure 41: SWOT Analysis - Future Perspectives for Europe

This analysis indicates that, if there is significant investment in Europe and new technologies are successfully deployed, then the industry, which is currently very fragmented, will build around some global players and Europe will cement its current leading position. However, the dependence on (mainly) the Far East for basic LED devices and the competitive threat from lower cost economies will remain.

5.2
Displays

5.2.1 SWOT Analysis – Current Perspectives and Market Positioning

The current competitive position of the display market, including current and emerging technologies is summarised in the following SWOT analysis.

Strengths	Weaknesses
• Europe is a world leader in OLED research • A strong R&D science base in key OLED & organic electronic technologies • SMEs have substantial IP portfolio • Significant national funding programmes supporting OLED research • European networks to provide good platform for discussion, cooperation and joint research • Capability for innovation in display sector • Production of base materials for OLED manufacture • Process equipment manufacture for OLEDs • Content production and stock of titles for e-books • Production of basic materials for e-paper manufacture • Printing technology know-how • High level of innovation in displays	• SME sector lacking global scale and capability • Poor Investment in sector (No innovative VC and Seed funds) • Production volume of displays is minimal in EU. No base. • Lack of industrial productive capacity or eco-system to support low-cost volume production • SME manufacturers lack scale to command global market and no support for growth • Lifetime, Quality of Light and cost are not mature for new display technologies • Capability to bring innovations to market – i.e. probability of export market success • Lack of branded consumer goods suppliers apart from mobile handsets – e.g. Nokia • Ability to move from innovation to mass production and weakness in ecosystems • Probability of export market success for finished devices against large Asian branded suppliers with diminished industrial base in consumer electronics
• Possible renaissance in OLED manufacturing at low-cost, perhaps in Eastern Europe • Use of IPR – with mitigations through agreements • Expansion in base OLED materials supply and process equipment manufacture for low temperatures • Large Innovation potential: S&T knowledge, SMEs • Develop significant European supply chain - (O)LED Manufacturing in EU • Large public procurement sector - Realize benchmark projects in large cities and government buildings • Possibility to establish a slight first mover advantage if i.e.-paper industrial base reinforced • Production of e-paper, display screens and e-readers in Europe, driven by the publishing industry • New markets and application that cannot be achieved by LCD on glass	• Key European industries could be taken over by competitors from Asia providing low quality products. E.g.; Liquavista and CDT • Significant investment in production capacity for next generation display technologies by emerging countries in Asia (China, Korea, Taiwan, India) • High European sovereign debt, lack of Finance and investment • Older technologies – TFT-LCDs which improve technically – become cheaper, flexible, lower power demands and better colour/contrast, scale up larger, etc, make existing (LCD) players far stronger • Strong competitive position and behaviour of current major players both globally and in the EU market make market entry difficult or increasingly impossible • Dominance of Asian LED and OLED production • Rising oil prices effecting supply chain especially OLEDs • Non-EU Governments strongly supporting or subsidising displays ecosystem • Strong competitive behaviour of major e-paper players, large and small, from the USA as well as Asia both globally and in the EU market • Entry of China in e-readers and e-paper
Opportunities	**Threats**

Figure 42: SWOT Analysis for European Display Industry – Current Position

This analysis can be discussed in more detail as follows:

- Strengths
  - The European displays market is highly respected as a leader in OLED materials research vital for successful OLED display manufacturing. The leadership position has been created from a strong R&D science base including key university groups which has been expanded to organic electronics know-how, which could prove valuable for e-paper based display systems. Substantial public funding in organic and large area electronics has been provided by the European Commission and national governments which has enabled Europe to take a leadership position in OLED and e-paper display technologies.
  - Europe has been a strong innovator in new display technologies for more than 40 years and it has a capability for future displays innovation which combines high precision printing and material processing.
  - Europe is home to OLED process equipment leaders which offer an opportunity to create a vertically aligned supply chain with low cost manufacturing of new OLED displays in Eastern Europe. Europe also contains significant publisher and content providers which would be ideally placed to exploit the latest e-reader products and offer a high value exploitation route to market.

- Weakness
  - A significant weakness is that SME manufacturers lack the scale to command the global displays market and there is not a wide level of financial support for SMEs to grow. This has been clearly demonstrated with early leaders in novel displays technologies seeking funding outside of Europe such as CDT and Plastic Logic whilst others have been acquired by overseas organisations such as Liquavista.
  - The displays market in Europe doesn't possess the large number of branded goods suppliers such as Korea (LG and Samsung) and Japan (Sony, Panasonic, Hitachi, Pioneer) which means there are very little routes to market for displays technologies. Nokia offers one such route, however, it is firmly placed in small mobile devices such as mobile phones that require smaller display technologies.

- Opportunities

The opportunity for Europe is based on the potential to transform the output of its world class research and innovation into a mass production capability.

- Threats
  - However, Europe has also found it difficult to translate world class research and innovation into a mass production environment within Europe mainly due to a weak displays ecosystem. A substantial threat to Europe comes in the form of large scale investment of OLED and e-paper display production capacity in Asia which could mean that Europe only plays a minor role as shown by the current LCD displays market.
  - Further threats to OLED and e-paper displays are the continued strength and technical performance improvements of incumbent LCD technologies which inhibit the adoption of new display technologies. Today, the cost of LCD display technologies is low and the rate of improvement of technical specifications such as colour gamut, contrast ratios, switching speed as well as 3D features means that the advantages heralded by new display technologies are not as great as perhaps a few years ago. There are new technologies for LCDs such as LED backlights and Quantum Dot backlights that enable lower cost and improved features being currently developed that will further enhance the LCD lifetime

5.2.2 Market Development

The global display market trends to 2015 and 2017 have already been shown in Section 2.2.5. These figures show a maturing market (at around €100 billion per annum), dominated by LCD technology.

5.2.3 Future Market Potential – Key Technologies

As indicated above and shown in Figure 20, LCD will remain the dominant technology for the foreseeable future. OLED technologies are expected to achieve a market of around €6 billion per annum in 2017 as shown in Figure 23 and e-paper technologies are expected to achieve a market of over €3 billion per annum by 2016, although the e-paper technology which will dominate the market is not yet clear. Thus, these emerging technologies are expected to gain less than 10% of the market by 2016/17.

5.2.4 Future Market Share for Europe

The majority of LCD manufacture is already established in the Far East and this situation is likely to remain in the future. As already indicated Europe is in a strong position in OLED and other emerging display technologies and it is expected that Europe can gain a major share of developing markets if there is sufficient investment in manufacturing to exploit the significant R&D investments to date.

5.2.5 SWOT Analysis – Future Perspectives for Market Positioning

The future perspectives for market positioning can therefore be presented as follows:

Strengths

- Europe retains an R&D capability in OLED displays
- Significant national funding programmes supporting OLED and e-paper research may still exist
- Production of base materials and equipment manufacturing tools for OLED and e-paper industries remains strong in Europe
- Content production and stock of titles for e-books
- Production of basic materials for e-paper manufacture
- Printing technology know-how
- A significant European supply chain - (O)LED and e-paper Manufacturing in EU has been created due to a 10 year industrial support strategy providing confidence to the private sector to invest in the EU
- EU captures new niche markets and applications that cannot be achieved by LCD on glass with focused research and exploitation programmes

Weaknesses

- Few SME's left to exploit innovation as many have failed due to lack of funding or have been acquired by Asian manufacturers
- Investment Market Failure remains so difficult to raise investment funds for remaining SME's or University Spin-outs.
- No production facilities for OLED displays in Europe so no opportunity to create a viable and sustainable local displays supply chain.
- SME manufacturers lack scale to command global market and no support for growth
- Capability to bring innovations to market
- Lack of branded consumer goods suppliers as established companies will have been acquired by US or Asian market players.
- Probability of export market success for finished devices against large Asian branded suppliers with diminished industrial base in consumer electronics

Opportunities

- Possible renaissance in OLED manufacturing at low-cost, perhaps in Eastern Europe
- Leveraging of IPR – with mitigations through agreements
- Expansion in base OLED materials supply and process equipment manufacture for low temperatures
- Large public procurement sector - Realize benchmark projects in large cities and government buildings
- European Industry acquires Asian displays companies and gains ownership of manufacturing facilities for exploiting IPR.
- European Universities transform into R&D and exploitation organisations to capitalise short falls in public funding providing more sustainable industry supply chain. Less of a spin-out culture but more of a create-in culture.

Threats

- Funding programmes are significantly reduced as politicians and civil servants focus scare funding monies to more sustainable sectors.
- Research & Development gravitates towards the production base and the EU relinquishes its intellectual lead over Asian Pacific countries.
- Significant falls in EU Innovation and Manufacturing due to Austerity measures and High European sovereign debt, lack of Finance and investment
- Older technologies – TFT-LCDs which improve technically – become cheaper, flexible, lower power demands and better colour/contrast, scale up larger, etc, make existing (LCD) players far stronger
- Dominance of Asian OLED/e-paper IPR becomes and exploitation barrier
- Financial Stability
- Non-EU Governments continue to strongly support or subsidise displays ecosystem
- China become major displays and e-readers consumer and manufacturing base

Figure 43: SWOT Analysis – Future Perspectives for Europe

Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

6

6. Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

Significant and timely investment in energy efficient lighting, especially the exploitation of new LED and OLED technologies will result in positive economic, social and environmental impacts for Europe with the creation and safeguarding of jobs as well as reducing the reliance on imported and increasingly costly energy from outside of Europe.

6.1 Economic Impact

In 2008, a selection of 1000 lighting companies across Europe employed approximately 98,608 people and had a cumulative turnover of €17.9 billion equating to a turnover per employee of €181,000. This translates to an approximate profit per employee of €12,608[58]. Extending these figures to 2014 and 2019, based on Western European lighting market forecasts[18], indicates a turnover of €18.5 billion in 2014 and €21 billion in 2019 and the creation of a further 101,000, and 115,641 jobs in 2014 and 2019 respectively compared to 2008. This predicted job creation will occur directly in the lighting supply chain at the fixture and electronic controls manufacturing stage. The benefits of a strong lighting fixture and electronic controls eco-system enables further job creation within system integrators, lighting system commissioners and installers none of which are included in the job creation figures as they may operate across several different sectors.

[58] Plimsoll Market Report, "Top 1000 European Lighting Companies", Aug 2009

It has been difficult to locate published data on GDP, GVA or job creation for the lighting sector worldwide let alone Europe. In addition, none of the major global companies could estimate either the global number of employees or forecasted increase/decrease within the global lighting sector. It is important to note that as Europe is a recognised leader in general lighting then future investment and support in the sector will significantly de-risk future job losses and help retain high value jobs within Europe.

An analysis of the scale of the market can be carried out based on numerous sources of data, as follows:

- In 2010, Philips Lighting reached a turnover of €7.6 billion and employed approximately 53,000 worldwide providing a GVA per employee of €143,400[59]
- Philips estimated that the global illumination market (excluding automotive) was approximately €55 billion giving them approximately 13.8% global share
- Assuming a similar turnover to employee ratio the global number of employees for the lighting industry would be close to 385,000
- However with the increasing dominance of lower fixed cost Asian countries within the lighting sector this figure could easily reach 500,000 employees within the lighting sector
- Europe in 2009 had approximately 21% of the global market which implies that the number of European employees within the lighting sector would sit within the range of 81,000 to 105,000
- However the ELC and CELMA state this would be closer to 150,000 employees within Europe[60]

This is shown in the following figure:

	Philips Lighting (2010)	Global Illumination Market		European Market Share	
Turnover	€ 7.600.000.000	€ 55.000.000.000		€ 11.550.000.000	
Employment	53.000	383.553	500.000	80.546	150.000
Turnover per employee	€ 143.396	assume Philips data	€ 110.000	assume Philips data	€ 77.000

Figure 44: Estimation of Scale of the Global and European Lighting Industries

[59] Philips, "Fourth Quarter and Annual Results 2010 Information Booklet", Jan 2011.
[60] CELMA & ELC, "The European Lighting Industry's Considerations Regarding the need for an EU Green Paper on Solid State Lighting", 2011

It is estimated that many of the jobs created in the lighting sector will be attributed to new technologies such as LEDs and OLEDs especially in the design, manufacturing and sales of lighting fixtures. Further it is expected that a significant proportion of the jobs created will be within the SME sector rather than from the top 45 lighting companies as new companies dedicated to the (O)LED products will be created and grow. These trends are already being noted. For example:

- Philips LED based sales grew 37% from 2009 and represents 14% of their total lighting sales or approximately €1 billion.
- The Chinese coordinated SSL programme aims to create Chinese exports of SSL of €0.76 billion and 1 million additional jobs[61]

6.2 Social Impact

There are a number of social benefits of solid state lighting including:

- **Improved visual comfort and quality of light:** SSL lighting fixtures are able to dynamically change colour temperature and offer high colour rendering enabling excellent working and leisure environments
- **Improved Safety:** SSL lighting fixtures can be dynamically controlled to dim or detect the presence of users that increase safety and well-being especially in outdoor lighting applications such as street, park and amenity lighting
- **Reduced Light Pollution:** The use of dynamic SSL lighting fixtures combined with smart lighting controls to reduce the amount of light required for a particular task. Light pollution has been shown to have a negative effect on the environment, impacting plants, animals, and people's sleeping habits
- **Biology and imaging:** Leapfrog advances in quantitative biology, particularly the rapid identification and counting of biological cells through adaptive and fully tuneable reflectance and fluorescence imaging

[61] Jürgen Sturm, ELC Secretary General, "The lamp and luminaire manufacturers' perspective on SSL", Feb. 2011

- **Display systems:** Liquid-crystal-displays and projectors with unprecedented efficiency and brilliancy (wide colour gamut) through polarisation-controlled lighting sources
- **Transportation:** Enhanced visibility (less glare) and safety through polarisation controlled headlights, controlled communicating headlights/brake lights/traffic lights, and interactive roadways
- **Communications:** Fundamentally new modes of broadcasting, communications, and sensing through visual light communication control of solid-state-light sources
- **Human factors:** Reduced dependency on sleep-inducing pharmaceuticals, higher productivity, prevention of certain cancers, and higher quality of life
- **Agriculture:** Efficient plant growth in non-native regions (including space) and non-native seasons

These impacts however cannot be quantified.

6.3 Environmental Impact

There are clear and significant environmental benefits from adopting current LED technologies for a wide range of lighting solutions. Two comprehensive lifecycle assessments (LCAs) have been undertaken - by OSRAM[62] and Navigant Consulting[63] in 2009. The life cycle assessment proves that LED lamps are amongst the most environmentally friendly lighting products. The OSRAM report includes conclusions on resource consumption and primary energy input and also on environmental categories[64] such as acidification, eutrophication, the greenhouse effect, photochemical ozone depletion and toxicity. Three types of lamps were analysed: a 40W incandescent lamp (GLS), an 8 W compact fluorescent lamp (CFL) and an 8 W LED lamp with 6 high power white LEDs.

The main findings of the reports were:

[62] OSRAM, “Life Cycle Assessment of Illuminants A Comparison of Light Bulbs, Compact Fluorescent Lamps and LED Lamps”, November 2009
[63] Navigant Consulting, “Life Cycle Assessment of Ultra-Efficient Lamps”, 5th May 2009
[64] IISI Sustainability Assessment in Internet http://www.steeluniversity.org

- Less than 2% of the total energy demand is needed for production of the LED lamp. The manufacturing phase is insignificant in comparison to the use phase for all three lamps as it uses less than 2% of the total energy demand. This study has dismissed any concern that production of LEDs particularly might be very energy-intensive. Merely about 0.4 kWh are needed for production of an LED (OSRAM Golden Dragon Plus), about 9.9 kWh for the production of the LED lamp including 6 LEDs
- In contrast to the primary energy consumption of incandescent lamps of around 3,302 kWh, CFL and LED lamps use less than 670 kWh of primary energy during their entire life. Thus 80% of energy can be saved by using CFL or LED lamps. The bottom line is that LED lamps are more efficient than conventional incandescent lamps and also ahead in terms of environmental friendliness. Today, LED lamps show improved impact on the environment compared to CFL
- Future improvements of LED lamps will further cut down energy demand. As the efficiency of LEDs continues to increase, LED lamps will be capable of saving more energy and achieving even better LCA results in future
- The total primary energy demand for the LED lamp is 9.9 kWh. The LEDs themselves have a share of 30% of the primary energy demand of the LED lamp, out of which the metals included have a dominant share

Since the LED has massive development potential in comparison to the relatively mature CFL and GLS technologies, a future scenario was calculated. In the near future, LEDs are predicted to achieve 150 lm/W for warm white light and 180 lm/W for cold white light emission. Taking into account losses in the electronic ballast and optics as well as thermal losses, an LED lamp could reach an efficacy of between 100 lm/W and 125 lm/W in the near future. Even this prediction may be short lived as Cree has recently announced that it has developed a 4500K Neutral White LED driven at 350mA which has achieved an efficacy of 231 lumens per watt in the research laboratory. In that case: 100lm/W light output of 400 lm can be achieved with just 4 W of power consumption or 2W with a 200lm/W LED. That would cut down all values for the LED use phase by between one half to one quarter. In the use phase the LED lamp would only need about 335 kWh of primary energy over its lifetime of 25,000 hours, or 100 kWh of electricity. In the manufacturing phase, improvements are also expected as less aluminium will be needed in the heat sink in the future.

Thus, the LED lamp will also be the favoured solution with respect to all environmental impact categories by 2014.

The Navigant Consulting Lifecycle analysis included analysis of further environment factors for both an integrated ballast LED lamp and a dedicated LED luminaire system.

The integrally ballast LED lamp did not score well on hazardous waste landfill and radioactive waste landfill because of its abbreviated operating life assumption (i.e., 20,000 hours). That is, compared to the dedicated LED luminaire, which contains similar parts and components, the dedicated LED luminaire has a smaller impact due to its ability to amortise the impacts over a longer operating life. As with the Osram LCA study, while the energy in the use phase had the dominant impact relative to all other life-cycle assessment stages, the aluminium heat sinks in the two LED products contributed to their relatively poor scores in human toxicity and freshwater aquatic ecotoxicity impacts.

In a recent report[65] it was highlighted that achieving a 20% energy saving using energy efficient lighting would save the following per annum

■ General lighting(global)	€53 billion	296 million tonnes of CO_2	779 million barrels of oil
■ Street lighting (EU)	€1.7 billion	3.5 million tonnes of CO_2	14 million barrels of oil
■ Office lighting (EU)	€2 billion	8 million tonnes of CO_2	29 million barrels of oil
■ Home lighting (EU)	€5 to 8 billion	20 million tonnes of CO_2	74 million barrels of oil

Further this report highlights that a saving of 40% is achievable using available technologies.

In terms of displays the main environmental impact is the energy usage of large area displays which has increased in real-terms compared to traditional cathode ray tubes. For example, a 60 inch flat panel display can consume more than 500W of operational power compared to less than 50W for a traditional CRT TV[66]. The advent of LED backlighting is reducing significantly the power consumed by large area displays and it is forecast that by 2015 the majority of flat panel displays will incorporate LED backlighting.

[65] Philips, “Energy efficient lighting A summary of “Green Switch” facts”, December 2007
[66] “The real impact of impact“,p.17 of Physics World, Vol. 24, No.5 May 2011

A future economic issue will be the ability of sustainable material supply for phosphors used in white lighting applications The policies created to stimulate the switch to energy efficient lighting are predicted to increase the use of lighting phosphors significantly.

The current lighting and LED supply chain is reliant on rare earth materials for the phosphors used. For fluorescent lamps and white LEDs the majority of the rare earth elements required originate from Asia (currently 80% of the world's lighting phosphors in 2010) causing a significant threat to future supply chain security if export limits are imposed. Indeed, phosphors accounted for 7% of all rare earth usage by volume and 32% of the total value in 2008. Emerging lighting technologies have dramatically lower rare earth content than fluorescent lamps. White LED designs eliminate the need for lanthanum and terbium phosphors but still use cerium and europium phosphors to convert blue LEDs to useful white light[67]. Estimated total phosphor demand in 2010 is reported by Lynas Corporation as 7,900 tonnes of rare earth oxide of which 85% is used for lighting (6,715 tonnes). The US Department of Energy[67] estimated that the volumes of rare earth phosphors required for lighting will be between 9,307 (2.2% CAGR) and 11,250 (3.5% CAGR) tonnes by 2025. Therefore, it is vital that Europe develops sustainable lighting products with new technologies to replace rare earth materials such as Quantum Dots or other nanotechnology materials. The most significant risk for phosphors is the element Yttrium as this represented over 69.2% of total 2010 phosphor demand and is deemed by the US Department of Energy[67] as being critical risk for supply in the short term 2010-2015. Interestingly, phosphors and component rare earths are not currently recovered from fluorescent lamps and this provides a great opportunity to developed recycling technologies that could mitigate the reliance on rare earths from China in the future. Furthermore, a dramatic shift to white LEDs and OLEDs will reduce the amount of phosphor materials required to produce white lighting systems reducing the demand for rare earths in lighting and possibly easing future pricing issues.

[67] US DOE, "Critical Materials Strategy", December 2010

Contribution to 2020 Low Carbon Economy Targets

7

7. Contribution to 2020 Low Carbon Economy Targets

The low carbon economy targets set for Europe[68] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

Energy efficient lighting and displays will contribute to the reduction in energy consumption and in the generation of greenhouse gases. As highlighted in section 6.3 above:

- 80% of energy consumption can be saved by using LED lamps rather than conventional light sources.
- Philips estimate[8] that a 20% energy saving using energy efficient lighting would save the following per annum

General lighting(global)	€53 billion	296 million tonnes of CO_2	779 million barrels of oil
Street lighting (EU)	€1.7 billion	3.5 million tonnes of CO_2	14 million barrels of oil
Office lighting (EU)	€2 billion	8 million tonnes of CO_2	29 million barrels of oil
Home lighting (EU)	€5 to 8 billion	20 million tonnes of CO_2	74 million barrels of oil

Furthermore this analysis indicates that a 40% energy saving is achievable.

Therefore, energy efficient lighting is expected to make a significant contribution to the reduction in energy consumption and greenhouse gas emissions.

[68] EUROPE 2020, A European strategy for smart, sustainable and inclusive growth, European Commission, March 2010

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

8

8.1
Solid State Lighting

This section identifies a number of barriers and challenges to the adoption and implementation of Solid State Lighting technologies that need to be addressed in order to realise the full impact and benefits of adoption. One or more of the challenges or barriers highlighted are deemed to have a potential impact on the market size, penetration rates, supply chain, Industrial capacity and capability as well as end user confidence in solid state lighting. In order to ensure lessons are learnt from introducing new energy efficient lighting to the market (such as with CFLs in the 1970s) the barriers will be discussed individually and their impacts explained. All the barriers will need to be considered from a timing perspective and a priority has been assigned to immediate, short-term and mid-term action of possible solutions. Each barrier can be discussed as follows:

- **Early, low- performing SSL products are likely to cause substantial and lasting market damage**

There is a significant risk to consumer adoption of SSL products if the quality of products is not sufficient to meet with consumer expectations of LEDs. The US lighting market suffered a significant set back in the 1970's when early compact fluorescent lamps fell significantly below customer expectations and caused long-term market damage. It has taken more than 30 years for CFLs to gain widespread recognition in the US residential lighting market and by 2006 they still had only about 2% of the national market in terms of unit sales.

In order to overcome any issues of SSL deployment an SSL communications strategy would need to be implemented to improve marketplace knowledge and awareness of SSL. More specifically, the strategy seeks to increase knowledge about the technology's characteristics, appropriate applications, and energy and economic performance in order to maximize national energy savings

- **High Costs**

High quality, high brightness LEDs currently sell at a substantial price premium over fluorescent/halogen lighting when measured on a per kilolumen basis. Even though roadmaps published by the DOE forecasts such differences will continue to decline rapidly, the LED costs will remain higher than conventional lighting for many years to come. Lighting equipment buyers, however, do not purchase light sources by comparing per kilolumen costs. They use such measures as simple payback and lifecycle costing. Careful analysis of the economics of using SSL for individual general illumination applications will be necessary to help guide programme planning and project designs.

As SSL products usually demonstrate a Return on Investment in the mid to long term but investors often look at short term RoI's and therefore growth capital will be hard to attract for SMEs in the fragmented European lighting sector. The lack of access to finance for growth will inhibit the growth profile of SMEs within Europe.

The high initial costs will only decrease with high volume production and therefore the SSL market can be considered within the standard chicken and egg scenario.

- **Low colour quality/high colour correlated colour temperature (CCT)**

A complaint of early generation CFLs was they did not produce warm light and they made skin colour look unnatural. Similarly, many early versions of LEDs being introduced as general illumination products use high-CCT, low-CRI LEDs because they are more efficacious than their warm white counterparts. These products may be defining LED products to the market for a whole generation of potential users, creating the possibility that like fluorescent lamps, LEDs could mean cold, unattractive light for a significant number of potential buyers.

- **Incomplete Standards and Test Procedures**

A number of industry standards and test procedures will be required, and until they are complete, the industry will continue to encounter problems that limit growth of the SSL industry. Among those still needed are those addressing interconnections between system components, LED device and LED array efficacy, and perhaps test procedures for low-cost methods to measure luminous flux from residential SSL luminaires.

- **Will SSL lead to profligate use of lighting?**

SSLs' flexible form factor, low-voltage circuits, and high durability, as well as high potential to become much less expensive and much more efficient combine to create the possibility of a future in which new applications for lighting become so numerous, and LED lighting so ubiquitous, that SSL technology could in the long run lead to more lighting energy use rather than less. This is similar to display technology where the average power consumed by displays has increased rapidly because FPDs are now much larger than their CRT equivalents and consume more power (300W compared to a CRT of 50W).

Rapid Obsolescence

The speed of technology improvement for SSL creates special challenges for their market introduction. Similar to computer hardware during the 1990s, technological improvements for LEDs are being introduced so quickly that systems become obsolete long before the end of their physical lives. For LED based lighting products this barrier is less of an issue as LED technologies have matured rapidly and within the next 2-3 years will have reached the point where their performance significantly outperforms any other light source technology and will make it the light source of choice.

It is slightly different for OLED lighting products as they are an emerging light source technology and are not yet at a performance level that can displace conventional or LED lighting technologies. Therefore, OLED lighting will require additional support.

SSL Product Format

Many of the LED general illumination products being introduced to the market are designed to imitate the function of incandescent lamps, and thus could be retrofit into lighting fixtures designed for incandescent lamp use. A large fraction of these products are poorly designed, from both a thermal management and optical perspective. In short, the limitations of current technology present very substantial challenges for designing LED products intended for retrofit into existing fixtures.

Commercial or Residential Luminaire Emphasis

There is a question of whether to focus efforts on the residential or commercial sector especially as the decision will be specific to each particular countries installed lamp mix. There is significant energy saving opportunity for SSL in applications in residential lighting. However, the commercial market remains the leading candidate for SSL.

It is vital that Government support programmes closely monitor changing economics for both commercial and residential applications, as well as changes in the technology affecting SSLs' suitability for various applications. Resources should be focused on lighting applications and projects most likely to maximize potential energy savings.

● LED Glare

Glare light scattering in the eye causes loss of contrast and leads to unsafe driving conditions, much like the glare on a dirty windshield from low-angle sunlight or the high beams from an oncoming car. In essence bright and/or badly shielded lights around roads can partially blind drivers or pedestrians and contribute to accidents.

Lighting fixture glare is covered by current lighting standards, however, further studies should be undertaken with a focus on glare in SSL based fixtures for different lighting applications. Glare is a lower barrier to market adoption compared to other barriers and therefore it should not be given a high priority.

● Lack of Awareness from Distributor to End Users and Consumers

An issue with lighting is that it has become a commodity resource over the last 100 years and as such there is a low level of interest in how lighting designs are developed from conception. The majority of consumers and end-users of lighting do not see the impact of electricity costs due to lighting and therefore they will not appreciate the full effects of energy saving by changing to highly efficient SSL technologies. End users are generally not aware of the new lighting technologies and their advantages or capabilities.

● Light Pollution

Light pollution is defined as "any adverse effect of artificial light including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste"[69]. Light pollution can be divided into two main types: (1) annoying light that intrudes on an otherwise natural or low-light setting and (2) excessive light (generally indoors) that leads to discomfort and adverse health effects. The prevalent use of lighting, especially outdoor lighting, can have a negative effect on the environment, impacting plants, animals, and people's sleeping habits.

[69] Wikipedia, "Light pollution", http://en.wikipedia.org/wiki/Light_pollution

Perverse Subsidies for Incumbent Technologies

A significant barrier for deployment of LED and OLED lighting is cost as identified previously, however, the differential price between the new technologies and incumbent technologies is distorted through subsidies assigned to Compact Fluorescent Lamps (CFL) that make them highly attractive from a price perspective to consumers.

For example, the mainland Chinese government subsidised the purchase of 62 million CFLs as energy-saving replacements for incandescent bulbs in 2008, and a further 150 million in 2009. In 2010, sales of a further 150 million CFLs were subsidised making it difficult for new lighting technologies to compete commercially[70].

The barrier can be overcome with relative ease through the removal of subsidies to CFL products and divert support to LED and OLED based lighting products. This single action would increase CFL market prices to a more sustainable and realistic level whilst providing a significant boost to the adoption of both LEDs and OLEDs fixtures through subsidised pricing that makes the products more attractive.

Lack of Innovation in SSL Marketplace Due to Innovative Funding Deficit

Despite a large and innovative SME lighting market there is little evidence of innovative product exploitation. One significant barrier to successful exploitation is that many of these Small and Micro sized companies do not have access to low cost routes of investment enabling them to grow and leverage their technology know-how. The Venture Capital market has not delivered the intended growth of high technology companies within Europe whilst access to finance investment through traditional private banking facilities has all but dried up since the financial crisis started in 2008. This barrier has significant long term consequences for Europe as many of the SME companies will not be able to invest rapidly in new SSL technologies which are vital to establish a long term, vibrant supply chain with such a disruptive technology. One initiative to overcome this barrier would be to help develop finance support interventions specifically for technology companies that would normally be considered outside of standard commercial lenders risk profiles.

[70] http://news.cens.com/cens/html/en/news/news_inner_32453.html

Principal-Agent Conflict

A significant barrier (rated second in importance after cost) to commercial lighting penetration is that of principal agent conflict between the mismatch of interests between the building contractor who pays the initial price of the lighting and the user who usually pays the running costs. Although LED lighting can be shown to provide a superior cost of ownership over most traditional lamp based lighting solutions, the resistance to adopt by principal contractors inhibits the adoption and energy saving opportunities afforded by energy efficient lighting.

SSL is not Considered an Important CO_2 Abatement Technology

LED and OLED technology has a low profile when it comes to greenhouse gas abatement discussions compared to other green-related technologies such as photovoltaic cells, heat pumps or efficient air conditioning units.

Intellectual Property

As the high brightness LED industry origins emanate from industry rather than academia the importance of Intellectual Property Rights (IPR) is paramount for commercialisation and freedom to operate in the LED space. Continuously over the last decade there have been significant numbers of legal matters relating to LED lighting and related technologies which have diverted resources away from innovation and into court rooms. The Japanese government had seen the potential barriers of the LED IPR in the middle of the last decade and the government brokered an agreement between all LED Japanese manufacturers not undertake litigation amongst themselves which resulted in the LED companies focusing on innovation and market penetration instead of courtroom action.

It is suggested that a similar scheme is developed within Europe to enable SMEs to take advantage of the growth opportunities.

These barriers can be summarised and categorised as follows:

Barrier Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
High Costs	Financial	High	Immediate	€billions	Market penetration in all sectors will be determined by the capital cost compared to traditional light sources. The SSL costs are prohibitive and therefore subsidised 5 year market entry programmes are required to bring forward adoption. Various programmes should be developed specifically for each segment.
Perverse Subsidies	Financial	High	Immediate	€millions	A significant barrier to SSL adoption is the use of market and trade subsidies for incumbent light sources such as CFLs that inflate the price differential between new and old light sources. The barrier can be overcome by removing subsidies for traditional light sources and replacing them with new market support subsidies for SSL products
Principal-Agent Conflict	Regulatory	High	Immediate	€millions	A significant challenge rated second only to cost for commercial lighting adoption is the conflict of between principal agent that owns the building and the tenant or user of the building. The principal agent has no incentive to invest in higher cost lighting as they do not pay operational costs which lie with the tenant. Regulation could be developed to either encourage principal agents to invest in energy efficiency lighting or a tax can be levied on the energy efficiency of buildings towards owners.
Intellectual Property	Technical/ Regulatory	Medium	Immediate	€millions	IPR issues have reduced the development speed of SSL technologies as most IPR has been generated commercially. Significant resources have and continue to be tied up in litigation rather than technical or market development and over 90% of IPR is owned by the top 6 LED manufacturers providing a dangerous market position that will suppress SME development and innovation. Government regulation could support innovation and growth of the SME sector through the adoption of an IPR agreement amongst EU based organisations.
Low Quality Lighting	Regulatory	Medium	Immediate	€millions	CFL market penetration suffered due to poor quality products on introduction. Europe cannot afford to let this happen to SSL. Need to create enforceable quality standards and European market surveillence programmes.
Incomplete standards	Regulatory	Medium	Mid Term	€millions	SSL products need standards to be updated or created to take into account the new light source characteristics. Several standards already exist however worldwide harmonisation is not apparent. Standards bodies are reacting in a slow manner meaning the technology is leading the process. The EU should encourage the acceleration of community wide defined standards including academia
Materials Development	Technical	Medium	Mid Term	€10's millions	OLED lighting requires significant materials development in order for it to succeed in the marketplace. Long life, high brightness, high efficiency light emitter materials are still required as well as low cost oxygen and moisture barrier material. Research support should be given to developing such materials in order for OLED lighting to succeed.
Quality of Light	Technical	Low	Mid Term	€10's millions	SSL products initially offered poor quality of light including low CRI and inconsistent CCT. The quality of light is increasing however the LED industry is driving develops. Support will be required for R&D into new wavelength converting materials and high spectral content light sources
Rapid Obsolescence	Technical	Low	Mid Term	€10's millions	A barrier for SSL is the speed of technical improvement increases the risk for end users to invest as they could wait for another 6 months and get a better light for less price. This means the market may delay purchasing new technology. This is more of a concern for OLED lighting as its development lags behind that of LEDs. Market education investment will be required to reduce the effects of this barrier. This should be focused at end-users and wholesale retailers
Proligation of Light	Regulatory	Low	Long Term	€millions	The use of light has expanded significantly to aid productivity however it is important the use of light is optimised otherwise energy consumprion for lighting could increase rather than decrease.
Market Priorities (commercial Vs Residential)	Financial / Regulatory	High	Immediate	€billions	Market support programmes offer limited resources for support and it is difficult to determine the priorities between commercial and residential lighting. This challenge is difficult to assess as the markets will develop at different pace however a combination of financial market support for residential applications combined with regulatory support that bans inefficient light sources that have a low improvement factor such as Halogen and CFLs will ensure both sectors will utilise SSL products in shorter timescales.

Barrier Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
Innovative SME growth	Financial	High	Immediate	€100's millions	Access to growth funding for SMEs is minimal in the current economic climate with the majority of financial institutions focusing on risk adverse opportunities. The lack of low-cost funding availability is suppressing innovation and SME growth in a dynamic and disruptive market. A European investment programme should be created for high growth SMEs focussing on priority sustainable technologies that can demonstrate market ready products within 3 years.
Supply Chain Support	Financial / Regulatory	High	Immediate	€100's millions	The European SSL supply chain provides significant global prescence for its size however in order to maintain technical superiority and a robust supply chain considerable support programmes should be developed to encourage capital spending on SSL production equipment. This can be supported through the development of an EU wide Green Investment Bank and a variety of Tax incentives
Market Performance Information	Technical	Medium	Immediate	€10's millions	The SSL industry often claim high performance, long life, low maintenance and energy efficiency figures which are superior to other technologies however much of this information is not validated for accuracy. Support programmes should be developed to assist users with proof of market feasibility for various applications and sectors.
Lighting not considered an important CO_2 abatement technology	Regulatory	Medium	Immediate	€millions	SSL technology is low profile compared to other greenhouse gas abatement technologies so Governments tend to subsidise other sectors that have a smaller impact reductions of GHG. Education and regulation of SSL technologies are required across european Governments in order to meet 2020 commitments and achieve improved energy security.
SSL Product format	Regulatory	Medium	Mid Term	€millions	Many SSL products are being developed for retrofit applications and this provides a limited scope for the advantage of new light sources. This is limited for LEDs but a significant challenge for OLED adoption as OLEDs do not conform to standard lighting formats. It may be possible to overcome this challenge with new standards and regulations.
LED Glare	Technical	Low	Mid Term	€10's millions	SSL products initially offered poor quality of light including low CRI and inconsistent CCT. The quality of light is increasing however the LED industry is driving develops. Support will be required for R&D into new wavelength converting materials and high spectral content light sources
Market Awareness	Regulatory	Low	Mid Term	€millions	The majority of decision makers in commercial and residential lighting are not technology aware and therefore cannot determine technology advantage against cost. Regulatory changes will determine customer choice similar to the phasing out of the incandescent bulb. It would be also possible to provide some end user awareness campaigns regarding energy efficient use of lighting that promotes new technologies such as LEDs and OLEDs
Light Pollution	Technical	Low	Mid Term	€millions	Light pollution is defined as the adverse effect of artificial light both outdoors and indoors leading to discomfort or excessive lighting. The use of LED lighting will be able to reduce light pollution effects as it offers a highly directional source that is also easily controlled. The challenges of light pollution will be overcome through industry efforts such as integrated control systems and improved optical systems for luminaires.

Figure 45: Barriers to Development and Adoption of Energy Efficient Lighting

8.2
Displays

This section identifies a number of barriers and challenges to the adoption and implementation of new display technologies. As the majority of LCD display manufacturing is undertaken in Asia the focus is on OLED and e-paper technologies as they could be manufactured in Europe due to their embryonic production status.

These barriers and challenges are detailed below:

- Technology / Product
    - Concerns about the performance and reliability of new technologies and suppliers. This is especially the case for OLED displays
    - Performance not fully exploited or proven yet
    - The OLED efficiency for blue colours is a limiting factors for the lifetime of the displays approximately 5 to 30k hours compared to >50k hours for LCD
    - High production and product costs compared to LCD displays
    - Limited screen sizes for current OLED production
    - E-displays are currently monochromatic and slow switching performance
    - High volume manufacturing processes for large OLED displays based on roll-to-roll or printing technologies not readily available. High cost and limited supply chain
    - Sunlight readability for AMOLED displays is currently poor compared to LCD displays
    - Current LCD technologies are improving rapidly especially with LED backlighting units and costs are reducing
    - Need alternative ITO materials for low cost transparent conductors
    - Need low cost alternatives for encapsulation materials to improve lifetimes, meet commercial specifications and enable flexible displays

- Market
    - Customers have become technology agnostic with the latest displays i.e. displays have achieved an acceptable level of performance in terms of colour, video speeds and features so new technologies have to offer something different

  - There are no killer applications for flexible displays
  - OLEDs have a poor image of a technology looking for an application. It has a slow market penetration
  - There is a lack of content for 3D displays

- Financial
  - Products have to compete with low price incumbent technologies making it difficult to support heavy investment into new technology supply chain
  - No strategic investments into the manufacturing supply chain

OLEDs, being organic polymers, suffer from degradation of the basic material, affecting the lifespan of displays. Such degradation occurs through chemical processes, especially oxidation, so OLEDS slowly lose their light emitting properties. The current materials used are expected to last between 10,000 and 14,000 hours although this is expected to improve. This implies a screen usage of 5.5 years for a 7 hour per day usage although this falls far short of current LCD lifespan at 50,000-60,000 hours.

While OLEDs can produce full colour images using the RGB matrix just like current LCD FPDs, the three OLED chemicals producing the red, green and blue colours have different ageing rates and brightness gains with age. In order to keep the display colour unchanged during their lifetime, compensation algorithms are required. Thus a key element is the signal-processing unit. Moreover, if an active TFT matrix is used for an AMOLED, it is often based on amorphous silicon, like an LCD. But with AMOLED technology, the light emitted is produced by the backplane itself and not through a separate backlight. The increased use of the TFT introduces further ageing issues – the more a pixel is used, the less efficient is the pixel-driving transistor. Thus, automatic compensation is also required to achieve a constant level of brightness over the matrix.

Furthermore, although printing is seen as the future for inexpensive organic electronics, there is still some way to go in developing both the materials and the processes. More specifically, some of the most widely used organic electronic materials, those based on small molecules (SMOLEDs), do not lend themselves to solution processing. Thus, today, perhaps 90% of the printed OLEDs are still created using vapour deposition of small molecules.

In order to reduce production costs and increase volumes, the industry needs to move towards materials and processes for process flow, if possible at closer to room temperatures with the OLED layer being in water soluble form for printing or coating attachment processes, in a roll-to-roll mode. This involves preparing solutions of the various organic materials for solution processing techniques (spin coating or inkjet printing) onto the substrate. Solution-processing methods – inkjet printing in particular has the potential to be a lower cost approach, scalable to large area displays.

Looking at current display technologies most flat panel displays, such as LCDs, consist of two main elements:

- a backplane to select which pixels on the display matrix of cells turn on and off
- a frontplane that either emits light, or acts as a shutter controlling the light coming from another source, at those pixel locations determined by the backplane.

Conventionally, fabrication of the transistors, which form the backplane switches, is by deposition of a thin layer of silicon on to a glass substrate, followed by standard semiconductor manufacturing techniques to create the transistors and associated circuitry. However, these processes require high temperatures, and perhaps in-vacuo techniques of masked deposition, making such backplanes expensive to manufacture while precluding use of a low melting point substrate such as a plastic. These barriers and challenges can therefore be summarised as follows:

Barrier Descrip-tion	Barrier Classifi-cation	Impor-tance	Action Timeline	Relative Cost to Implement	Explanation
Material Costs	Technical	High	Immediate	€10's millions	The market penetration of OLEDs and e-paper will in-part be determined by the material costs of the light emitters, backplane and encapsulation technologies. In order for OLED and e-paper technology based displays to reduce in cost materials research programmes should be supported to develop low cost alternatives.
Low Volume Manu-facturing	Technical	Medium	Mid Term	€100's millions	OLED and e-paper technologies are not able to be scaled to large production volumes due to low volume manufacturing processes. Research programmes should be focussed to develop high volume manufacturing processes including Roll to Roll. Support for companies wishing to invest in EU production facilities should be provided in order to attract global investment funds.
Display Lifetime	Technical	Medium	Immediate	€10's millions	The lifetime of OLED display materials is still limited by comparison to LCD displays and research projects focussing on increasing the lifetime of materials for OLED displays would enable this barrier to be overcome
Fast multi-coloured e-paper displays	Technical	Low	Mid Term	€10's millions	E-paper technologies are currently slow and monochromatic however future e-paper displays will be required to show animations in full colour in high resolution. Research priorities and programmes should be developed to focus on implementing fast, high resolution and multicoloured e-paper displays
Supply Chain Support	Financial / Regulatory	High	Immediate	€100's millions	The European Display supply chain is small and fragmented and there is no strategic investments into manufacturing of new display technologies resulting in a worsening of the supply chain. Strategic investments in the OLED and e-paper supply chains would provide focus for R&D activities and enable EU to partly support its internal market demands.
No killer application for flexible displays	Application	High	Mid Term	€ millions	The use of flexible displays will be limited until a substantial application is developed that utilises the benefits of flexible displays. Research into user applications of flexible displays could determine high growth applications and stimulate future market demand for such devices.
Incumbent technology is improving	Technical	High	Mid Term	€ millions	LCD displays have improved their performance significantly which provides a challenge to OLED and e-paper technologies at the market entrance criteria is continually being increased. LCDs currently provide quality performance and end-users are not compelled to change technologies.
Production Screen Size	Technical	Medium	Mid Term	€10's millions	The size of OLED and e-paper displays are currently limited by the lack of high yield large area production equipment. Research and Development activities should be focussed on equipment suppliers to develop the next generation of production equipment.
Lack of 3D content	Application	Low	Mid Term	€10's millions	The lack of 3D content for displays will effect the deployment of 3D displays and content provision. Investment should be made in developing applications to exploit 3D displays.

Figure 46: Barriers to the Development and Adoption of Display Technologies

Potential Intervention Options

9

9.1 Energy Efficient Lighting

The major barriers to development of the European energy efficient lighting industry have been assessed and the following actions to address these barriers have been identified:

1. **High Capital Cost** of energy efficient lighting compared to traditional light sources. Energy efficient lighting capital costs are currently uncompetitive and this will inhibit market penetration.

   This barrier can be overcome by:
   a) Subsidised market development programmes, such as demonstrator programmes and investment incentives.
   These programmes should focus on public sector infrastructure and industrial and commercial buildings
   b) RDI and commercialisation programmes, including near market R&D and proof of concept programmes

   These should focus on near market technologies such as those listed in section 3.1 to endeavour to develop more cost effective technologies

2. **Subsidies** for other light sources, such as compact fluorescent lighting, that are inflating the price differential of energy efficient lighting.

   This barrier can be overcome by revising the subsidy regime. This may include:
   - Removal of subsidies for other light sources and introduction of a disposal tax
   - Introduction of similar subsidies for energy efficient lighting products
   - Discounted energy prices for energy efficient lighting users

3. **Principal-Agent Conflict,** where there is no incentive for the principal (the infrastructure owner) to invest in higher cost lighting as they do not benefit from subsequent lower operational costs.

This issue can be addressed by:

a) Energy cost incentives for energy efficient lighting use
   These may include capital grant support for investment in energy efficient lighting or subsidised prices for energy efficient lighting products
b) Development of innovative cost models for energy efficient lighting investment

These would enable the investor in energy efficient lighting systems to share in the subsequent saving in energy costs.

4. **Competing Market Priorities** between commercial and residential markets that are difficult to determine due to uncertainties about how the markets will develop.

   Investment in market development programmes in both market sectors will catalyse growth of both. This can be achieved by capital grant support for investment in energy efficient lighting or subsidised prices for energy efficient lighting products.

5. **Incomplete Standards.** New standards are required that take into account the characteristics of energy efficient lighting products.

   A standards development programme is required that addresses the need for standards for, e.g.
   - LED fixture lifetime
   - Flicker and stroboscopic performance
   - Light metric definitions
   - Colour shift and power consumption performance

6. **Lack of SME Growth** and suppression of innovation due to the lack of attractive RDI and manufacturing support funding.

7. **Supply Chain Competition** that is threatening the strong position of the European energy efficient lighting supply chain.

   These two barriers can be address by business development support programmes. These programmes should include:
   a) Proof of concept programme, focusing on the near market technologies listed in section 3.1, above

b) Capital grant support programmes for investment in energy efficient lighting production equipment.

These intervention options can be summarised as follows:

Intervention Options	Key Barriers to Deployment						
	High Capital Cost	Perverse Subsidies	Principal-Agent Conflict	Competing Market Priorities	Incomplete standards	Lack of SME Growth	Supply Chain Competition
"Subsidised market development programmes – Prototype development programmes – Demonstrator programmes"	●						
"Subsidised market development programmes – Investment incentives – Capital grant programmes"	●		●	●		●	●
"R&D and commercialisation programmes – Near market R&D – Proof of concept programmes"	●					●	●
Revised subsidy regimes		●	●	●			
Standards development programme					●		

Figure 47: Potential Interventions to Address Major Barriers to Uptake

9.2 Displays

The major barriers to development of the European display industry have been assessed and the following actions to address these barriers have been identified:

1. **Materials costs** of key components are currently not competitive for OLED market development.

   This barrier can be overcome by RDI programmes focusing on development of high performance, low cost materials options.
   These should focus on emitter, backplane and encapsulation materials technologies.

2. **Supply chain structure.** The European displays supply chain is small and fragmented and there is no apparent strategic technologies iden-

tified for development.

This barrier can be also be addressed by RDI Programmes. These should focus on OLED device development and manufacturing technologies as well as materials.

3. **No "killer" application for flexible displays** that will drive investment in development, commercialisation and manufacturing.

   Investment in demonstrator programmes that would show the performance of flexible displays in key target applications (e.g. newspapers, e-books) would catalyse interest and investment in key applications

4. **Incumbent technologies are improving,** reducing the interest in investment in new technologies.

Performance improvements in OLED technologies are essential to achieve competitive performance. Investment in materials, device and manufacturing RDI programmes will enhance performance and thus the competitive position of OLEDs

These intervention options can be summarised as follows:

Intervention Options	Key Barriers to Deployment			
	Materials Costs	Supply Chain Structure	No "Killer" Application for Flexible Displays	Competitiveness of Incumbent Technology
"R&D and innovation programmes – Materials / devices / manufacturing technologies"	●	●		●
Demonstrator Programmes			●	

Figure 48: Potential Interventions to Address Major Barriers to Uptake

PHOTONICS TECHNOLOGIES

and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Annex 3:

Energy Efficient Communications Technologies and Applications

17th February 2012

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Executive Summary

Executive Summary

This document reviews energy efficient communications applications of photonics. It summarises a specific green photonics technology, assesses its current and potential future markets and identifies potential intervention options to maximise the development of European activity.

Photonic technologies already play a central role in today's telecommunications and data infrastructure. They underpin the infrastructure (from information provider to end user), data networks, data centres and communication networks. The supply chain includes the manufacture of electro-optic materials, components and devices and their subsequent integration into communication networks.

Key existing photonics technologies range from materials (e.g. optical fibre, silicon, III-V materials, liquid crystals and numerous other electro-optic materials) to components (e.g. lasers, photodetectors, modulators, filters, amplifiers and switches) and to systems and sub-systems (e.g. photonic integrated circuits, gigabit-capable passive optical network (GPON), wave division multiplexing (WDM), next generation passive optical network (NGPON) and synchronous optical network / synchronous digital hierarchy (SONET/SDH)). These are being developed to address demand for high capacity fibre based communication networks and infrastructures.

The current market for photonics in communications is driven by the dramatic growth in demand for capacity in communication networks. This is due to the bandwidth demands of the new mobile and fixed technologies that are being adopted by consumers. The optical communications equipment market is expected to grow from €10.4 billion in 2010 to €17 billion by 2017[1] while the optical communications component market is expected to double between 2009 and 2020 to €6.2 billion[1]. European companies or companies with significant European operations[2] were estimated to have a 45% market share of the global optical networking

[1] Photonics 21 Strategic Research Agenda, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf

[2] European companies include, for example, Draka, Gooch and Housego, Genexis, Proximion, Alcatel Lucent and Ericsson while global companies with major European operations include Corning, Oclaro, Cisco and Fujitsu.

equipment market in 2008[3]. There are key European players at all stages of the photonics value chain and the industry has a strong presence in research and development activity. However, a number of corporate acquisitions by Chinese companies is reducing the independence of the European company base (e.g. Huawei's recent acquisition of CIP to add to its existing network of research centres in Europe).

There is a wide range of promising new photonics technologies, all of which will have a significant impact on the energy efficiency of communication networks. These include photonic integrated circuits, tunable lasers, transmitters, receivers, multiplexing components and un-cooled operation. Adoption of these technologies is expected to begin between 2011 and 2015, with full implementation in the period to 2020. Over the longer term higher and higher performance demands will be placed on photonic components and this will require new materials and device designs. It is estimated that the use of photonics components will contribute 5% of the energy saving (estimated at 3% of energy usage) achiered through the optimised use of communications technologies.

National governments are not driving investment in green photonics technologies for communications in the same way as for photovoltaics and energy efficient lighting. Activities outside Europe tend to be organised by institutions, companies and academia and are typically driven by capacity expansion and cost reduction requirements rather than energy efficiency (e.g. Infinera initiatives to develop large scale photonics integration). Major global players, such as AT&T, Bell Labs, Huawei and Chunghwa Telecom[4], have recently joined forces to try to improve energy efficiency in communication technologies and have set a goal of increasing efficiency by a factor of 1000 in 5 years[5]. It is estimated that the application of photonics technologies will contribute 5% of this target.

The SWOT analysis for Europe, included in Annex 3, shows that it has an historic strength in photonic materials, components and systems, an internationally recognised research capability and a large group of high technology SMEs. However, the industry is increasingly under threat from lower cost Far East imports and its own inability to commercialise the re-

[3] Altera press release [http://www.lightreading.com/document.asp?doc_id=206206]
[4] A full list is available at http://www.greentouch.org/index.php?page=members
[5] http://www.greentouch.org/index.php?page=about-us

sults of research and development activities[6].

Significant growth is expected in the markets for optical communications equipment and photonics components as described above. A number of new photonics technologies will be required, such as integrated laser arrays, photodetector arrays, tunable lasers, high bandwidth photodiodes, optical amplifiers, optical modulation components and integrated wave division multiplexers, but it is difficult to predict which ones as this is dependent on the network architectures selected. European companies are expected to be leading in the development of new technologies and are likely to benefit from developing markets if they are able to bridge the gap between research and commercial exploitation.

The demand for photonics technologies to address the ever increasing growth in communication networks is expected to double between 2005 and 2015[7]. This is in line with the growth in the telecommunications sector itself[1].

A number of barriers to the adoption of new technologies have been identified[8]. These are generally linked to

- Insufficient clarity in market requirements, caused by a number of factors such as the lack of a common approach for development of the European fibre infrastructure, fragmented national policies, the impact of EU competition policy on investment in the fibre infrastructure and the lack of a standardised deployment approach by public sector organisations and network operators
- Insufficient investment in product development and commercialisation by optical component companies
- Insufficient capacity and capability in high volume silicon manufacture in Europe to apply its expertise to the development of a high volume, cost competitive European photonic industry.

There are also concerns regarding potential restrictions that will arise due to REACH categorisation of InP as a hazardous material and the registration and precautions that users will be required to follow.

[6] Stakeholder interview programme completed as part of this study
[7] Strategic Research Agenda for Photonics, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf
[8] Stakeholder interview programme completed as part of this study

These barriers and concerns are inhibiting investment in next generation networks and the underpinning photonics technologies.

Each of these issues can be addressed by the following intervention actions as follows:

Barrier 1: Insufficient clarity in market requirements
This barrier and its subsidiary issues can be addressed by the following intervention options:

a. Demonstrator programmes that show the potential of different technical approaches (e.g. GPON, point to point and WDM-PON) to FTTH
b. Capital grant programmes to support investment in preferred technical approaches to FTTH, determined by the demonstrator programmes proposed – this intervention will, therefore, follow successful demonstration programmes
c. Developing a common European strategy and establishing the European communications infrastructure as a regulated monopoly
d. R&D and commercialisation programmes. These should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration, as already delivered by the European Commission and national governments.

Barrier 2: Insufficient funding for near market development and commercialisation of photonics technologies
This barrier and its subsidiary issues can be addressed by the following intervention options:

a. Near market R&D and commercialisation programmes.
b. Proof of concept and demonstrator programmes

These commercialisation and demonstrator should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration.

c. Capital grant programmes to support investment in facilities for photonics manufacturing.

Barrier 3: Insufficient capacity and capability in high volume silicon manufacture in Europe
It is considered unlikely that new large scale manufacturing facilities can

be established in Europe. Therefore, it is proposed that this barrier can be partially addressed by interventions options that influence the market to invest in the development, demonstration and potential adoption of new photonics technologies, such as pre-commercial procurement programmes. Further, if these can be linked to interventions that are designed to achieve clarity in market requirements (see Barrier 1, above) then it is considered that the impact is likely to be more significant.

Concern 1: Potential REACH restrictions
The potential restrictions to company operations that will be caused if key materials (e.g. InP) are registered under REACH are causing significant uncertainty in the industry. The industry is itself responding to the current situation but it is important that similar issues do not arise in the future. This concern can be addressed by an intervention that monitors ongoing European Chemical Agency activities, identifies potential issues at an early stage, influences key stakeholders on behalf of the photonics industry and catalyses photonics industry activity as required.
Of course, this intervention is appropriate to monitor and address REACH activities that may affect any green photonics technologies.

It is clear that communications technology is very important to Europe, and it is important that we continue to focus on the development of new technologies. Communications traffic will increase "super-linearly"[9] over the next five years. It is essential, therefore, that new photonics and other technologies and network architectures are deployed in this expansion to avoid the energy usage of communications networks rising in the same way as the traffic. This will be partly achieved by the development of lower energy photonics components and integrated components, but the biggest opportunity will be in the greater use of photonics transport deeper into the network, e.g. optical distribution to cell antennas in mobile networks and in access networks, as this is the most efficient way of transmitting information. The photonics technologies required are determined from network architectures and systems designs that are developed based on assumptions of what photonics technologies are expected to become available. New network architectures will optimise performance and power efficiency differently, and at present the focus is on performance.

[9] Greater than a linear increase but not as large as exponential

Europe needs to foster the development of new photonics products incorporating new power efficient technology by reducing the risks to individual companies through collaborative project support, policy making and international standards. This will give a clear direction for product development and help broaden the market size for European manufacturers. Europe can learn from the experiences of widespread fibre access deployments in Japan and South Korea.

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Glossary

Acronym	Description
µm	Micrometre
µS	Microsecond
2D	Two Dimensional
3D	Three Dimensional
AlN	Aluminium Nitride
AMOLED	Active Matrix Organic Light Emitting Diode
AMEPD	Active-Matrix Electrophoretic Display
AMS	Automated Measuring System
APD	Avalanche Photodiode
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act (2009)
a-Si	Amorphous Silicon
ASP	Average Selling Price
AWG	Arrayed Waveguide Grating
BAT	Best Available Technology
BIPV	Building Integrated Photovoltaics
CAGR	Compound Annual Growth Rate
CALiPER	US Department of Energy Commercially Available LED Product Evaluation and Reporting Programme
CCS	Carbon Capture and Storage
CCT	Correlated Colour Temperature
CD/M^2	Candela per Meter Squared
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformité Européenne
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires
CEM	Continuous Emissions Monitors
CEMS	Continuous Emissions Monitoring Systems
CEN	European Committee for Standardisation
CEN TC 264	CEN Standards Committee
CFL	Compact Fluorescent Light
CFP	C-Form Factor Pluggable
CIE	International Commission on Illumination
CIGS	Copper Indium Gallium Diselenide
CIP	Centre of Integrated Photonics

CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPV	Concentrator Photovoltaics
CQS	Colour Quality Scale
CRI	Colour Rendering Index
CRT	Cathode Ray Tube
CSM	Sustainable Manufacturing
CuZnSnSe	Copper Zinc Tin Selenide
CVD	Chemical Vapour Deposition
CW	Continuous Wave
DCICC	Dynamic Coalition on Internet and Climate Change
DFB	Distributed Feedback
DG ENV	Environment Directorate, European Commission
DIAL	Differential Absorption Lidar
DLP	Digital Light Projection
DMD	Digital Micro-mirror Device
DOE	Department of Energy
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electroabsorption Modulator
EBM	Environmentally Benign Manufacturing
EC	European Commission
EC JRC	European Commission Joint Research Centres
EDFA	Erbium Doped Fibre Amplifier
e-ink	Electronic Ink
EISA	Energy Independence and Security Act
EL	Electroluminescent
ELC	European Lamp Companies Federation
EML	Electroabsorption Modulated Laser
EMS	Environmental Management System
EN 15267	European Standard for Instrument Type Approval
EN 1911	Standard method for monitoring HCl
e-paper	Electronic Paper
EPA (US)	Environment Protection Agency
EPI	Epitaxy
EPIA	European Photovoltaic Industry Association
ESL	Electronic Shelf Label
ETV	Environmental Technologies Verification Scheme
EU	European Union
EU-ETS	European Emissions Trading Scheme

FBG	Fibre Bragg Grating
FEC	Forward Error Correction
FED	Field Emission Display
FP	Fabry Perot
FP8	Framework Programme 8
FPD	Flat Panel Displays
fs	Femtosecond
FTIR	Fourier Transform Infra red
FTTC	Fibre to the Kerb or Building
FTTH	Fibre to the Home
GaN	Gallium Nitride
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GDP	Gross Domestic Product
GE	General Electric
GEPON	Gigabit Ethernet Passive Optical Network
GHG	Greenhouse gas
GLS	General Lighting Service
GPON	Gigabit-Capable Passive Optical Network
gw	Gigawatt
HB-LED	High Brightness Light Emitting Diode
HCl	Hydrogen Chloride
HDTV	High Definition Television
HTPS	High Temperature PolySilicon
IALD	International Association of Lighting Designers
ICT	Information and Communications Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ILS	Industrial Laser Solutions for Manufacturing
InAsSb	Indium Arsenic Antimonide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infra Red
ISO	International Standards Organisation
ISO 14001	International environmental quality standard
ITO	Indium Tin Oxide
ITRI	Industrial Technologies Research Institute, Taiwan

ITU	International Telecommunications Union
JRCM	Japan R&D Centre of Metals
kg	Kilogramme
KOPTI	Korean Photonics Technology Institute
KTN	Knowledge Transfer Network
kW	Kilo Watt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LED	Light Emitting Diode
LEP	Light Emitting Polymer
LIDAR	Light detection and Ranging
lm/W	Lumens per Watt
LTE	Long Term Evolution
LTPS	Low Temperature PolySIlicon
MACT	Maximum Achievable Control Technology
MCERTS	UK Product Certification Scheme
MEMS	Microelectromechanical Systems
MIIT	Ministry of Industry and Information Technology
MOVCD	Metal-Organic Chemical Vapour Deposition
MP3	Media Player
Mtoe	Million tonnes oil equivalent
MW	Megawatt
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
NEDO	New Energy and Industrial Technology Development Organisation
NER 300	Support Programme for Installations of Innovative Renewable Energy Technology and CCS in the EU
NGLI	Next Generation Lighting Initiative
NGLIA	Next Generation Lighting Industry Association
NGO	Non Governmental Organisation
NGPON	Next Generation Passive Optical Network
NMP	Nanotechnology, Materials and Production Technologies
nm	Nanometre
NO_x	Nitrous Oxide
NPL	National Physical Laboratory
NREL	National Renewable Energy Laboratories
NRZ	Non Return to Zero
ns	Nanosecond

OEM	Original Equipment Manufacturer
OIML	International Organisation of Legal Metrology
OLED	Organic Light Emitting Diode
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPV	Organic Photovoltaics
OVPD	Organic Vapour Phase Deposition
OXC	Optical Cross Connect
PDA	Personal Digital Assistant
PDP	Plasma Display Panels
PIC	Photonic Integrated Circuit
PLED	Polymer Light Emitting Diode
PM	Particulate Monitoring
PMEPD	Passive Matrix Electrophoretic Display
PMLCD	Passive Matrix Liquid Crystal Display
PMOLED	Passive Matrix Organic Light Emitting Diode
PMP	Portable Media Player
PON	Passive Optical Network
POP	Point of Presence
POS	Point of Sale
PPE KTN	Photonics and Plastic Electronics Knowledge Transfer Network
ps	Picosecond
PSD	Power Spectral Density
p-Si	Polycrystalline Silicon
PV	Photovoltaics
PVI	Photovoltaic International
PVTP	Photovoltaic Technology Platform
QC / QCL	Quantum Cascade (laser)
QPSK	Quadrature Phase Shifting Keying
R&D	Research and Development
RDI	Research, development and Innovation
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RGB	Red, Green Blue
RMB	Chinese currency
ROADM	Reconfigurable Optical Add Drop Multiplexer
R2R	Roll to Roll

RoI	Return on Investment
SCR	Selective Catalytic Reduction
SED	Surface-conduction Electron-emitter Display
SEMI	Global Industry Association Serving the Manufacturing Supply Chain for the Micro- and Nano-electronics Industries
SERDES	Serilaiser/Deserialiser
Si	Silicon
SiC	Silicon Carbide
SME	Small and Medium Enterprise
SMOLED	Small Molecule Organic Light Emitting Diode
SOA	Semiconductor Optical Amplifier
SONET/SDH	Synchronous Optical Network/ Synchronous Digital Hierarchy
SSL	Solid-State Lighting
STN	Super-Twisted Nematic
SWOT	Strengths, Weaknesses, Opportunities and Threats
Tb	Terabyte
TCO	Transparent Conducting Oxide
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing Passive Optical Networks
TEC	Thermo-Electric Cooler
TFT	Thin Film Transistor
TDL	Tunable Diode Laser
TN	Twisted Nematic
TV	Television
TWh	Terra Watt Hour
TWI	The Welding Institute
UBA	German Type Approval Scheme
USD	United States Dollar
USP	Unique Selling Proposition
UV	Ultra Violet
VCSEL	Vertical Cavity Surface Emitting Laser
VDSL	Very-High-Bit-Rate Digital Subscriber Line
VFD	Vacuum Fluorescent Display
VOC	Volatile Organic Compound
WDM	Wave Division Multiplexing
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
WOLED	White Organic Light Emitting Diode

Notes

Exchange rates of €1 = £0.87 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source.

Introduction

1

1. Introduction

This document reviews energy efficient communications applications of photonics. It summarises a specific green photonics technology, assesses its current and potential future markets and identifies potential intervention options to maximise the development of European activity. It has been prepared to address the following specific objectives and to underpin a summary report on the potential of green photonics technologies in Europe:

1. Overview of existing green photonics technologies and today's related markets and market players
2. Identification and analysis of promising new green photonics technology developments for market deployment in the period 2011-2015
3. Overview of major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
4. Analysis of Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
5. Assessment of the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
6. Assessment of how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
7. Identification and analysis of the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
8. Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries.

Each of these objectives is addressed in turn in the following eight sections of this report.

1.1 Definition – Photonics for Energy Efficient Communications

Photonics technology has a pivotal role to play in today's telecommunications and data networks. It underpins the infrastructure from information provider to end-user, data networks, data centres and communications networks. This report includes all types of data transmission infrastructure: copper, wireless, mobile and optical fibre. Although the focus of this report is on what photonics can contribute to a low carbon economy, the primary focus of photonics in telecommunications is to improve capacity and reduce cost per bit. The goal is, therefore, to increase capacity but in doing so, to limit the increase in power consumed. This can be seen as an improved efficiency in optical transmission. Furthermore, photonics can improve efficiency in the other infrastructure areas too via displacement (e.g. it can improve energy efficiency in mobile telecoms by changing the architecture towards smaller cell sizes that require lower power transmitters).

The supply chain for photonics in telecommunications is complex, as shown in Figure 1, as it includes the manufacture of electro-optic materials and devices and the subsequent integration into communication networks. The range of materials used is extensive and devices of importance include distributed feedback (DFB) lasers, PIN photodiodes, fibre Bragg gratings, continuous and discrete wavelength tunable lasers, photonic crystal and bandgap fibres, photonic integrated circuits, optical switches, modulators and amplifiers.

Optical components and technologies are employed at all steps in the supply chain up to the deployment of systems by network operators and carriers. Therefore, it is impossible to divorce systems level design from component technological advances. Components cannot be developed in isolation of systems, and innovation at the systems level must, therefore, be seen as technological advances in their own right. This report focuses on the photonics materials, component and subsystems parts of the supply chain, as shown in the shaded area in Figure 1 but also recognises the importance of market drivers and needs in influencing the requirements for photonic materials, components and subsystems.

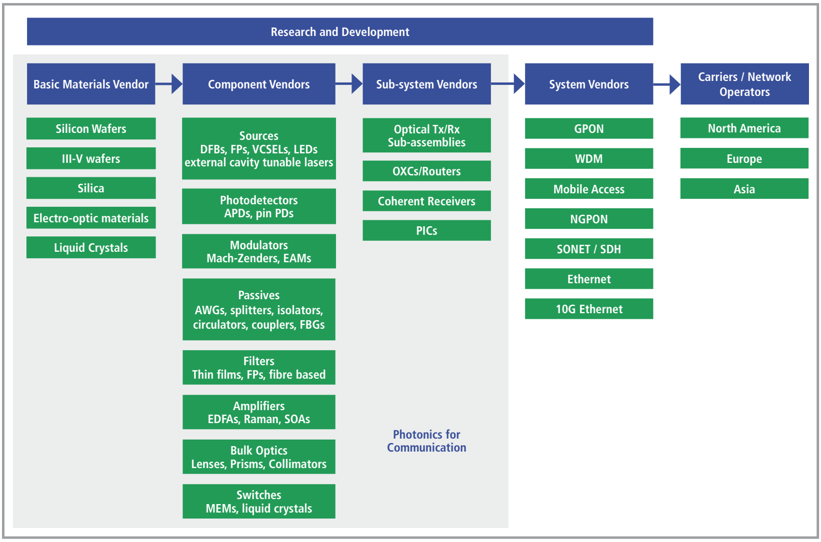

Figure 1: Photonics Supply Chain in Communications

There are many sources of energy inefficiency in telecom networks at present. It has been estimated that annual energy savings within Europe of up to €7 billion could be achieved if ICT was to replace the other physical means of doing the same business[10]. Whilst the use of ICT reduces the need to travel, a net saving in overall energy consumption is more difficult to realise because the increased productivity and global economic growth generated by ICT creates its own demand for more energy consumption; not to mention the additional appetite for leisure travel. However, the proportion of the world's energy which is being consumed by ICT is increasing year on year. It has been estimated[11] that ICT is responsible for 2% of global carbon emissions and this is expected to increase to 4% in 2020. It is preticted[12] that in 2020 ICT energy consumption will be as follows:

[10] "Power consumption and energy efficiency of fixed and mobile telecom networks" Hans-Otto Scheck, ITU-T, Kyoto, April 2008

[11] Green IT: The New Industry Shockwave, Gartner presentation at Symposium/ITXPO conference, April 2007

[12] SMART 2020; enabling the low carbon economy in the information age, The Climate Group on behalf of the Global eSustainability Initiative (GeSI), 2008

- 57% in personal computers, printers and peripherals
- 18% in data centres
- 25% in telecommunications infrastructure (12% in fixed broadband networks, 13% in mobile networks)

Many of the sources of energy inefficiency in telecom networks are because, over many years, new networks have been installed as overlay networks on previous networks. BT is, at present, trying to rationalise its networks in its 21st Century Network plan – the simplification that can be achieved is shown in Figure 2. Such system simplification will obviously offer both cost and environmental benefits.

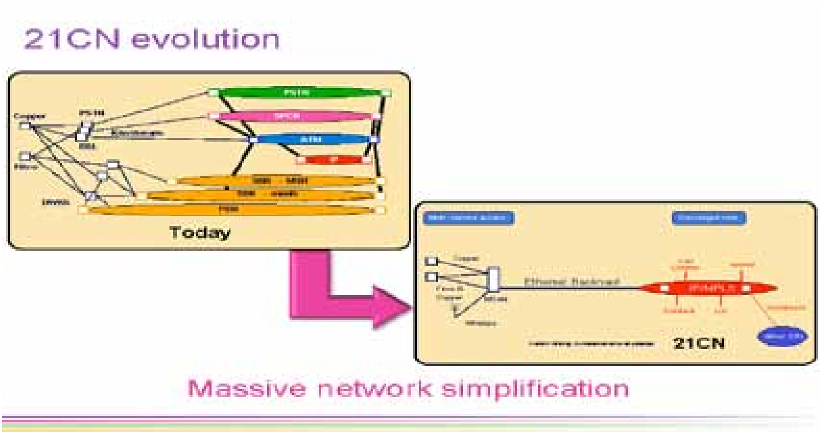

Figure 2: BT's Migration to a 21st Century Network

Within the central office or data centre, the overall savings of energy through improved power efficiency of the individual component parts is multiplied up by the so called "energy escalator". The major US telecom operator Verizon has estimated that each watt saved on an equipment card is multiplied by 2.41 when the impact of air-conditioning and cascaded power converter inefficiencies in the central office is taken into account[13]. When we consider what types of component may be on the circuit card the situation could actually be worse. For many photonic devices this is because it is necessary to use localised thermo-electric coolers (TEC) within the component. These TEC's typically consume and dissipate twice as much power as they remove. So, for widely used components

[13] MR-204 Energy Efficiency White paper, Broadband Forum, September 2009

such as dense wavelength division multiplexing (DWDM) lasers, which are temperature controlled, each watt of power consumed by the laser transmitter results in up to 6 watts of power taken from the grid. Of course, if the absolute conversion efficiency of electricity into photons is also considered the situation would appear much worse; 1W of optical power transmitted out of the central office could require nearly 1kW of electrical power from the grid! However, as most of the power in today's central office is consumed by the electronics and not the optics, this has not been considered previously to be so significant. But with the projected need for Terabit inter-connectivity, optics will increasingly play a greater role, and in particular, the use of dense and ultra-dense WDM with spectrally efficient transmission formats will become widespread. These advanced transmission formats will actually consume more electrical power per bit unless urgent attention is paid to the sophisticated photonics and digital signal processing needed to support them. One trend in an attempt to reduce the overall power consumed by data centres and central offices is to operate them at higher ambient temperatures to reduce the need for cooling, but this must be treated with some caution unless the temperature performance of the active photonic devices can be improved.

Wireless Technology

For the telecoms access network, the competition for power saving is not just between copper based very-high-bit-rate digital subscriber line (VDSL) solutions and fibre, but also with wireless. Whilst the flexibility of advanced broadband cellular wireless networks, e.g. long term evolution (LTE) standard, will offer many attractions for the customer, they are always likely to have poorer energy efficiency compared with a fixed fibre connection. The use of smart multiple element beam steerable antennas can go to help reduce the wastage of energy at base stations, but the ultimate solution to reduce power, reuse scarce spectrum and provide the required capacity will be to make the air path as short as possible. To achieve this, extensive fibre networks will then be required to back-haul the capacity to where it can be processed efficiently. Meeting these future needs in a power efficient way represents a major new opportunity for photonics and one which can also lever investments being made in fixed fibre access networks.

Overview of Existing Green Photonics Technologies and Today's Related Markets and Market Players

2

2.1
Existing Technologies

The photonic technologies that are already critically important to communications applications include optical fibres, lasers, modulators, amplifiers, detectors, passive devices (optical fibres, wavelength division multiplexing (WDM) filters) and integrated devices. These components, which are described below, are used in data transmitters and receivers, transmission lines (optical fibres), optical amplifiers, WDM systems, optical switching, optical WDM switching. Widely used for core and metro networks, these are now starting to appear in access networks. They have already fundamentally increased the capacity capability of communications, whilst reducing costs and increasing reach.

Optical Fibre
Optical fibres have become the technology for the transmission of high speed data over long distances and are increasingly being used over much shorter distances within data centres and for fixed broadband access. Up until now the choice of optical transmission over copper or point-to-point radio has been based on the capital cost to provide the required data transmission capacity. However, it is now increasingly important that the operational cost of the alternative transmission media must be considered and in particular the energy cost and carbon footprint.

The drivers for energy saving affect the use of photonics in telecommunications in three ways:

- Increased use of optical fibre to transmit high speed data rather than copper or radio because it is more energy efficient over almost all distances (from <1metre to 10,000km)
- The development of photonic components with improved energy efficiency
- The development of photonic components that can operate at higher temperatures without the need for inefficient coolers

Optical fibre is recognised as the most power efficient way to transmit high speed data. Tucker[14] has shown that the total power per bit to transmit data over long distance cables has reduced by 3 orders of magnitude during the transition from electrical coaxial cable transmission to the WDM based, optical fibre transmission systems used today. For long distances optical fibre transmission is much more power efficient than copper because of the low loss and low dispersion of the medium, requiring signals only to be amplified every 30km to 100km. With copper cable the transmission distance before signals require regeneration falls off rapidly with high data rates. For example, for 10GbE transmission over copper (using 4 parallel lanes) can achieve just 15 metres over twisted pair and up to 100 metres over screened cable. For higher data rates copper becomes increasingly unattractive even for intra-equipment connections within the data centre. It is interesting to note the recent and rapid commercial development of the "active optical cable," which is predicted to grow to $3.6 billion by 2015[15]. This is simply an optical cable with the optoelectronic transducers housed within the electrical connectors, a solution that provides the reach and efficiency of optical fibre but with the user familiarity of an electrical connector.

In long-haul, existing installed fibre still has capacity to exploit. Therefore, significant technological developments are unlikely to take place until capacity has been maximised by the transmitters, receivers and system architectures.

Lasers

DFB lasers - Current distributed feedback (DFB) laser technology has increased the capacity for long haul WDM systems dramatically. The industry has been driven to greater spectral efficiency to make better use of the capacity of optical fibre to cope with increasing traffic demand. Up to the current 10G line rate, capacity has been increased fairly smoothly. However, to maximise spectral efficiency further, and with 25G line rates in mind, advanced modulation formats are needed, which actually consume far greater energy per bit than before. This means that DFB laser technology faces a challenge to ensure that capacity can be increased whilst energy consumption per bit does not increase also. Unfortunately,

[14] Green Optical Communications, Part I: Energy Limitations in Transport, Part II: Energy Limitations in Networks; Rodney S. Tucker; IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, Volume 17, 2, March/April 2011 pp245-260, 261-274

[15] http://www.electronics.ca/presscenter/articles/1374/1/Cumulative-Active-Optical-Cables-Revenue-to-Reach-36-Billion-Between-2011-2015/Page1.html

this is not currently the emphasis of the industry: the need for capacity is driving development of new technology and increasing power consumption is a secondary issue. Laser Array technology, and the subsequent sharing of sources between different access networks is one possible solution, but this is an innovation that is yet to happen at the system level.

VCSELs – vertical cavity surface emitting laser (VCSEL) technology has progressed well at 850nm for multimode systems, and 95% of datacom sources are now multimode VCSELs transmitters. These have gradually replaced Fabry Perot (FP) lasers and have lower threshold currents and greater power efficiency. They are also significantly cheaper due to on-wafer testing, and simple low cost packaging.

Modulators

For bitrates to 2.5G and even 10G, direct modulation is provided by the laser itself. The majority of separate modulators deployed in networks today are intensity modulators, though phase modulators are used. Modulators are based on various technologies such as lithium niobate or indium phosphide Mach-Zehnder types; or electro-absorption sections integrated with DFBs (electro- absorption modulated lasers (EMLs)).

Intensity modulators are not considered particularly efficient as they discard 50% of the power of the laser (whilst it is in its off state), whereas phase modulators make full use of the optical power emitted by the laser, by emitting it as another phase.

Amplifiers

Currently EDFA technology dominates amplifier types in the C and L-bands due to the flat gain spectrums and low cost they have achieved via the build up of large volumes. They reduced power in previous networks by expanding the distance between the previously incumbent electronic regenerators dramatically, thus reducing the amount of repeaters needed. In certain telecom applications we are also finally seeing real-world applications of semiconductor optical amplifiers. These are being deployed because their small size lends them to be more easily integrated whilst both the technology and volumes have matured due to sales from other markets meaning that price and qualification status are now in line with telecom requirements. 1.3um operation also enables wavelengths (for long reach) that erbium doped fibre amplifiers (EDFA) can't address. Semiconductor optical amplifiers (SOA) are being used as booster amplifiers on the output of 100GbE transmitters to increase reach to 40km.

Detectors

Photodetectors and avalanche photodiodes (APD) are the current incumbent detector technologies. APDs allow for enhanced power budgets in networks and greater distance between regenerators, though they require greater control and operate at higher voltage.

Passive Devices

The realisation of athermal arrayed-waveguide gratings (AWGs) has the potential to unlock a significant reduction in cooling requirements for potential network architectures such as wavelength division multiplexing passive optical networks (WDM-PON). Currently, to control wavelength, there is a need to control the temperature of AWGs that consumes power.

Integrated Devices

Integrated devices are promising to reduce power consumption in networks by reducing the number of active components in the central office. A 10 channel laser array, for example, has the potential to remove 10 separate TECs, making cooling more efficient.

Another important factor to consider with integrated devices is that less interfaces leads to a reduction in lost optical power.

2.2 Current Market

The market for photonics in telecommunications is driven by the overall telecommunications market and its development. It has shown astonishing growth over the last 10 years. Usage of telecommunications has soared with new technologies and new applications, mobile and fixed, changing the way that people live their lives. Figure 3 shows growth of network traffic over the last five years. While voice traffic has stayed static, growth in conventional internet traffic has been large, but on top of this, video traffic has had a dramatic impact, growing from practically nothing in 2006 to be the dominant component now at around 200 Exabytes (1 EB = 10^{18} Bytes).

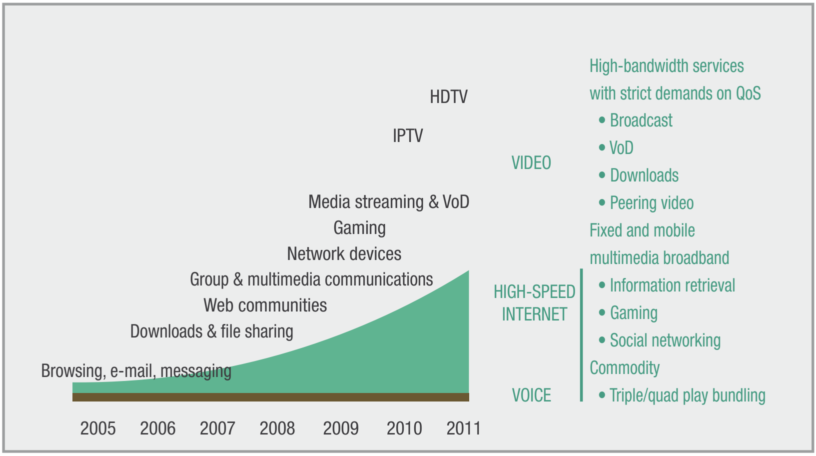

Figure 3: The Explosive Growth in Network Traffic[16]

The impact of this dramatic growth in demand on different stages in the supply chain, including photonics components, is shown in the following figures.

Telecommunications Market

Total global revenue generated by the telecommunications industry reached €2.6 trillion in 2008, growing by 3.2% from 2007. The market is predicted to reach €4.6 trillion by 2020[17] as shown in Figure 4.

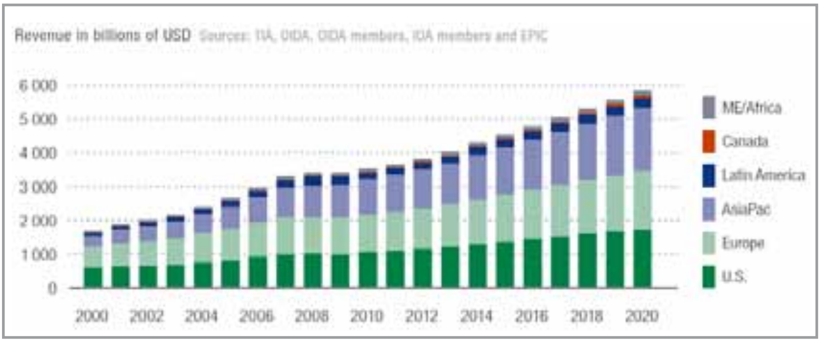

Figure 4: Worldwide Telecoms Market by Region17

[16] Richard Dorward, Ericsson Broadband Networks, Presentation at Photon '08, 28th August 2008
[17] Photonics 21 Strategic Research Agenda, Photonics 21, http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf

Total OECD telecommunications industry revenue reached €0.92 trillion in 2007[18] as shown in Figure 5.

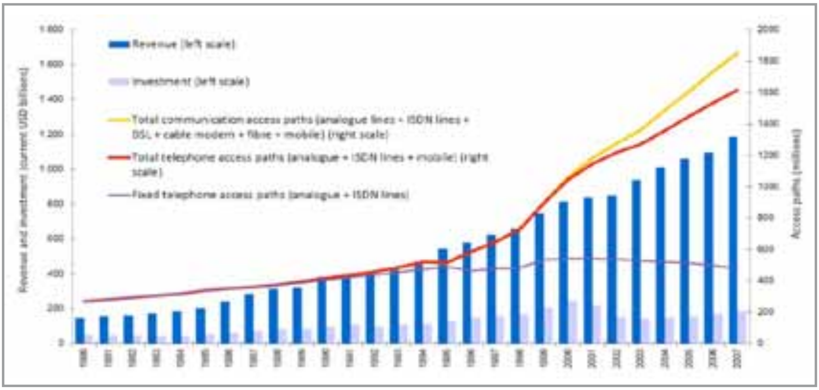

Figure 5: OECD Trends in Public Telecommunication Revenue, Investment and Access Paths, 1980-2007[18]

Optical Telecommunications Market

The global market for optical communications equipment grew in 2010 by 7.7% to €10.4 billion[19]. Growth is predicted to continue over the next decade, with estimates ranging from exceeding €15.4 billion by 2020[17], as shown in Figure 6, to reaching €17 billion by 2014[19].

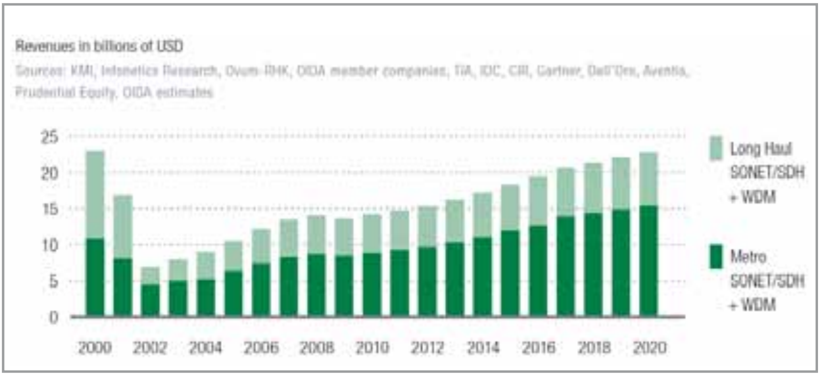

Figure 6: Global Optical Equipment Market, 2000 – 2020[17]

[18] OECD Communications Outlook 2009 http://browse.oecdbookshop.org/oecd/pdfs/browseit/9309031E.PDF

[19] http://www.isuppli.com/Home-and-Consumer-Electronics/News/Pages/Optical-Telecom-Gear-Market-Finally-Recovers-from-Dot-Com-Bust.aspx

Optical Communications Component Market

The global optical communications component market was estimated at €3.1 billion in 2009[20] and is predicted to grow to over €6.2 billion by 2020[17] as shown in Figure 7. The worldwide market for telecoms lasers grew by 28% in 2010 to €1.5 billion and is predicted to grow by 14.1% in 2011 to €1.7 billion[21]. 2010 growth estimates for transceiver, Ethernet, Fibre Channel, and 10 Gbit/s DWDM transceiver modules were 16%, 17%, 25% and 22% respectively[22]. By 2015 network bit rates will be dominated by 40 Gbps in the core and 10 Gbps in metro areas, with total transmission capacity per carrier in the 100 Tbps range[23].

Figure 7: Components for Datacom and Telecom, 2000 – 2020[17]

[20] OIDA Global Optoelectronics Industry Market Report and Forecast 2009
[21] http://www.optoiq.com/index/photonics-technologies-applications/lfw-display/lfw-article-display/7159555246/articles/laser-focus-world/volume-47/issue-1/features/annual-review-and-forecast-skies-may-be-clearing-but-fog-still-lingers.html
[22] http://www.lightcounting.com/news/092910.pdf
[23] http://www.photonics21.org/AboutPhotonics21/workgroup1.php

2.3

Important Market Drivers and Challenges

Internet traffic continues to grow rapidly, at around 60% per year. However, revenue for network operators is being squeezed as shown in Figure 8. Consumer expectation is for more bits for the same price as before, which squeezes the network operators' revenues, unless they can lower the cost of their operations through simplified networks. This provides a key driver for photonics solutions for communications since photonics can provide the lowest power loss as a function of distance of any transport medium.

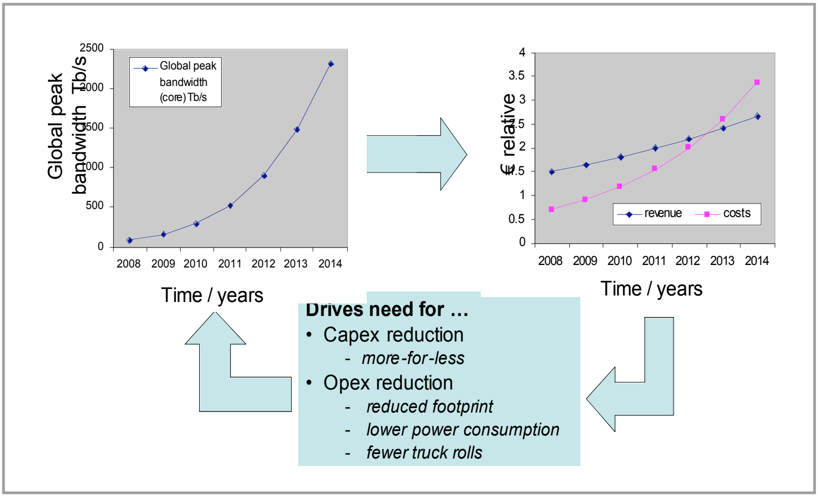

Figure 8: Graph of Squeezed Revenue

Future successful companies will operate in countries with a good ICT infrastructure. Fibre to the home (FTTH) is regarded as essential, and the pace of roll-out in Europe has lagged behind both the Far East and the USA. This is affecting the opportunities for development of photonic components to address the needs of the communications market.

Over this time period the Internet will continue to be the dominant user of the core network capacity. The growth of new video based internet services is expected to fuel capacity growth, matching or exceeding previous rates. However, as there will be a reluctance to install additional core network fibre infrastructure on routes where fibre already exists, the emphasis will be to use existing fibre but with greater spectral efficiency.

The big advantage of optical communications up to now has been that the fibre medium itself has been viewed as being future proof. The backbone of the internet is an optical fibre network and its capacity is being continuously increased by augmenting and enhancing the photonic technology within the network terminating equipment. The photonic equipment that supports the internet is to be found in long haul networks, both terrestrial and undersea, and now increasingly in metro and access networks. Broadband optical access networks are being deployed in greater numbers, especially in China, now the largest market for fibre based networks, where it is predicted[24] there will be 50M connections by 2012. Mobile back-haul is also a growing application for optical fibre and associated photonic components but the full impact will not be felt until extensive roll outs of broadband 4th generation LTE networks. Optics is also finding increasing application within enterprise networks and data centres. Companies such as Google, Facebook and Amazon are aggressive users of data-com equipment and their insatiable data requirements are starting to become a major driver for a new generation of higher capacity photonic technology.

In the past five years, network operators have been evolving their optical network architectures from dumb point-to-point optical links managed by electronic cross-connects to dynamically optically reconfigurable networks that avoid many expensive intermediate conversions back and forth to the electronic domain. This is achieved using reconfigurable optical add drop multiplexer (ROADM) architectures that use combinations of optical switches filters, amplifiers and WDM multiplexers. The advantage of the ROADM architecture is that it can save on electronic terminal equipment and, hence, cost and power because only the traffic destined for a particular node needs to be electronically handled by the node; other traffic can be passed through without intervention.

[24] China Broadband Capital Expenditure Soars, HIS iSuppli Market Watch, 12/05/2011, http://www.isuppli.com/China-Electronics-Supply-Chain/MarketWatch/Pages/China-Broadband-Capital-Spending-Soars.aspx

2.4
Market Trends – Photonic Components

Key photonics components used in communications, and their power consumption, can be summarised as shown in Figure 9:

Existing Photonics Devices	Level of Power Consumption	Device Developments for Reduced Power Consumption
Lasers	High	Remove the need for cooling – developing devices that operate at higher temperatures Make the electrical to optical conversion more efficient – remove non-radiative recombination processes
Modulators	Moderate	Reduce operating voltage – electro-absorption modulators should have lower power consumption than Mach-Zehnder interferometers
Detectors	Low	None
Erbium doped fibre amplifiers	High	Un-cooled pump lasers already in use – no other obvious improvements
Semiconductor optical amplifiers	Very high	As for lasers, but more critical
VCSELs	Moderate	Short wavelength (850nm) devices are efficient, but conventional wavelength (1550nm) devices both inefficient (see lasers) and difficult to make (growth of multilayer reflector stack)
Integrated devices	High	As for lasers and modulators

Figure 9: Market Trends – Photonic Components

The devices in the table above are already in use and device developments to reduce power consumption are ongoing. More details of the most relevant developments are provided later in this report in Section 3.

Integration of optics and electronics e.g. silicon photonics, will be beneficial in the long term for power reduction and cost reduction, as long as the optical performance is high enough for the required applications. The lack of a directly generated light source in silicon is potentially a disadvantage, since many telecoms applications use a directly modulated light source (e.g. VCSEL, DFB) as a relatively low power and efficient device. In the access network, cost is the key driver - any optical components must be very low cost. Board to board and on-chip communications are also large potential markets for photonics technology, as silicon electronic chips are largely already at their thermal limit in design. As chip data capacities and bitrates increase, these short optical links avoid the problems of radio frequency (RF) crosstalk and can save power on the electrical driver circuits. This is a growing field of interest, not only from the data and telecoms industry, but also from the electronic chip manufacturers themselves[25]. Factors driving this interest include:

- More data processing is being done in the power-hungry electrical domain. Here photonics technologies should be more energy efficient than electronics. However, photonics is becoming more and more analogue, whilst functions going beyond pure transmission are all done in electronics, such as Chromatic Dispersion compensation for >10G. This trend is not consistent with reducing energy consumption. Instead, standards are demanding additional electronic processing after transmission, raising the need for power-hungry computational power. Power benefits can be realised if dispersion compensation is done in the optical domain. This can done passively using negative dispersion compensating fibre, but currently gives poorer performance. If the emphasis is on energy saving this should be looked at again
- The basic channel rate is moving from 10Gb/s to 25Gb/s. Wavelengths and wavelength management is expensive, moving to higher speeds and lower numbers of lanes is a progressive activity. Interestingly, this is not a view that is necessarily shared by the electronics industry, with the opinion here that a lower lane speed is more power efficient
- Bandwidth is a bigger driver than the demand for low power. Power is at present seen across the industry as secondary to cost. Any solution that addresses power and offers energy saving must win or at least be comparable on a cost basis first and foremost
- There is a perception in industry that VDSL electronic chips are getting increasingly power hungry
- Regarding transceiver development, the 100Gb c-form factor pluggable (CFP) module is widely regarded as too big and power hungry. Current power requirements are ~20W. The version that was recently demonstrated exhibits 12W, which was achieved by moving from EMLs to directly modulated sources and a higher level of integration. The next step is un-cooled sources at higher speeds. One

[25] Altera press release [http://www.lightreading.com/document.asp?doc_id=206206]

particular aspect of the module that is power hungry is the gearbox electronic serialiser/deserialiser (SERDES) chip that uses a few Watts on its own. As the electrical lanes move from 10Gb/s to 25Gb/s, this interim switching is rendered obsolete so power consumption of the module will be reduced. How much benefit this will be to the system however is not clear. Overall 25Gb/s per line transceiver development will follow the route of 10Gb/s. The gearbox will become obsolete and the optics be simplified

2.5
Market Players

EU companies or companies with significant EU operations held 45% of the global optical networking equipment market in 2008, worth €5.4 billion, with sales in Europe at €1.8 billion and exports at €3.8 billion[17]. A basic supply chain is shown in figure 10 and Europe's major players and their position in the global market are then described for each section of the chain.

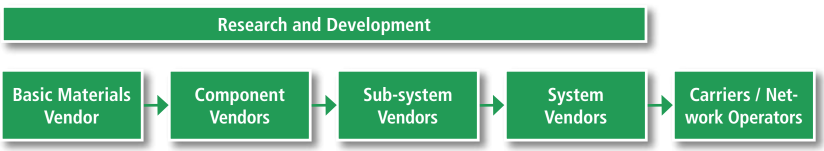

Figure 10: Telecommunications value chain showing each area of supply.

Note: Research is an ongoing process occurring at every stage of the chain, up to the supply to the end users

Basic Material Vendors

Europe plays a significant role in many aspects of the telecommunications global supply chain. For optical devices, this is considered to be mainly silica and semiconductor materials (predominantly III/V). Corning Inc is the major fibre optic supplier in the world and research activities are mainly limited to the US. Volume manufacturing meanwhile, is predominantly in Asia. Europe does have some presence in this field, however, with companies such as Draka and SHF. Regarding semiconductor wafers, Europe possesses the largest supplier of III-V epitaxial wafers in the world in the UK-based IQE plc.

Research and Development

Research activities shown in Figure 10 above consider research performed on light sources, modulators, amplifiers, waveguides and other active and passive components used for future telecommunication optical networks. More crucially, it also considers how these components can be best optimised for performance, price and power consumption. This is a critical point for the reader to consider. It is impossible to divorce component development from systems/network level development. The two aspects go hand in hand in telecommunications applications, and useful developments in one area can only be achieved from working closely with the other, as can be evidenced in many European funded collaborative projects.

A second key point to consider is the supply-chain model used by telecoms companies today. Ten to fifteen years ago, systems companies possessed in-house photonic component teams to work closely with the systems engineers to develop components vital for their needs. This vertical integration approach was dropped in favour of out-sourced component supply. This has led to a discontinuity between the desires of the systems houses, and the realities of deliverable components. This is why research within telecoms must be done with the cooperation of both components and systems, and also, why innovation at the systems level can be seen as new technology itself.

Despite having a limited number of European companies active in research, Europe has typically been strong (within research) at every stage of supply (component, sub-system and system). This is because the European companies thhat are active in research are supplemented by many large non-European companies that choose to base their key research departments within Europe. Figure 11 shows the key players in telecommunications, at each stage along the value chain. Non-European companies with R&D activity within Europe are in yellow.

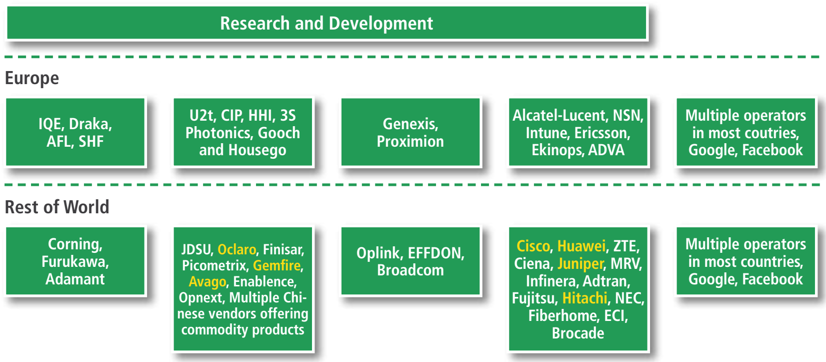

Figure 11: Supply Chain with Key Companies at each stage in Europe identified, against the Rest of the World.
Note: Companies performing R&D are included in their respective stages, rather than in the R&D category, to show where their R&D activities lie

The scale (in terms of turnover), of these companies is shown in Figure 12:

	Basic Material Vendors	Component Vendors	Sub-system Vendors	System Vendors
EUROPE	IQE (€ 82.5m)	U2t (n/a)	Genexis (n/a)	Alcatel-Lucent (€15.9b)
	SHF (n/a)	CIP (n/a)	Proximion (n/a)	NSN (€ 12.6b)
	AFL (Fujikura) (n/a)	HHI (n/a)		Intune (n/a)
	Draka (€ 2.4b)	3S Photonics (€ 50m)		Ericsson (€ 4.51b)
		Gooch&Housego (€ 49.5m)		Ekinops (n/a)
				ADVA (€ 292m)
REST OF THE WORLD	Corning (€ 1.32b)	JDSU (€ 828m)	Oplink (€ 96m)	Cisco (€ 27.6b)
	Furukawa (€1.1b)	Oclaro (€ 270m)	EFFDON (n/a)	Huawei (€ 53b)
	Adamant (n/a)	Finisar (€ 435m)	Broadcom (€ 4.7b)	ZTE (€ 4.5b)
		Picometrix (€ 4.97m)		Ciena (€ 828m)
		Gemfire (n/a)		Juniper (€ 2b)
		Avago (€ 1.45b)		MRV (€ 181m)
		Enablence (€ 37.2m)		Infinera (€ 313m)
		Opnext (€ 53m)		Adtran (€ 417m)
				Fujitsu (€ 34.5b)
				Hitachi (€ 66b)
				NEC (€ 26b)
				FiberHome (€ 570m)
				ECI (€ 414m)
				Brocade (€ 1.55b)

Figure 12: Turnover of Major Supply Chain Companies

Component Vendors

The component vendor category describes the sale of optical components within telecoms such as light sources, modulators, detectors, amplifiers and waveguides.

Europe possesses only one major component vendor, Oclaro (though it is actually a US company, it has a substantial UK base), serving volume markets. Others, for example JDSU, Opnext and Finisar are US based. There are several successful component vendors, such as U2t and Gemfire, selling to niche markets - markets that have the prospect to be very big in the coming years (100Gb/s transport). Volume component supply is at present dominated by Chinese vendors offering commodity products with similar functionality.

Sub-system Vendors

Sub-system vendors are companies supplying optical 'engines' or complex circuits for use in systems. There is a lot of cross-over here with components, as the definition between advanced components and basic sub-systems and even systems blurs. Genexis is one such company and is one of Europe's true FTTH success stories, rolling out the technology in accordance with a successful commercial model in the Netherlands.

System Vendors

Europe has a number of high profile system vendors that compete on the global stage (e.g. NSN, Ericsson, Alcatel-lucent, ADVA and Transmode). They have seen a rapidly developed challenge to their strength by the rise of Huawei and ZTE over the past decade, and are now competing to offer competitive advantage in response to shrinking market shares.

Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

3

3.1

Potential of New Technology Developments (2011–2015)

Existing Fibre with Greater Spectral Efficiency

The first wave of spectral efficiency improvement was by the use of DWDM in the past decade and we would expect the trend to continue through efficient use of channels within the standard 50GHz International Telecommunications Union (ITU) grid. For metro distance applications, 10Gbit/s data rate per wavelength channel using non return to zero (NRZ) signalling will still usually be the most economical solution rather than to go to higher rates and the emphasis will likely be on reducing the cost and improving the power efficiency of DWDM transceivers by photonic integration. However, to the latter end of this period, it is also anticipated that higher data rates will also be required on each wavelength channel and the use of transceiver featuring advanced modulation formats, such as quadrature phase shifting keying (QPSK), currently being developed for longer distance applications.

Spectrally Efficient Modulation Schemes and Coherent Optical Detection

For longer haul applications, both terrestrial and undersea, the pressure will be to further increase capacity. The cost, however, of the terminal equipment represents a smaller proportion of the equipment cost, so the use of spectrally efficient modulation schemes and coherent optical detection will increase. The emerging 100 gigabit ethernet (GbE) standard uses QPSK combined with polarisation modulation to enable 100GbE to be transmitted within a single 50GHz channel. This trend towards spectrally efficient modulation formats is now driving the development of integrated photonic circuits to support the complex optical functionality as well as exploiting advances in electronic digital signal processing.

A major challenge for these new spectrally efficient transmission schemes will be to contain their power consumption. The additional digital signal processing means that the terminal equipment is actually less power efficient on a per bit basis than the simpler on-off keyed systems they will replace. For long and ultra-long haul systems this may not be such a problem because the terminal power only represents a proportion of the total power used by the whole transmission link. However, for this technology to move into the data centre or metro networks, reducing power must be addressed.

Time Division Multiple Access (TDMA) Passive Optical Networks

During the early part of this time period, fibre FTTH access technology is likely to be dominated by TDMA passive optical networks such as GPON and gigabit ethernet passive optical network (GEPON), although there will continue to be point-to-point fibre also being deployed in parts of Europe. The shared access TDMA passive optical networks (PON) have a major disadvantage over point-to-point in that their capacity is limited. Although it is possible that 10Gbit/s TDMA PON's will eventually be deployed as upgrades to 1Gbit/s and 2.4Gbit/s PON's there is increased interest in new solutions, such as WDM-PON.

Reflective Components for WDM-PON

WDM-PON offers the virtues of a dedicated point-to-point connection, but over a shared fibre by giving each customer their own wavelength. Although first generation WDM-PON systems are available, their initial deployment has been limited because there are still cost challenges that must be overcome. The commercial success of WDM-PON will be dependent on the photonic components industry's ability to reduce the cost of WDM technology down to access prices. This means the development of reflective components such as R-SOAs and R-EAMs as well as integrated laser arrays. Photonic integration technology both monolithic and hybrid will have a role to achieve this goal. The development of lower cost WDM technology for access networks could also have an important role in the future development of back-haul capacity for 4th generation base stations.

Higher Temperature Components

Whilst WDM –PON offers the possibility of much higher symmetrical bandwidth and lower latency for individual customers, ideally this should not be at the cost of increased power consumption. As there will be more photonic components in the central office in a WDM-PON system, when compared to TDMA scheme such as GPON, it will be increasingly important to develop photonic components that consume less power. Within the central office, higher temperature operation of the active devices will help reduce power by eliminating coolers and will enable higher density packing.

Shared Central Office Equipment

Power saving can also be achieved by employing WDM-PON architectures that share central office equipment such as laser arrays. It is possible to share these components between several access networks, thus reducing the amount of active components overall.

Athermal AWGs

To separate the wavelengths routed to individual customers in a WDM-PON, a planar array waveguide grating (AWG) component constructed from silica waveguides formed on a silicon substrate is used. The AWG is likely to be located in outside plant whose temperature can fluctuate over a range, so it is important that the performance of the AWG is not unduly affected. The current solution to avoid this is to actually heat the AWG to maintain a constant temperature, which not only wastes energy but also requires electrical power to be provided to what would otherwise be a passive access network. An alternative is to use athermal designs for the AWG. This is a technique that is now being used in devices for long haul DWDM transmission and will also be used in WDM-PON.

Specific new technologies are described in Figure 13, segmented by network application with an indication of the likely impact on power consumption.

Moving to Higher than 10Gbps Data Rates

National core networks in Europe are fully meshed to allow optimum connectivity and resilience. Links of several hundred kilometres are required and, as traffic rises, new technologies are required to upgrade bandwidth without the need for installation of additional fibre, which is expensive. To achieve this, higher bitrates have been used, but the scope for this beyond 10Gb/s requires either:

1. Forward error correction (FEC) using digital signal processing (DSP),
2. Advanced modulation formats to increase the baud rate or
3. Parallel 10Gb/s channels using the wavelength domain in dense wavelength division multiplexing (DWDM).

The first of these increases power consumption as DSP consumes additional power. In the second, more complex modulation formats require devices with multiple modulators and hence additional drive power. However, there is scope for novel designs that reduce power consumption, and

New Technology	Network Applications	Power Consumption	Comments
Photonic Integrated Circuits	Advanced modulation formats for Core/Metro	Higher but could be lower	Multiple modulators to drive may use more power; consumption could be lower depending on the modulator used
	Array technology for DWDM Core/Metro	Lower	Potentially x10 lower power if semi/ uncooled lasers are developed
ROADM	Core/Metro	Lower	If latchable devices are available
Pre-amp Rx	Core/Metro	Lower	Uncooled EDFA with PIN detector array for WDM
APD - Rx	Core/Metro	Lower	Requires novel materials to achieve low noise at low voltage
Tunable Laser (local oscillator or DWDM laser)	Core/Metro	Lower	Latchable tunable laser to save power - there will be a trade off of DSP power and laser stability
Un-cooled Tx	CWDM	Lower	Conventional, but use of un-cooled lasers allows power reduction
Burst mode receiver	Access - GPON	Lower	Difficult to get adequate performance for the OLT
Cheap Tx Rx	Access - GPON	Neutral	High powers required for large split ratio but could be improved by use of un-cooled lasers
Integrated optical Line Terminal (OLT)	Access	Lower	Integration offers power reduction
PIC DWDM	Access - WDM-PON	Lower	Un-cooled, wavelength stability required (without increased power consumption)
Complex Tx, Rx	Access - Coherent	Higher	Spectrally efficient, but significant control power and DSP power
	Access - OFDM	Higher	Signal to noise enhancement, but greater control power and DSP power

Figure 13: Key New Technologies

since the basic optical signal is now encoded to carry additional information, the power per bit may be reduced. The third is at first sight power neutral – multiple channels of a basic bit rate – unless there is a power penalty incurred to control the wavelengths. However, if a photonic integrated circuit (PIC) is used, wavelength control can be achieved by design and cooling for multiple lasers carried out using a single thermoelectric cooler. As a result less power would be consumed. Further power saving would be achieved by use of un-cooled lasers. This is essentially a material issue, and as already noted, materials that are more efficient at conversion of electricity into light are required.

Switching

In a ROADM, rather than carrying out a complete optical to electronic conversion, optical wavelength channels are dropped or added. The increased use of ROADMs and optical space switches is expected, where wavelength switched mesh networks can be used to energy efficiently route bypass traffic at network nodes. With current technologies, power has to be applied to maintain the path settings, however, a latchable design would only require power to set or reset the paths that could be considerably more efficient.

Receivers

Power savings in receivers could be made using more efficient transimpedance amplifiers (TIAs). Alternatively, optically pre-amplifiers in front of the detectors can be used to remove the requirement for TIAs. An SOA preamp is not currently very efficient because of non-radiative recombination. This is a fundamental materials issue, which will only be resolved by the development of new materials. An FP7 project, BIANCHO, is looking at this. For an array of photodetectors, one un-cooled EDFA may be a more efficient preamp, as the pump laser at 980nm is much more efficient (lower Auger recombination). An APD can provide gain and an improved link budget. However, conventional SAGM InGaAs/InP APDs introduce excess noise that limits their performance. There has been some work on new materials with better impact ionisation coefficients, and this may be a fruitful area for further activity.

Latchable Tunable Lasers

A latchable tunable laser for the local oscillator may reduce the power consumption required to keep the tunable laser at the correct wavelength. The DSP uses a significant amount of power, though there may be a trade-off between laser linewidth and DSP power required, which would mean that there was merit in work to improve laser stability and linewidth to reduce the level and power of DSP required. As the components for coherent communications become more mature to the point where the required devices are mass manufacturable, they will be deployed across the board in Core, Metro and Long Haul. These moves will occur to maximise the data capacity of the fibre and amplifier chain. For the Core network, 40G and 100G coherent are already being introduced. The coherent optical approach increases system margins, and thus power efficiency, though the sophisticated electronic DSP is power inefficient. There is however, work being undertaken to increase the efficiency of the DSP.

Photonics Integration

Optoelectronic components in the transmitters and receivers will require optical integration to provide the coherent functionality for optical phase control and detection. Different types of integration approaches (silicon photonics or monolithic or hybrid InP integration) are all valid for different applications.

Technologies for Metro Networks

The previous points above apply principally to photonic devices for use in the core network. Metro networks are simpler and arranged in rings to provide resilience. Metro network links are shorter than core links and are more numerous - at least by a factor of 10. Most of the same technologies and arguments apply to Metro networks as to Core networks, but cost and power consumption are more important considerations. Metro networks are also expected to use more ROADMs to avoid unnecessary and expensive demultiplexing and multiplexing. Coarse WDM (CWDM) is an extra technology used for metro but not for Core. Here, the use of un-cooled (low power) conventional transmitters is possible because the wavelength bands are far enough apart to avoid crosstalk over the operating temperature range. More efficient lasers offer the opportunity to reduce power further.

Technologies for Access Networks

Fibre to the Home

FTTH is one technology that has the potential to reduce power consumption dramatically, compared to existing access technologies. Its primary competitor, as carriers decide what to deploy, is VDSL.

Current access networks are short distance < 10km and a factor of 10 greater in volume than metro networks. In the move to upgrade from copper access networks, fibre to the kerb or building (FTTC) and VDSL over copper is the lowest investment cost option, currently being rolled out in some countries (e.g. UK and Germany). There are various estimates of how much lower the power consumption of FTTH is compared with VDSL, some suggesting a factor as high as 20, but these do not consider all sources of power consumption. Two detailed studies comparing all aspects[26],[27] conclude that VDSL network power consumption is a factor of 1.6 – 3 greater than that for a PON (including the power consumption of the network termination equipment in the customers' premises). The VDSL solution incorporates DSP used to compensate for the losses of the copper drop. Moreover, the FTTH solution is scaleable to much higher bandwidths (1GB/s as opposed to 100MB/s). More importantly from an energy saving perspective, the FTTH solution enables a change in network architecture "long reach access" in which the need for local exchanges with their equipment and its power consumption is no longer required (see Figure 12 and the following section).

Uncooled Lasers for GPON

GPON currently uses very low cost FP lasers and PIN photodiodes in the ONU, and more expensive components (DFB laser and APD) in the OLT as they are shared. As reach is increased, system power budgets become harder to achieve and dispersion becomes a problem. Components that are currently more expensive, such as DFB lasers and APDs are required for the optical network unit (ONU) to give the required power margins. The main power saving opportunity in both cases is to use uncooled devices in both ONU and OLT.

Burst Mode Receivers

In a time division multiplexing passive optical networks (TDM PON) system, a particular requirement is a burst mode receiver. At a bandwidth of 10Gb/s, this is currently a difficult and expensive component to make. For point to point systems, the system margin is easier, so the requirements for ONU components are eased. However, a large number of components are required at the head end, and there is the opportunity to use laser and photodiode arrays with the potential to reduce power that this offers (as discussed above).

Colourless Components

For WDM PON systems, colourless transmitter components are attractive for the ONU to avoid the need for inventories of different wavelength lasers. These can be based on reflective semiconductor optical amplifiers or tunable lasers. Some of the challenges are to make these components

[26] J. Baliga, R. Ayre, W. Sorin, K, Hinton and R. Tucker, "Energy consumption in access networks", OFC 2008,

[27] C. Lange, M. Braune, N. Gieschen, "On the energy consumption of FTTB and FTTH access networks", OFC2008

low cost and to develop them to work over a wide temperature range without the need for temperature control which is expensive and power hungry for use in the ONU.

Multi-wavelength Lasers

At the OLT, low cost stable multi-wavelength sources are required. The wavelength splitting function should be passive to ensure low cost and high reliability. Array waveguide devices are a good choice for this, but must be athermal.

Long Wavelength VCSELs for Access

In access networks, because cost dominates, pluggable un-cooled low cost optical Tx and Rx will be used, possibly based on long wavelength VCSELs to simplify packaging and testing. However, development work is required on materials issues for good reflectors in VCSELs at 1.55um. At the central office, photonic integration will provide efficient array components in order to deal with the high density of connections. Enabling sleep modes in equipment, particularly in the access network, will reduce overall power consumption.

Picocells for Wireless access

Wireless access systems will move to larger numbers of smaller lower power base stations connected optically (i.e. picocells or femtocells), so essentially wireless and wireline networks will converge, and photonic components at this interface will become increasingly important .

Photonic Crystal Fibres (PCF)

These may offer higher bandwidths at longer wavelengths (2 μm), but also require new lasers and detectors. Thus, these are only likely to have a limited specialist market. Other types of PCF offer higher power handling than conventional fibres, but this is also only relevant to a limited market. Neither application will have a significant impact on power consumption.

Optoelectronic Devices Incorporating Photonic Crystals

Although laser and integrated devices have been designed incorporating photonic crystals, to provide wavelength control or provide optical waveguiding, to date performance has been insufficient to displace existing technology approaches; and in any case these have not proven to have lower power consumption than conventional devices.

Fibre Amplifiers for 1.3µm Wavelength

Work using the rare earth praesodymium in fibre was undertaken 15 years ago to provide gain at 1.3µm, however, performance was inadequate. Possibly a different host material such as a glass ceramic may provide some success.

This could have an impact on power consumption by making longer reach networks feasible in the 1.3µm wavelength band.

Magneto-Optical Devices

Very little work has been undertaken on using magneto-optical effects in photonic devices. Magneto-optical materials capable of light emission are relatively undeveloped, but could ultimately offer the opportunity of "latchable" devices, i.e. low power consumption optical switches, routers or memories.

Optical Phase Locked Loops

As discussed, electrical DSP is used in coherent systems with the consequence of high power consumption. Electrical DSP is being widely utilised because the conventional approach using an optical phase locked loop has proven too technically difficult (the loop feedback time at the operating optical frequency is very short). However, integrated devices have now been reported, and though technically very difficult to achieve currently, show the feasibility of this lower power approach.[28]

Raman Amplifiers

Raman amplifiers provide amplification within optical fibre by using a high power pump laser. A very high level of pump power is required, but high power diode pump lasers are now available. Multiple wavelength channels can be amplified using a wall-plug power of ~20W. This compares with 15-20W per channel power consumption for DSP in a coherent system.

[28] A Compact Tunable Coherent Terahertz Source based on an Hybrid Integrated Optical Phase-lock Loop, L. Ponnampalam, et al, Microwave Photonics 2010, Montreal, Paper TH1-2

3.2
Identification and Analysis of New Technologies (2016–2020)

Many of the technologies listed in the table above, which start to be implemented between 2011 and 2015, will see full implementation in this time period. Core networks are expected to reach 1Tb/s speeds using coherent, with 40G and 100G in the metro networks and 10G in access. Photonic technologies that allow cost-effective use of the usable fibre bandwidth are required. These include amplifiers, sources, detectors, and possibly new types of optical fibre, though the costs of fibre installation make this unlikely except in new build. Optical memories, high speed switching and routing and optical processing (above 200GHz) are possibilities in this time frame though specific technology advances are as yet unknown.

We can expect fibre to be ubiquitous in the access network and more advanced WDM technology, including schemes based on coherent transmission for Access as proposed by Nokia Siemens Networks (NSN). This requirement will need advanced complex integrated photonic components to be produced in volume and low cost. The higher network split and longer reach of this next generation optical network will help reduce the overall power consumption of the access network. Longer reach will allow network operators to eliminate equipment and buildings within the network, for example BT currently has over 5600 local exchange sites but with suitable long reach access technologies this could reduce this down to about 100 sites (EU 6th framework project PIEMAN[29]). An illustration of the dramatic impact that this long reach access network architecture enabled by novel photonic components could have is shown in Figure 14.

[29] http:// www.ist-pieman.org

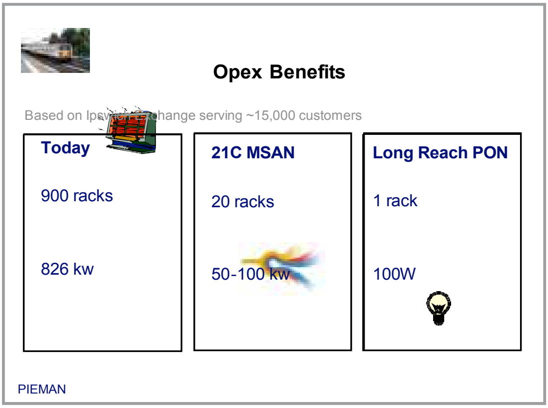

Figure 14: Network Power Savings Predicted using a Long Reach PON Architecture[29]

These more advanced access networks will require additional functionality built into the customers' equipment, which could consume more power if not addressed. So, to avoid increased power consumption when not in use, it is anticipated that the photonics will have to be able to intelligently switch in and out of "sleep mode". This presents a challenge for future ultra-dense WDM schemes that will require exceptionally tight spectral control of lasers and any associated optical filter components.

To improve the temperature performance and reduce power consumption of photonic active devices such as lasers, modulators and semiconductor amplifiers, new materials for optoelectronic devices for improved efficiency are being investigated. One route to this is to tackle one of the main physical limitations of the current Indium Phosphide (InP) technology which is Auger recombination, early research is being carried out on EU project BIANCHO[30] to this end.

Specific network approaches expected:

- Advanced modulation formats are likely to be implemented, especially in datacoms to get the bit rate up requiring specific photonic integrated circuits
- Reconfigurable optical switching configurations are likely to use latchable technology for energy efficiency
- Should switching and routers have been addressed by this point

[30] http://www.biancho.org

then transport will be left as the dominant energy cost; therefore power efficient modulation schemes and low loss fibres (halve the energy use by halving the loss) will be critical developments

- A radical approach would be to distribute switching through the network, although this would require a complete greenfield redesign. However, Intune, a startup system vendor, is advocating this approach
- Right now, current photonics technology is a bottleneck in the sense that the footprint of the photonic modules to interface to a high capacity electronic linecard (~terabyte per second (Tb/s) capacity) is larger than the linecard itself

Specific technologies expected are:

- Silicon Photonics as a potential technology for lower power and higher speeds. Si Photonics might also help with transceiver size reduction in the medium to long-term future
- Quantum Dot materials
- Photonic Integration - Photonics needs to get to a wafer scale platform to reduce cost

3.3 Assessment of the Impact on the Market of these Technologies

These new technologies will have a massive impact on the telecommunications market because they will be required to scale communication networks to higher data rate per user. Predictions of future growth scenarios, underlining the need for increases capacities, are shown in Figure 15. These demands will have an impact on the whole network to support vastly increased capacity compared with even today[31]. This in turn should lead to the substitution of travel by telecoms - business meetings, social

[31] Dave Payne, "World bandwidth growth over the next decade – is it viable?", CIP white paper www.ciphotonics.com

communications, and shopping (which is already happening), leading to reduced energy consumption. Optical fibre access to the user (as it provides almost infinite capacity) is the end-game for communications, as presently viewed.

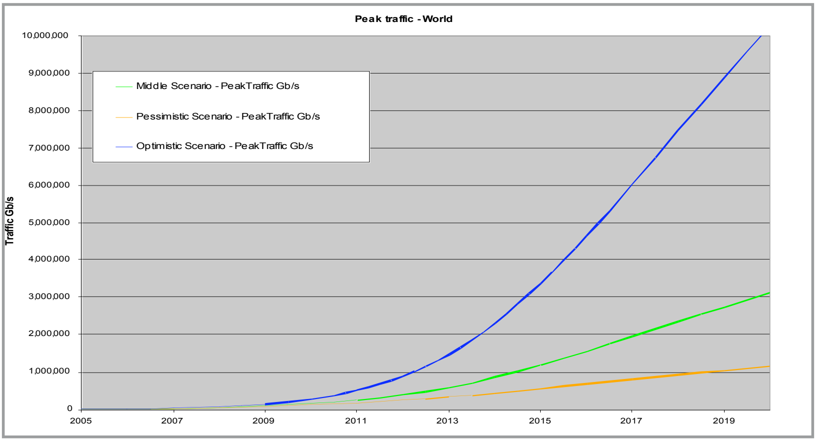

Figure 15: Predicted Peak Traffic Growth Scenarios

Although currently a significant number of photonic devices are made in Europe (but sent to Asia for packaging), Asia is becoming a major competitor in the production of low cost high volume devices. If European industry can lead in developing new components with reduced power consumption, new technologies for optical integration, and deployment of 'green' fibre networks then there is the potential for retaining this area of manufacturing within Europe, or even growing it. This will require European policy makers to put in place regulation to support their industries in the development of components for green photonics. This could create a 'home' market for EU companies, who would then be able to export to a worldwide market (all markets are looking for a solution to solving the capacity/cost/power triangle). This would lead to an industry which could support thousands of jobs and create sustainable economic strength for years to come.

Overview of Major Research Programmes and Deployment Initiatives outside Europe

4

4. Overview of Major Research Programmes and Deployment Initiatives outside Europe

Activities outside of Europe in this field tend to be organised by international institutions, companies and academia and are typically driven by systems manufacturers and infrastructure operators, the key influencers in the supply chain. Historically, the drivers of all activities have been capacity expansion and cost reduction requirements. This continues to be the case today and is expected to be so for the foreseeable future[32]. These priorities are also driving developments within photonics components as organisations respond to the key market drivers and customer needs.

Initiatives to develop energy efficient communications are currently a low priority. While many large ICT companies like, for example Google[33], give prominence to "green" initiatives on their websites, typically component and system suppliers still do not - despite the importance given to the topic by their customers.

Ever increasing energy prices and continued demand for increased capacity is catalysing interest in the energy efficiency of photonics components and systems but it is not yet a key development priority for either systems manufacturers or their supply chain. Therefore, there are very few dedicated research programmes and deployment initiatives. Support tends to be included with generic support programmes. Those programmes that have been identified are described in Sections 4.1 to 4.4.

[32] Stakeholder interview programme carried out as part of this study
[33] http://www.google.com/corporate/green/operations.html

4.1 Green Photonics Communications Global Initiatives

The Institute of Electrical and Electronics Engineers (IEEE) has set up an Energy Efficient Ethernet task force to develop new standards aiming to 'Define a mechanism to reduce power consumption during periods of low link utilization' that encompasses Cu and fibre links[34,,35]. The International Telecommunication Union (ITU) has run symposia focusing on 'Dynamic Coalition on Internet and Climate Change (DCICC)'[36]. Although overtly focused on telecommunications systems, these initiatives will also influence key component supply capability, including photonics.

In addition, a number of large global companies from the communications sector have formed the Global e-Sustainability Initiative[37]. The Greentouch organisation, www.greentouch.org, a global, open consortium of currently 36 companies and universities was formed a year ago with the goal of improving energy efficiency in ICT. They have set themselves a goal of increasing efficiency by 1000 in 5 years. It is difficult to define precisely what part in this photonics technology can play, as it can not only enhance efficiency through its part in more efficient optical transport of information, but also by displacing other less efficient parts of the network through changes in network architecture.

As shown in Figure 16, they predict that it will be possible to improve the efficiency of mobile communications by a factor of 2000, while optical transmission, which is already relatively efficient, can only be improved by a factor of 20. However, the improvements in mobile communications efficiency are likely to involve more use of optical technologies to handle network traffic, suggesting that photonics will contribute to the energy saving in these areas. However this contribution has not been quantified.

[34] http://www.ieee802.org/3/az/public/index.html
[35] IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, Improving Energy Efficiency in IEEE 802.3ba High-Rate Ethernet Optical Links; Reviriego, P. et al, http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5492136
[36] http://www.itu.int/themes/climate/dc/meetings.html
[37] http://www.gesi.org/

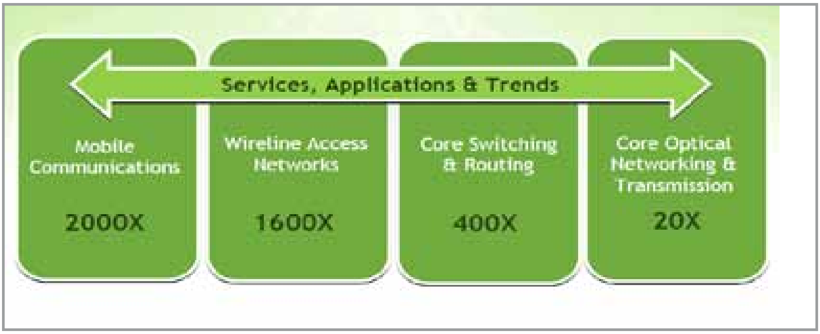

Figure 16: Greentouch Calculated Potential Energy Savings

4.2 Green Photonics Communications Initiatives in North America

There are several large photonics components and telecommunications systems manufacturers located in the USA and some of these companies are investing in green photonics developments. For example, Infinera is a vertically integrated company selling systems and claims to have 'pioneered the technique of large scale photonic integration' in photonic integrated circuits (PICs). It claims that "by consolidating many optical devices into a single device, PICs enable system designers to implement improvements in system size, power consumption, reliability and cost." Their argument for power saving is that by reducing the number of optical interfaces between different material systems the laser drive currents can be significantly reduced to achieve the same performance as a non-integrated system. There may be benefits in terms of locating more components on the same thermo-electric cooler (TEC) although these were not outlined in published information[38]. They also claim that the monolithic optical integration approach has significant power saving benefits over the alternative hybrid integration approach.

[38] http://www.infinera.com/technology/pic/what.html

Many of the giant internet data-centres are located in the USA and it has been estimated that they 'consume more than 3% of all the power consumed in the US'[39]. This is driving a number of energy efficiency activities. Focusing on photonics components, fibre optics is being increasingly used in transporting data between servers and with the trend towards higher bit-rates per cable, the standards for the relatively long 40 and 100 Gbit/s cables involve n fibres each carrying 10 Gbit/s or 25 Gbit/s. Intel is also developing optical links within servers aiming to increase speed and reduce power consumption.

4.3 Green Photonics Communications Initiatives in China

The Chinese government has set emission reduction targets into their "Twelfth Five-Year" plan: China's 2020 carbon dioxide emissions per GDP unit will be 40% - 45% lower in comparison to the emissions in 2005. The Chinese government has also set up a low-carbon industry fund to encourage low carbon emission by using new materials, new equipment, new technology to upgrade existing equipment, and low-carbon alternatives including new sources of energy; nuclear, wind and solar energy. This has encouraged activities within some of the leading telecommunications companies that have focused on photonics. For example Fiberhome has applied low-carbon technologies to WDM optical transmission equipment, using system integration technologies, to improve energy efficiency on OTN, PTN products by 20% - 40%.

[39] http://www.thefoa.org/tech/ref/appln/datacenters.html

4.4
Green Photonics Communications Initiatives in Japan and South Korea

There are several large Japanese optoelectronics components and telecommunications systems manufacturers that are focusing on energy efficiency. The major telecommunications operator NTT has pledged a >10% reduction in its CO_2 emissions over the 2008 – 2012 period[40]. At the component level companies such as NTT are well regarded for their technical strength across a wide range of photonics and other components. Key recent photonics developments include uncooled integrated laser modulators for 40 Gbit/s operation[41].

These countries are also good practice examples of developing optical fibre based infrastructures. According to a global FTTH/B survey taken in 2010[42], 'South Korea remains the global leader in FTTH/B market penetration with more than 50% of broadband subscribers connected to all-fibre networks, while Japan has more than 35% of households actively using FTTH/B connections'.

[40] http://www.ntt.com/csr_e/report2010/data/environment_vision.html
[41] JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 28, NO. 1, JANUARY 1, 2010, Design and Fabrication of 10-/40-Gb/s, Uncooled Electroabsorption Modulator Integrated DFB Laser With Butt-Joint Structure; Kobayashi, W.; Arai, M.; Yamanaka, T.; Fujiwara, N.; Fujisawa, T.; Tadokoro, T.; Tsuzuki, K.; Kondo, Y.; Kano, F. http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5339226
[42] http://www.ftthcouncil.org/en/newsroom/2010/09/26/global-ftth-survey-shows-continuous-growth-in-first-half-of-2010

4.5
Analysis of Initiatives and Transferability to Europe

There are no major focused investments in energy efficient communications in major countries that can be compared to the initiatives for photovoltaics and solid state lighting. However, there still are lessons to be gained from elsewhere. Work done elsewhere could benefit Europe in several ways: international standards can give a clear direction for product development and help broaden the market size. Europe can learn from the:

- Experiences of widespread fibre access deployments in Japan and South Korea
- USA and Far East where FTTH is regarded as a strategic national infrastructure that underpins economic growth
- Strategic and coherent approaches at all stages in the value chain in these regions.

Europe's Current and Future Perspectives for Market Positioning Market Positioning in Identified Green Photonics Areas and Related Applications

5

5.1 SWOT for Europe – Current Perspectives for Market Positioning

The current position of Europe in photonics for global telecommunications markets is summarised in Figure 17:

Strengths	Weaknesses
• Historical industrial strength in photonics components and systems • Academic base – strong component modelling knowledge • Mature extensive infrastructure • Sophisticated consumer base – demanding better services • EU Framework programme encouraging collaboration in research and development • Hundreds of high tech photonics and communications SMEs	• Existing copper network infrastructure (sweat the assets) • Ageing network infrastructure (wireless backhaul) • Funding gap between research and commercialisation of new ideas • Difficulty in growing SMEs into larger companies
• Sophisticated consumer base • Greater competition through breakdown of national relationships between operators, system suppliers and component companies • Component and system companies to make lower power product as a system differentiator • European-wide standardisation of component specifications • Higher energy costs will provide incentive for change • Reduced carbon emissions - improved energy security • Copper recovery	• Economic climate • Loss of sustainable industrial infrastructure due to imports of products made in Far East • Regulatory environment • Photonic component part of the telecom industry is not making sufficient profit to invest - business model is broken • Availability issues for key materials, e.g. rare earths, GaAs. InP
Opportunities	**Threats**

Figure 17: SWOT – Current Position

The SWOT analysis above shows that although Europe has been historically strong in photonic components for communications, it is now threatened by imports from the Far East. While there is a strong knowledge base in Europe, there is a gap between ideas and commercialisation to generate wealth.

The high level of growth in internet traffic through new applications, and intense competition has driven down the price per bit delivered. This means that, currently, the telecoms industry is not making sufficient profit to invest in the extra backhaul capacity and FTTH capacity. This problem flows down into the photonics sector, where short term, cost focused activities dominates over enhanced performance and improved energy efficiency.

5.2
Market Development

The expected growth in telecommunication and associated photonics components markets has already been shown in Figures 4 to 7. This shows that the global optical communications equipment market (both long haul and metro) will grow significantly to 2020. Estimates vary depending on the source but global market figures of up to €18 billion per annum by 2020 compared to €11 billion per annum in 2011 are typical. Similarly, the Photonics 21 Strategic Research Agenda indicates that the global communications market for photonics components is expected to double between 2009 and 2020 to €6.2 billion per annum.

5.3
Future Market Potential – Key Technologies

A number of key technologies have been discussed in sections 2 and 3 above and the main applications of new technologies tabulated in Figure 13. As already underlined, growth will be driven by FTTH developments and associated network (core and metro) growth, but the specific photonics technologies that have the most market potential depends on the network architecture(s) that will be preferred. It is, therefore, difficult to predict the photonics technologies that will be central to future development and will, therefore, demonstrate large market growth. However, these can be identified for different architectures as follows:

1. **WDM-PON** – key underpinning photonics technologies will be integrated laser arrays (that have stable wavelengths over a wide temperature range initially, by use of temperature control, but ultimately without external temperature control to reduce power consumption) and photodetector arrays.

2. **Coherent Access Network** – key underpinning photonics technologies will be narrow linewidth wavelength stable tunable lasers (initially temperature control will be required, but ultimately to reduce power consumption operation without temperature control will be necessary) and high bandwidth photodiodes.
3. **Long Reach PON** – low cost semiconductor optical amplifiers for signal enhancement and higher gain lower noise APDs for higher link power budget will be required here.
4. **Mobile Back Haul (& Front Haul):** The roll out of 4^{th} generation long term evolution (LTE) networks will place more demands on back haul transmission capacity from base stations. Key underpinning photonic technologies for reducing power for the backhaul could be based on those needed for WDM-PON, whereas for antenna remoting (Front Haul) optical cable is a lower power solution than microwave cable. For this, linear lasers or modulators and wideband photodiodes would be needed.
5. **Metro Networks:** For this application it is necessary to get the best balance of operating cost, including power, and spectral efficiency. The optimum solution will be different to long haul systems. Key underpinning technologies include cooler-less pluggable low cost tuneable lasers, optical modulation schemes (that can improve spectral efficiency without increasing receiver complexity (e.g. duobinary) and power consumption). Further energy savings might be possible through the use of reflective architectures, such as those that are being researched in FP7 project C3PO, since this approach eliminates the need for individual temperature controlled lasers on equipment cards.
6. **Data Centres:** Within data centres, short reach optical interconnects are increasingly being used to handle the increased capacity, reduce power consumption and overcome space limitations. Key underpinning technologies are integrated WDM transceiver arrays that should be capable of operating at reduced drive voltages and over wider temperature ranges without need for a TEC. This will place requirements on both optoelectronic device design and material choices.
7. **Long Haul & Ultra-Long Haul:** Key underpinning technologies to increase capacity through increased spectral efficiency are based on the combination of higher order modulation formats and coherent detection. The first generation of these schemes is heavy on power consumption because of the electrical digital signal process-

ing needed. Future advances in digital signal processing that reduce power consumption will enable overall integration densities, both photonic and electronic.

Identification of the preferred communication architectures will, therefore, provide clarity in the requirements for photonics technology development.

5.4 Future Market Share for Europe

As communications traffic continues to increase superlinearly, and with communications typically accounting for around 3% of national energy usage and rising[43], it is important for Europe to take the lead, setting best practice for low energy telecommunications, and as a result create new markets. If European companies can develop energy efficient photonic components, they will be well-positioned to exploit these new markets and take a significant market share.

For example, for many photonic devices it is currently necessary to use localised thermo-electric coolers (TEC) within the component. These TECs typically consume and dissipate twice as much power as they remove. So for widely used components such as DWDM lasers, which are temperature controlled, each watt of power consumed by the laser transmitter results in up to 6 watts of power taken from the grid. Of course if the absolute conversion efficiency of electricity into photons is also considered, the situation would appear much worse; 1W of optical power transmitted out of the central office could require nearly 1kW of electrical power from the grid! However, as most of the power in today's central office is consumed by the electronics and not the optics, this has not been considered previously to be so significant. But with the projected need for Terabit inter-connectivity, increasingly optics will play a greater role and in par-

[43] ICT Energy Consumption – Trends and Challenges, Gerhard Fettweis, Technische Universitat, Dresden, ICT 2020, March 2009, Brussels

ticular the use of dense and ultra-dense WDM with spectrally efficient transmission formats will become widespread. These advanced transmission formats will actually consume more electrical power per bit unless sophisticated photonics and digital signal processing can be developed to support them.

5.5
SWOT Analysis – Future Perspectives for Market Positioning

A SWOT analysis for Europe if new technologies are deployed is shown in Figure 18. This will vary to some extent, depending on exactly which technologies are deployed.

Strengths	Weaknesses
• Market lead in global photonic component market • Future-proof telecom networks • Lower power/bit networks • More high value communications services • Greater home-working – less carbon emissions	• Scale of network investment required • Increased power-per-bit due to higher-order modulation schemes • Network investment often based on CAPEX not OPEX - may drive lower power efficiency
• Strengthen European industry against foreign competition • Will become enabling technology • EU regulation targets on energy efficiency	• European market mature, emerging markets may take lead • Danger of acting before technologies are mature
Opportunities	**Threats**

Figure 18: SWOT Based on Deployment of Technologies

Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

6

6.1 Economic Impact

There is no direct evidence from the literature or industry that could be identified during this study that quantifies (in terms of either GDP or GVA) the potential economic benefits for Europe that may be accrued by development of photonics for energy efficient communications. However, some estimates can be made of the scale of the industry in Europe based on the segmentation of the global photonics market and data on the European industry. The value of the optical communications and information technology segments of the European photonics industry are jointly expected to grow from €57 billion in 2005 to €114 billion in 2015[44], indicating a significant economic benefit for Europe.

This segment of the industry has a significant leverage on downstream markets – according to Photonics 21 "the major highways of communication and information flow are optical where major growth is predicted". For example the European telecommunications market is quoted by Photonics 21 to grow from over €800 billion to almost €1,500 billion between 2011 and 2020.

6.2 Social Impact

There are significant social benefits which can be accrued from the exploitation of photonics based communications infrastructure, but these are generally linked to the overall communications infrastructure rather than to the photonic components.

One example closely linked to photonic components is the reduction in cell sizes in mobile networks using photonics. Smaller mobile cells require lower power RF transmitters. As some people believe that high levels of electromagnetic radiation are a health hazard, this provides an oppor-

[44] Photonics in Europe, Economic Impact, Photonics 21 and Optech Consulting, December 2007

tunity to reduce radiation levels by using more photonic components in mobile networks.

6.3
Environmental Impacts

Energy Efficiency

As has been stated above, network simplification and increased use of photonics should lead to improved energy efficiency. The Greentouch organisation suggests improvement by a factor of 20 is possible in 5 years in optical transmission and a factor of 2000 in mobile communications (see discussion in Section 4, above). Photonics will, as already highlighted, contribute to the 2000 times improvement but this cannot be quantified.

Industry stakeholders[45] have estimated that photonics will contribute 5% to the energy saving potential of energy efficient communications.

The manufacture of optical fibre is a much more energy efficient process than the manufacture of copper cable and has a higher transmission capacity. To carry the equivalent amount of data a copper cable is estimated to require >100 times more energy to manufacture than an optical fibre.

However, the ever increasing demand for communications capacity is likely to lead to an overall increase in energy demand.

Raw Materials Availability

Photonics components for communications will be affected by the lack of availability of rare earths and other elements[46] if increased availability or substitution options are not achieved. Indium is identified as the element where there is most concern, although volumes required are very small. There are concerns regarding some rare earth materials but these are relatively small in comparison.

[45] Stakeholder interview programme carried out as part of this study
[46] Critical Materials Strategy, US Department of Energy, December 2010

Regulations

Recent developments under REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances) have become a major issue for this segment of the photonics industry. The European Chemicals Agency (ECHA) has accepted proposals to classify Gallium Arsenide (GaAs) and Indium Phosphide (InP) as hazardous substances under REACH regulations. These decisions would have major serious impacts on the European GaAs and InP industries – extinction is being claimed by some commentators[47].

The GaAs industry actively challenged this decision and ECHA was directed to reopen public consultation in March 2011 for a 6 week period. Further decisions, following this further consultation are not yet available. It is understood that the InP industry is taking similar action but it is unclear what impact it will have due to its relatively small scale.

It seems that the relevant industries were initially unaware of these developments and were not in an ideal position to react. It is possible that similar problems may be raised on other photonic materials in the future and it is important that the industry is more aware of such developments and is in a position to act at the earliest opportunity.

[47] "REACH Threatens to Make GaAs Extinct", Compound Semiconductors, 5th April 2011

Contribution to Low Carbon Policy Targets

7

7.
Contribution to Low Carbon Policy Targets

The low carbon economy targets set for Europe[48] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020 compared to 1990 levels
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

Photonic components in energy efficient communications systems will make a contribution to reducing energy consumption and greenhouse gas emissions, but robust quantitative evidence of the contribution is not available. However, as highlighted in Section 4 above, analysis by the Greentouch organisation indicates that this contribution will be a small percentage of the potential overall energy savings. We estimate, assuming that the optical contribution is only 5% of the total energy saving and that energy consumption in communications is 3% of national usage, that the energy saving due to photonics in communications is 0.15% of usage.

[48] EUROPE 2020, A European strategy for smart, sustainable and inclusive growth, European Commission, March 2010

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

8

8. Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

There are significant opportunities to introduce new photonics components into communication systems and infrastructures, each of which can contribute to energy efficiency but there are currently barriers to implementation. These barriers can be described as follows:

Insufficient Clarity in the Market Requirements for Photonics Components

There is no clear definition of the strategy or the approach for development of a coherent pan-European communications infrastructure. Thus there is no standardisation and the associated cost benefits that standardisation will deliver. This is inhibiting infrastructure development and a commitment to developing and implementing the optimum technology solutions, as highlighted in Section 6, above. This, in turn, is leading to a reluctance to commit to, and invest in, the key photonics (and other) technologies that will underpin the preferred network approach(es). There are several major contributory factors to this barrier:

a) **Insufficient Common Approaches to FTTH**
At present there are a number of different technical approaches for the communications infrastructure (FTTH); for example GPON, point-to-point and WDM-PON. Installation of any of these is capital intensive. For the UK, for example, Analysys Mason has calculated[49] the cost of FTTH for the whole of the UK would cost €33 billion. There is a reluctance to invest until a common approach is defined, architectures are generic and the cost benefits of large volume requirements are gained.

[49] The costs of deploying fibre-based next-generation broadband infrastructure, Analysys Mason for the UK Broadband Stakeholder Group, September 2008

b) "Piecemeal" Investment in Communications Strategies

As a result of the high cost of FTTH installations, incumbent operators in European countries have preferred to adopt lower cost strategies to rolling out fast broadband connections. In the UK and Germany, fibre to the cabinet and VDSL have been favoured, as the final drop using copper is retained, avoiding the need for the majority of the civil engineering costs. Analysys Mason[49] calculated that the cost of this approach in the UK would be €6 billion. Although with lower capital cost, FTTC-VDSL is a higher power option than FTTH as it uses more signal processing electronics (VDSL uses DSP to optimise the frequency distribution on the copper pair to maximise bandwidth). It also has a lower bitrate limit than FTTH, and is, therefore, less "future-proof". There is a danger that VDSL, a sub-optimal solution, will be adopted because in the short term, the capital costs are lower even though operating costs are higher.

c) EU Competition Policy that Makes Deploying Fibre Infrastructure Commercially Challenging

EU competition policy in the telecoms sector has focused on consumer choice in the telecoms field. This is a challenging approach in an area where high capital investment is required. For instance, it would be unjustified from economic and practical perspectives to have multiple operators cabling up the same streets in the hope of picking up customers. The communications infrastructure in each case is a natural monopoly. The business model in the access network needs to be segmented into three parts; Application, Service and Infrastructure as shown in Figure 19.

Category	Risk	Cost	Timescale
Application	High	Low	Short
Service	Medium	Medium	Medium
Infrastructure	Low	High	Long

Figure 19: Business Categories for the Access Network

These three areas should have very different business models. The infrastructure is a utility with very high cost, but low risk, and if optical fibre is installed, a long term investment that should last at least 50 years (glass fibre does not degrade). It is, therefore, ideal for a regulated monopoly situation. The service is defined as the way in which data is transmitted over the network; the transport and control layers. These will be lower cost than the infrastructure (they are generally located in buildings and can be changed relatively easily). Their lifetime will be ~10 years as new technologies are introduced to replace them. Competition can serve a useful purpose at this level. The applications are software programmes running over this infrastructure and will be updated on perhaps an annual basis. Competition should definitely take place at this level.

Competition policy in the EU to date has generally focussed on demanding competition in all these business models. The result of this has been that companies within the EU have delayed investment in FTTH, because they cannot see how they can get a return on their investment, given that they will be expected to let their competitors use their network infrastructure, a concern that was confirmed by the industry[50] during this study. This has resulted in comparatively slow development of FTTH in Europe, compared to e.g. Asia, where the strategic importance of FTTH to wealth creation is fully recognised.

To overcome this, the infrastructure should be treated as a regulated monopoly, with interfaces standardised so that networks deployed in different areas are compatible, and competition focussed at the service and application level.

d) Fragmentation of National Policies regarding fibre deployment

Europe needs to come up with a single solution that future-proofs future fibre deployment. It is not necessary to specify technologies now, but we should choose a fibre topology that does not exclude future technologies. If a point to point fibre topology is chosen now and then in 20 years a NXGPON or point to point technology is chosen then neither are a problem.

e) Fragmentation of National Policies regarding technological choices

Europe must work with one common strategy and target investment in the technologies that underpin this strategy. It needs to increase support to high investment photonics technologies (e.g. silicon photonics, all-optical technologies, integration etc) to ensure Europe re-

[50] Industry stakeholder consultation programme carried out as part of this study

tains a strong position. Europe still has the opportunity of leading in these fields.

Insufficient Funding for Development and Commercialisation of Photonics Technologies

This is a critical barrier to the development of the new photonics technologies required for next generation networks. There are a number of contributory factors to this issue, including:

1. **A fragmented European supply chain leading to a lack of development money in optical component companies as a result of squeezed profit margins**
   The move away from vertical integrated photonic components AND communications systems companies has created both financial and technical barriers, resulting in less money for component development and poorer communication between system designers and component designers of what is required and what is possible.

2. **Capital cost of development (entry costs) in photonics is huge**
   To retain market share/grow in Europe small companies will need investment. Europe needs to grow an entrepreneurial culture - there is a plethora of applications in Europe, such as smart home/smart city etc, which offer opportunities to create a large number of SME companies that do not currently exist. New economic activity can be catalysed by effective investment in these areas. Photonics foundry approaches being developed currently (e.g. EU projects Helios, Paradigm and Europic) were regarded as a positive approach to overcoming this barrier.

3. **Insufficient support for technology commercialisation activities**
   In Europe almost all public funding is allocated to pre-competitive research and development. That is not the case in USA and Far East. For example, in Japan, a substantial amount of funding goes directly to the major companies that results in products in a much shorter time. Also in Japan and the USA, government supports universities to do long term research, which allows industry focus on close to market development. In Europe it is necessary to duplicate "best practice" from these other regions. If not, there are numerous photonics technologies that were developed with EU funding that are being exploited by companies outside the EU.

Emerging 100G standards do not presently support energy efficiency

The fact that optical Ethernet line coded data generates continuous data indicates that a move to burst mode optical data transmission is not under consideration. With Ethernet, idle bits are inserted when useful information is not being sent. Burst mode is more efficient as it only sends or receives real data. However, there is a system penalty for burst mode. There is a trade-off between performance and energy efficiency. Future standards should promote energy efficiency.

Insufficient global semiconductor manufacturers in Europe

Europe has few major players in the silicon based electronics industry. Compared to the US or Far East, this lack of semiconductor manufacturers means that the semiconductor chip industry is not driving the inclusion of photonics as strongly as in these other regions/markets. This will inhibit the opportunity for European companies to develop market presence.

Technology Migration to Low Cost Economies

Too often technology developed in Europe is exploited elsewhere. There are numerous examples in the Far East of manufacture of 1st generation of components based on European research. A large part of photonics today is discrete, hand-made and very expensive. With the advent of automation, array devices and integration it will be possible to overcome this. This will allow Europe to maintain its technology lead. The potential of funding start-up manufacturing companies in Europe, based on technologies developed in Europe that can be competitive should be investigated.

High labour costs

Labour costs in Europe are relatively high, affecting the competitiveness of European companies and their opportunity to compete and grow in global markets.

In addition there are concerns regarding the **Implementation of proposed REACH regulations.**

These regulations, if implemented, will have a major impact on the industry as the use of some of the key materials on which photonics components are based will be severely restricted, if not banned.

These barriers and concerns are classified and summarised in Figure 20:

	Barrier / Concern Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
Insufficient Clarity in Market Requirements - exhibited by						
a)	Lack of an Optimum Strategy for FTTH	Financial	High	Immediate	€100s Billion	There is a reluctance to invest until standardisation takes place and the costs are reduced due to increased volumes.
b)	"Piecemeal" Investment in Communications Strategies	Financial	High	Immediate	Billions	The high costs of optimum solutions have encouraged operators to follow low capital cost strategies. This is not likely to offer the optimum long term solution.
c)	EU Competition Policy	Policy	High	Immediate	Low	Has driven competition in the market but has affected the ability of companies to deliver optimum solutions. A regulated monopoly would offer an enhanced solution.
d)	Fragmented National Policies	Policy	High	Immediate	Low	A common future proof European strategy would optimise the opportunity for indigenous companies and offer the optimum infrastructure for users
Insufficient Funding for Development and Commercialisation of Photonics Technologies - exhibited by						
a)	A Fragmented European Supply Chain	Financial	High	Immediate	High	The move away from vertical integration and the squeeze on components companies means they are unable to invest in R&D and are not likely be competitive in the future.
b)	Capital Costs of Entry to Photonics is Huge	Financial	Medium	Immediate	Medium	Investment costs are inhibiting SMEs from fully exploiting opportunities. Mechanisms to access facilities on an "as required" basis partially addresses this issue
c)	Insufficient Support for Technology Commercialisation	Policy	Medium	Immediate	Low	Europe needs support for near market technology development to ensure successful R&D is exploited. Funding programmes need to be restructured to enable this support to be provided.
Emerging 100G Standards		Regulatory	Medium	Mid Term	Medium	Preferred systems are not energy efficient which will have a negative impact to the the low carbon economy.
Insufficient Global Semiconductor Manufacturers in Europe		Industrial	High	Immediate	?? Ability to Influence??	The market drive for inclusion of new technologies in other regions which will affect the opportunity for European photonics companies.
High Labour Costs		Industrial	Medium	Immediate	High	This affects the competitiveness of European companies and inhibits their opportunity to grow.
REACH Restrictions		Regulatory	High	Short Term	High	Key photonics materials would not be available

Figure 20: Classification and Analysis of Barriers

Potential Intervention Options

9

9. Potential Intervention Options

The major barriers to development of photonic technologies for telecommunications application in Europe have been assessed and the following actions to address these barriers have been identified:

1. Insufficient clarity in market requirements, exhibited by

a. The lack of an optimum strategy for a coherent pan-European communications infrastructure
b. "Piecemeal" investment in communication strategies
c. EU competition policy that makes deploying fibre infrastructure commercially challenging
d. Fragmented national policies in Europe regarding fibre deployment and underpinning technologies that results in a lack of investment in infrastructure and key technologies

The potential for Europe of overcoming this barrier is discussed in Section 3.3.

This barrier and its subsidiary issues can be addressed by:

e. Demonstrator programmes that show the potential of different technical approaches (e.g. GPON, point to point and WDM-PON) to FTTH
f. Capital grant programmes to support investment in preferred technical approaches to FTTH. These programmes would guide investment into the right infrastructure solution and would, therefore, inhibit the development of local initiatives that may not be scaleable or interoperable
g. Developing a common strategy and establishing the European communications infrastructure as a regulated monopoly
h. R&D and commercialisation programmes. These should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration

2. Insufficient funding for development and commercialisation of photonics technologies, exhibited by

a. A fragmented European supply chain
b. High capital costs of market entry
c. A lack of (financial) support for technology commercialisation

This barrier and its subsidiary issues can be addressed by:

d. R&D and commercialisation programmes
e. Proof of concept and demonstrator programmes

These should focus on key emerging technologies such as silicon photonics, all optical technologies and photonics integration.

f. Capital grant programmes to support investment in facilities for photonics manufacturing

3. Insufficient global semiconductor manufacturing presence in Europe

It is considered unlikely that this situation can be addressed by industrial development. Therefore, interventions that influence the market to invest in the development, demonstration and potential adoption of new photonics technologies, such as pre-commercial procurement programmes, are required. Further, if these can be linked to interventions that are designed to achieve clarity in market requirements (see 1, above) then it is considered that the impact is likely to be more significant.

4. Potential REACH restrictions

This is, as already highlighted is a concern rather than a barrier. It may become a major current issue for the photonics industry if GaAs and InP are designated as hazardous substances. The industry is itself responding to the current situation but it is important that similar issues do not arise in the future. This can be achieved by establishing an initiative that engages with European Chemical Agency activities, becomes aware of all potential issues at an early stage, influences on behalf of the photonics industry and catalyses photonics industry activity if required.
Of course, this intervention is appropriate to monitor and address issues affecting all green photonics technologies.

These intervention options are summarised in Figure 21:

		Intervention Options						
		R&D and Commercialisation Programmes		Subsidised Market Development Programmes		Market Re-engineering		Monitoring Regulation
		Near Market R&D Programmes	Proof of Concept Programmes	Demonstrator Programmes	Capital Grant Programmes	Pre-Commercial Procurement	Influencing Market Structure and Development	
Key Barriers to Market Development	Insufficient Clarity in Market Requirements	●	●	●	●		●	
	Insufficient Funding for Development and Commercialisation	●	●	●	●			
	Insufficient Global Semiconductor Manufacturers in Europe					●		
	Potential REACH Restrictions							●

Figure 21: Potential Interventions to Address Major Barriers to Uptake

PHOTONICS TECHNOLOGIES and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Annex 4:

Advanced Sensors and Instrumentation Technologies and Applications

17th February 2012

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Prepared by

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Executive Summary

Executive Summary

This document reviews advanced sensor and instrumentation applications for photonics. It summarises a specific green photonics technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity.

The application of photonics based sensing and instrumentation technologies in the energy generation industry, transport and for monitoring green house gas (GHG) emissions from industry was analysed in this study. These applications have been chosen as they have the greatest impact on the transfer to a low carbon economy.

The requirements for industrial emission and related fugitive source measurements using photonics technologies are driven by legislation[1]. These are generally based on EU legislation, which in turn is based on pollution limits to protect human health effects and prevent damage to the environment. Photonic or optical based technologies are used extensively in both existing and new emissions monitors. They rely on the ability of the pollutants to absorb optical, ultra-violet and infra-red radiation.

The worldwide market for continuous emission monitoring equipment was estimated at around €500 million in 2009 with estimates of growth to €700 million by 2013[2]. Market growth is expected to be in developing countries, especially those in the Far East.

Europe has a number of key suppliers of photonics based instrumentation that operate on a global scale and a number of highly innovative niche market players. This part of the photonics industry, due to its rather small scale, tends to adopt technologies developed for other applications. It is expected that new sources (e.g. lasers, LEDs and broadband sources), new and enhanced detection techniques and new materials and optics will be exploited to develop enhanced sensors and instrumentation.

Formal initiatives outside of Europe are restricted to the USA, Japan, Ko-

[1] http://ec.europa.eu/clima/policies/ets/index_en.htm, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ: L:2009:140:0114:0135:EN:PDF and http://ec.europa.eu/environment/waste/landfill_index.htm

[2] Continuous Emission Monitoring Systems Worldwide, ARC Advisory Group, 2009

rea and Saudi Arabia and, to a lesser extent, China. They are generic photonics or sensor initiatives rather than technology specific.

The main strengths of the European industry are its established position as a market leader[3] and its reputation, its existing globally competitive company base and its leading position in key market sectors (e.g. Continuous Emission Monitoring Systems). Its high cost base compared to elsewhere is a key weakness.

It is expected that the market will generally grow in line with GDP in the developed world but increased adoption of environmental controls in industry in the developing world will lead to faster worldwide growth. The introduction of new regulation (e.g. for greenhouse gas emissions[4] and carbon capture and storage[5]) will offer additional market growth opportunities. It is also expected that Europe will retain its current position as a market leader.

Given the rather limited size of the markets, the potential impacts are modest compared to the other photonics technologies reviewed. The most significant impact is that improved sensor capability will underpin future legislation.

Three major barriers to deployment of new technology were identified – regulations (due to the constraints on the types of instrument that can be used), instrument type approval requirements and the relatively small scale of the market (which does not justify focused investment in new product development).

These barriers can be addressed by the following actions:

1. **Legislation and instrument type approval requirements,** being barriers to the adoption of innovative sensor and instrumentation technologies. These barriers can be overcome by

    - Prototype development and demonstrator programmes that show the performance and suitability of innovative technologies

[3] Published evidence on market share is not available but key industry stakeholders all assert that Europe holds this position
[4] http://ec.europa.eu/clima/policies/ets/index_en.htm
[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

- Rationalisation and simplification of the regulatory requirements to demonstrate "equivalence" of innovative technologies

2. **Market Size,** being such that it will not support much dedicated product development activities

   This barrier can be overcome by a dedicated research, development and innovation programme focusing on developing technologies (e.g. lasers and detectors) that are optimised for sensing applications. It must be noted that due to the small scale of the market the economic impact accrued is likely to be modest. However, such an intervention would underpin Europe's leading position in a key enabling technology for the low carbon economy.

In summary, this is a relatively small scale application for photonics technology but one that is critically important to support the application and enforcement of regulation.

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Glossary

Acronym	Description
µm	Micrometre
µS	Microsecond
2D	Two Dimensional
3D	Three Dimensional
AlN	Aluminium Nitride
AMOLED	Active Matrix Organic Light Emitting Diode
AMEPD	Active-Matrix Electrophoretic Display
AMS	Automated Measuring System
APD	Avalanche Photodiode
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act (2009)
a-Si	Amorphous Silicon
ASP	Average Selling Price
AWG	Arrayed Waveguide Grating
BAT	Best Available Technology
BIPV	Building Integrated Photovoltaics
CAGR	Compound Annual Growth Rate
CALiPER	US Department of Energy Commercially Available LED Product Evaluation and Reporting Programme
CCS	Carbon Capture and Storage
CCT	Correlated Colour Temperature
CD/M^2	Candela per Meter Squared
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformité Européenne
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires
CEM	Continuous Emissions Monitors
CEMS	Continuous Emissions Monitoring Systems
CEN	European Committee for Standardisation
CEN TC 264	CEN Standards Committee
CFL	Compact Fluorescent Light
CFP	C-Form Factor Pluggable
CIE	International Commission on Illumination
CIGS	Copper Indium Gallium Diselenide
CIP	Centre of Integrated Photonics
CO	Carbon Monoxide

CO_2	Carbon Dioxide
CPV	Concentrator Photovoltaics
CQS	Colour Quality Scale
CRI	Colour Rendering Index
CRT	Cathode Ray Tube
CSM	Sustainable Manufacturing
CuZnSnSe	Copper Zinc Tin Selenide
CVD	Chemical Vapour Deposition
CW	Continuous Wave
DCICC	Dynamic Coalition on Internet and Climate Change
DFB	Distributed Feedback
DG ENV	Environment Directorate, European Commission
DIAL	Differential Absorption Lidar
DLP	Digital Light Projection
DMD	Digital Micro-mirror Device
DOE	Department of Energy
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electroabsorption Modulator
EBM	Environmentally Benign Manufacturing
EC	European Commission
EC JRC	European Commission Joint Research Centres
EDFA	Erbium Doped Fibre Amplifier
e-ink	Electronic Ink
EISA	Energy Independence and Security Act
EL	Electroluminescent
ELC	European Lamp Companies Federation
EML	Electroabsorption Modulated Laser
EMS	Environmental Management System
EN 15267	European Standard for Instrument Type Approval
EN 1911	Standard method for monitoring HCl
e-paper	Electronic Paper
EPA (US)	Environment Protection Agency
EPI	Epitaxy
EPIA	European Photovoltaic Industry Association
ESL	Electronic Shelf Label
ETV	Environmental Technologies Verification Scheme
EU	European Union
EU-ETS	European Emissions Trading Scheme
FBG	Fibre Bragg Grating

FEC	Forward Error Correction
FED	Field Emission Display
FP	Fabry Perot
FP8	Framework Programme 8
FPD	Flat Panel Displays
fs	Femtosecond
FTIR	Fourier Transform Infra red
FTTC	Fibre to the Kerb or Building
FTTH	Fibre to the Home
GaN	Gallium Nitride
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GDP	Gross Domestic Product
GE	General Electric
GEPON	Gigabit Ethernet Passive Optical Network
GHG	Greenhouse gas
GLS	General Lighting Service
GPON	Gigabit-Capable Passive Optical Network
gw	Gigawatt
HB-LED	High Brightness Light Emitting Diode
HCl	Hydrogen Chloride
HDTV	High Definition Television
HTPS	High Temperature PolySilicon
IALD	International Association of Lighting Designers
ICT	Information and Communications Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ILS	Industrial Laser Solutions for Manufacturing
InAsSb	Indium Arsenic Antimonide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infra Red
ISO	International Standards Organisation
ISO 14001	International environmental quality standard
ITO	Indium Tin Oxide
ITRI	Industrial Technologies Research Institute, Taiwan
ITU	International Telecommunications Union

JRCM	Japan R&D Centre of Metals
kg	Kilogramme
KOPTI	Korean Photonics Technology Institute
KTN	Knowledge Transfer Network
kW	Kilo Watt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LED	Light Emitting Diode
LEP	Light Emitting Polymer
LIDAR	Light detection and Ranging
lm/W	Lumens per Watt
LTE	Long Term Evolution
LTPS	Low Temperature PolySIlicon
MACT	Maximum Achievable Control Technology
MCERTS	UK Product Certification Scheme
MEMS	Microelectromechanical Systems
MIIT	Ministry of Industry and Information Technology
MOVCD	Metal-Organic Chemical Vapour Deposition
MP3	Media Player
Mtoe	Million tonnes oil equivalent
MW	Megawatt
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
NEDO	New Energy and Industrial Technology Development Organisation
NER 300	Support Programme for Installations of Innovative Renewable Energy Technology and CCS in the EU
NGLI	Next Generation Lighting Initiative
NGLIA	Next Generation Lighting Industry Association
NGO	Non Governmental Organisation
NGPON	Next Generation Passive Optical Network
NMP	Nanotechnology, Materials and Production Technologies
nm	Nanometre
NO_x	Nitrous Oxide
NPL	National Physical Laboratory
NREL	National Renewable Energy Laboratories
NRZ	Non Return to Zero
ns	Nanosecond
OEM	Original Equipment Manufacturer

OIML	International Organisation of Legal Metrology
OLED	Organic Light Emitting Diode
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPV	Organic Photovoltaics
OVPD	Organic Vapour Phase Deposition
OXC	Optical Cross Connect
PDA	Personal Digital Assistant
PDP	Plasma Display Panels
PIC	Photonic Integrated Circuit
PLED	Polymer Light Emitting Diode
PM	Particulate Monitoring
PMEPD	Passive Matrix Electrophoretic Display
PMLCD	Passive Matrix Liquid Crystal Display
PMOLED	Passive Matrix Organic Light Emitting Diode
PMP	Portable Media Player
PON	Passive Optical Network
POP	Point of Presence
POS	Point of Sale
PPE KTN	Photonics and Plastic Electronics Knowledge Transfer Network
ps	Picosecond
PSD	Power Spectral Density
p-Si	Polycrystalline Silicon
PV	Photovoltaics
PVI	Photovoltaic International
PVTP	Photovoltaic Technology Platform
QC / QCL	Quantum Cascade (laser)
QPSK	Quadrature Phase Shifting Keying
R&D	Research and Development
RDI	Research, development and Innovation
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RGB	Red, Green Blue
RMB	Chinese currency
ROADM	Reconfigurable Optical Add Drop Multiplexer
R2R	Roll to Roll
RoI	Return on Investment
SCR	Selective Catalytic Reduction

SED	Surface-conduction Electron-emitter Display
SEMI	Global Industry Association Serving the Manufacturing Supply Chain for the Micro- and Nano-electronics Industries
SERDES	Serilaiser/Deserialiser
Si	Silicon
SiC	Silicon Carbide
SME	Small and Medium Enterprise
SMOLED	Small Molecule Organic Light Emitting Diode
SOA	Semiconductor Optical Amplifier
SONET/SDH	Synchronous Optical Network/ Synchronous Digital Hierarchy
SSL	Solid-State Lighting
STN	Super-Twisted Nematic
SWOT	Strengths, Weaknesses, Opportunities and Threats
Tb	Terabyte
TCO	Transparent Conducting Oxide
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing Passive Optical Networks
TEC	Thermo-Electric Cooler
TFT	Thin Film Transistor
TDL	Tunable Diode Laser
TN	Twisted Nematic
TV	Television
TWh	Terra Watt Hour
TWI	The Welding Institute
UBA	German Type Approval Scheme
USD	United States Dollar
USP	Unique Selling Proposition
UV	Ultra Violet
VCSEL	Vertical Cavity Surface Emitting Laser
VDSL	Very-High-Bit-Rate Digital Subscriber Line
VFD	Vacuum Fluorescent Display
VOC	Volatile Organic Compound
WDM	Wave Division Multiplexing
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
WOLED	White Organic Light Emitting Diode

Note:
Exchange rates of €1 = £0.87 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source.

Introduction

1

1. Introduction

This document, reviews advanced sensor and instrumentation applications for photonics. It summarises a specific green photonics technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity. It has been prepared to address the following specific objectives and to underpin a summary report on the potential of green photonics technologies in Europe:

1. Overview of existing green photonics technologies and today's related markets and market players
2. Identification and analysis of promising new green photonics technology developments for market deployment in the period 2011-2015
3. Overview of major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
4. Analysis of Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
5. Assessment of the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
6. Assessment of how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
7. Identification and analysis of the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
8. Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries.

Each of these objectives is addressed in turn in the following eight sections of this report.

1.1

Overview – Advanced Sensors and Instrumentation

This report addresses the application of photonics based sensing and instrumentation technologies to the energy generation industry, transport and to the monitoring of green house gas (GHG) emissions from industry. These applications have been chosen as they have the greatest impact on the transfer to a low carbon economy. The focus will be on industries within the European Emissions Trading Scheme (EU ETS) as these are targeted with the greatest reduction of carbon emissions. The EU ETS is the cornerstone of European policies to reduce carbon emissions.

The study will primarily address photonics based (or enabled) technologies for monitoring emissions to air, as this is the main route for GHG and carbon emission from industry, transport and the power sector. Emissions of other pollutants will also be addressed. Emissions through other matrices, for example emissions through water and fly ash, will not be specifically addressed, unless common technologies are identified. Typical industrial processes that will be covered include combustion processes used in energy generation, including energy from waste applications, carbon capture and storage technologies to reduce CO_2 emissions from fossil fuel based energy generation, the use of renewables in energy generation, for example biomass burning, and the direct sensing of GHG emissions from energy intensive and waste industry sources.

The study will also identify photonics technologies used for process control, where the aim of the process control is to improve the efficiency of processes and reduce energy usage or reduce GHG emissions.

Transport is an important source of GHG emissions. Regulation targeted at reducing the emissions from transport is focused both on reduced emissions per vehicle mile and on the promotion of biofuels and low carbon electricity as fuels. Significant improvements in engine management and reductions to vehicle weight have already produced important reductions in carbon emissions. Attention is now focused on implementation of biofuels and/or electric vehicles.

Within the scope of this study, the definition of photonics technologies is broadly taken to be defined as the generation, manipulation and detection of light. Within its application to sensing and instrumentation, photonics primarily provides innovation in the optical source and sensing elements of measurement instrumentation. This instrumentation in general utilises optical properties of the environmental parameter of interest, to provide the required data (for example the spectroscopic properties of a pollutant gas may be used to enable a photonics based measurement which provides concentration information). Typical techniques include spectroscopic measurements to determine GHG and pollutant concentrations, optical measurement of flow parameters in emission streams, the use of optical radar (lidar) to map wind fields to optimise wind turbine installations and the use of remote sensing imaging technologies to identify leaks from industrial sources.

Overview of Existing Green Photonics Technologies and Today's Related Markets and Market Players

2

2.1 Existing Green Photonic Technologies

2.1.1 Emissions Monitoring

The requirements for industrial emission and related fugitive source measurements using photonics technologies are driven by legislative requirements. These are generally based on EU legislation, which in turn is based on pollution limits due to human health effects and damage to the environment.

Photonic or optical based technologies are used extensively in existing and new emissions monitors. They rely on the ability of the pollutants to absorb optical, ultra-violet and infra-red radiation. Historically, they use components which have been developed for other, larger scale applications e.g. defence or telecommunications. Other techniques are also used including electrochemical, radioactive, pressure sensing and MEMS technologies. Typically, photonics based technologies offer rapid sensing with high accuracy and specificity, especially for gases, but are currently often larger and more expensive than instrumentation based on other techniques. Published market figures do not differentiate between the technology types.

Globally, there are different general types of legislation and regulatory instruments to ensure that relevant emissions are controlled:

- Legislation based on control technologies, including best available (control) technology (BAT, Europe), and maximum achievable control technology (MACT, USA);
- Integrated pollution (prevention) and control;
- Emission limits (and financial penalties);
- Emissions trading/emissions caps and trade;

Different countries and/or economic regions employ these different types of regulation or regulatory instruments in different ways but most require measurements to confirm compliance.
Legislation typically specifies types of instrumentation that is already ap-

plied to determine emissions. There are a number of established technologies, which are specified as "reference methods", that must be used for different pollutant species. Some of these require automatic and continuous instruments, whilst others specify intermittent manual methods that must be sampled chemically and subsequently analysed in a laboratory. Photonics technologies are generally most relevant to the automatic and continuous instruments, and these will become increasingly required as new, better, more reliable, cost-effective photonic technologies become available in future. Currently used measurement techniques, which have been developed to address specific requirements, that employ a range of photonic and opto-electronic components and that are specified for the regulatory pollutants include:

- **Chemiluminescence and Fluorescence-Based Instrumentation**
  This instrumentation is used in the ultraviolet and visible spectral regions for sulphur dioxide and nitrogen oxide gaseous pollutants

- **Dispersive and Non-Dispersive Infrared Spectral Instrumentation**
  Used for the measurement of carbon dioxide and carbon monoxide pollutant emissions, for other pollutant gases, and greenhouse gas emissions including nitrous oxide, methane, and a range of volatile organic compounds

- **Optical Sources**
  Optical sources, including laser based instrumentation for the determination of the emissions of particulate-based pollutants, including certain toxic components of these

- **X-ray Fluorescence**
  Techniques such as X-ray fluorescence show considerable potential for the measurement of toxic and hazardous components contained within particles, but the source/detector components limit their applicability to a broad range of routine measurements.

  This instrumentation integrates currently available, rather than dedicated optical sources, detectors, and associated optical components to provide on-line automated measurement techniques for a wide range of greenhouse gases and pollutants. The instrumentation suffers from deficiencies as a consequence of limitations in these components including:

- High cost of ownership due first to high capital and installation costs
- High cost of ownership due to on-going requirements for regular servicing and repairs
- Significant electric power consumption
- Complex operational and regular calibration procedures required from the industrial plant operators

- **Light Detection and Ranging (Lidar)**
  This technique has been developed for measurements of flow in process control applications in order to optimise its productivity and minimise the waste streams, for monitoring of wind fields around different plant (e.g. wind farms) to optimise their generation efficiency

- **Differential Absorption Lidar (DIAL)**
  This technology has been developed for remote sensing for a number of years (as one-offs) by university researchers and by industry. There are, however, major challenges to developing DIAL systems that are capable of measuring expensive fugitive emission losses such as petrochemicals from oil refineries, methane greenhouse losses from landfill, carbon dioxide leakages from carbon capture and storage, and different greenhouse gas emissions (e.g. methane and nitrous oxide) from industry

  Currently only two DIAL systems exist worldwide, both of which were developed by the National Physical Laboratory. These systems are being deployed increasingly, but they currently have very high capital and maintenance costs and require skilled operators, and this limits their more frequent applicability to target different industrial problems. Nevertheless the cost benefits and the applications of these to support a greener industry are now being recognised widely in Europe and the USA

- **Cross Duct and Cross Plant Sensing Instruments**
  These instruments for measurement and process control are available and employ infrared lasers (e.g. infrared tunable diode and quantum cascade lasers) or other ultraviolet/visible sources for the measurement of greenhouse and pollutant gases and for real-time process operational control, and for monitoring the atmosphere directly. Their applicability is currently limited by their detection capabilities, which are related to current source and detector technology, their costs, and their ease of use

- **Infrared Imaging Cameras**
  Infrared imaging cameras are currently available for the identification of losses of pollutants and greenhouse gases from complex industrial plant. They currently have limitations on their detection sensitivity, spatial resolution, and field of view. Similar issues relate to the remote sensing of water and land surface contamination

- **Multi-Species Detection Instruments**
  Multi-species pollutant and greenhouse gas detection instruments, such as Fourier-transform and other dispersive spectroscopy, and opto-acoustic spectrometry, are available for an increasing range of applications, but present mechanical and optical designs, poor detection sensitivities, lack of robustness, and costs, limit their current applications

- **In-Situ Photonic Sensors**
  In-situ photonic and other sensors are used to monitor and/or control vehicle engine management systems as these become increasingly sophisticated, but improvements are limited by available sensor technologies. In addition, developments for screening the emissions from vehicles directly on the road are restricted due to current limitations in photonics source and detector technologies

- **Infrared Sensors**
  There is a developing market for infrared and other optical sensors for industrial combustion management and control (e.g. burner efficiency improvement)

- **Fibre Optic Sensing**
  This technique is used increasingly as components of advanced instrumentation in a range of different applications but there are current limitations in their applicability due to their optical properties

One important specific and related area is in the spectroscopic data required to underpin many of the technologies. These data represent significant IP for many manufacturers.

2.1.2 Transportation

Transportation employs a range of sensors in order to optimise management and control of all the engine functions and to monitor and control all the vehicle's emissions to atmosphere.

Vehicle engine management for petrol and diesel vehicles is increasingly sophisticated in practice but it depends generally on a fixed number of sensors – including two oxygen sensors for fuel air ratio optimisation (in a feedback loop), temperature of engine coolant, engine air flow sensor, intake manifold temperature sensor, manifold pressure sensor to monitor vacuum of the intake manifold and a throttle position sensor. All these sensors are linked to an on-board engine function controller. These are all required to be reliable cost effective sensors, within the environment of the engine, and currently none of these utilise optical sensors that could be better developed by the use of photonics. For example, the least reliable of these are the oxygen sensors that are based on solid-state detection techniques, which are subject to degradation in use and contamination by the exhaust gases, and are required to be changed every 60,000 miles. However, there are no suitable reliable opto-electronic sensors that would overcome these deficiencies.

Vehicle engine management with different power sources (e.g. hydrogen) is not as mature or well developed; although at present these also use simple solid-state sensors for engine management and control. It is not clear how the use of current or new photonics technologies could bring significant practical benefits.

Monitoring and control of the exhaust emissions of petrol and diesel vehicles is still a developing issue as new EC regulations on emission controls continue to be introduced (e.g. Euro IV –VI). Sensors are used for monitoring the gaseous emissions before and after the catalytic converters, or other converters, in the exhausts of vehicles, but these also use small solid-state sensors, for example, for monitoring NO_x, CO, and (sometimes) volatile organic compounds. These are required to operate in the high temperature contaminated environment of the exhaust gases and this represents a challenge to photonics sensing that has not yet been met successfully, reliably and cost effectively. In the EU, some research has been completed successfully that uses fibre-optic based tuneable laser and LED sensing, but this has not yet been adopted commercially. Examples of research activities include work by P. Martin at Manchester University (UK), F. Slemr at Fraunhofer Institute (Germany) and C.Camy-Peyret at University of Paris (France) and also research at Heriot-Watt University and Leeds University, (UK).

In future, there will be requirements to monitor other emission species that are amenable to optoelectronic sensing using photonics, including ammonia (from catalytic conversion) and carbon dioxide (to control greenhouse gas emissions), and this will be a challenging opportunity in future for photonic sensors.

2.2 Current Market

The current sensor and instrument market for emissions monitoring encompasses on-line instrumentation for emissions of pollutants known to cause direct harm to human health and ecosystems, which includes principally acid gases, VOCs and fine particulate matter. Some compounds are also present in both discharges to air and water. These instruments are known as Continuous Emissions Monitors (CEMs).

The market for on-line sensors and instrumentation in the environmental and power sector is largely driven by regulation. The equipment is used almost exclusively to demonstrate compliance with environmental legislation although it does have a secondary use in process control and optimisation. In the EU, a number of Directives regulate emissions to air and water and provide a statutory framework that lays down the requirement for continuous emissions monitoring of all large sources of pollution. The Directives, which cover longstanding pollutants, include the Large Combustion Plant Directive, the Waste Incineration Directive and the Water Framework Directive. In the US, similar legislation covers largely the same list of pollutants. Regulation in the rest of the world is less rigorous but usually follows US or EU models such that suppliers of instrumentation to EU and US industries also supply to the rest of the world.

However, published evidence on market size is difficult to obtain – according to Chemical and Engineering News[6], ***"the global market for instruments that monitor stack emissions is hard to put a finger on"***. Available evidence includes:

[6] Monitoring Greenhouse Gases, Chemical and Engineering News, August 9th, 2010

- In 2008 the worldwide market for CEMS was estimated at €425 million by the ARC Advisory Group[7] with growth to around €700 million projected for 2013, as shown in Figure 1.

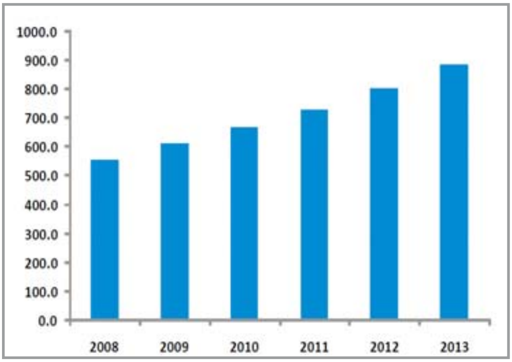

Figure 1: The Worldwide Continuous Emission Monitoring Systems Market ($ millions)

This report underlines that the market is driven by the implementation and enforcement of regulation and highlighted that market growth in the USA is affected by a lack of enforcement.

- An estimated market of €538 million in 2009[4]

- A recent report published by the McIlvaine company[8] claimed that the world market for all continuous emissions monitors (CEMs) will exceed €750 million per annum in 2012. There are related markets for monitoring of pollutants in ambient air in conurbations, from diesel engines during manufacture and testing and for process control. Pollutant concentrations are different in these applications so modified instrumentation is required, but the markets are linked and often have common providers. Taking into account the additional revenues for these applications the market is claimed by McIlvaine to be above €2.3 billion per annum in 2011. The market for existing technologies is expected to grow with overall GDP. No breakdown of the market by region is available in the literature. Information is available from non-published sources and this is included where appropriate. It is estimated by the industry that photonics sensors account for approximately 80% of the CEMS market

There is a view that market research reports tend to overestimate the size of the market, and the market for emissions monitoring instrumentation

[7] Continuous Emission Monitoring Systems Worldwide, ARC Advisory Group, 2009
[8] "CEMS Market Exceeds €1 billion" http://home.mcilvainecompany.com, September 2010

in Europe is viewed as mature. A European market value in the region of €60M is suggested by industry. There is a view that accession countries and former Soviet states provide a new growing market but that this market will mature rapidly. Any market in Europe would be driven by regulatory changes. One aspect that may represent a growth area would be the integration of emissions (pollutant) monitoring with process control capabilities – providing an economic benefit to plant operators.

New market opportunities are likely to be mainly in the developing world and in China and India. Anecdotal evidence suggests that China was tending more towards European standards and methods rather than US methods. This would support the sale of instruments from Europe. European manufacturers tended to be small and serve niche markets. There is strong competition on price between the larger manufacturers within Europe. Approximately 70% of business for European manufacturers is outside Europe, even though this brings them into open competition with US and far eastern competitors.

As this is a regulation driven market, standardisation is important. European standardisation of methods relating to emissions monitoring is carried out in CEN technical committee TC264. This committee responds to mandates from the Commission (primarily DG ENV and DG ENTR) and develops standards to meet the requirements of European directives. Some other standardisation is undertaken in ISO committee 146, where the work is of wider application. Recent standardisation activities, which impact the use of photonics based technology for emissions monitoring, has included reference methods for instrumental techniques for the determination of flow in emission ducts, required for the determination of mass emissions, which is of relevance to emissions trading. Recently mandated work includes a new method to address the use of techniques using infrared detection for the measurement of hydrogen chloride in ducts, instrumental techniques for the determination of sulphur dioxide emissions and the use of Fourier-transform based instruments (FTIR) for a range of species. These methods are all being developed to allow the use of optical instrument based techniques as alternatives to the existing wet chemistry based reference methods. In addition work is being mandated to cover the determination of fugitive emissions, which will include the use of optical techniques.

There is little directly funded pre-normative research within this field; any such work tends to be undertaken at a national level, by, for example, regulatory bodies or industry trade associations.

2.3 Market Players

Europe has a number of important suppliers of photonics based instrumentation to the emissions monitoring and energy sectors. Historically the US has also been important but now Japanese companies are taking market share. Large European companies include Sick AG, Siemens, Servomex, Environment SA, Crowcon and Testo AG. These companies operate on a global scale. A number of smaller European companies, which had innovative new products or niche market positions, have been taken over by large US companies in recent years. Examples include Land Instruments which was taken over by Amatek Inc., and Rupprecht and Patashnick , which was taken over by Thermo Fisher Scientific .

In the energy sector, suppliers of services and instrumentation to oil companies are now seeing new low carbon technologies, like Carbon Capture and Storage (CCS), as important new markets. Both Siemens and Schlumberger, large European oil sector service companies, are expanding into the supply of instrumentation and control technology to the CCS sector. European providers of combustion or process technology have also developed relationships with a local instrumentation provider to bring a complete technology package to the market. Wind farms also require instrumentation to measure wind speed and direction and optimise turbine performance.

It is very difficult to quote reliable market figures for these companies, as the majority of the larger companies are diversified in nature and it is, therefore, difficult to estimate photonics based activities. Some start-ups are also being created, e.g. PCME (UK), Alphasense (UK), Toptica (Germany) and Leosphere (France).

Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

3

3. Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

As yet, there have not been many major developments of the specific photonics technologies that are required to advance innovation in this sector. Instead, the photonics technologies that are applicable and beneficial to this market have generally (but not always) relied on developments in other photonics areas (e.g. infrared lasers developed for the telecommunications field applied to greenhouse gas and pollutant sensing). Examples of advanced photonics technologies that will provide growth for European industry, increased use of green technologies, energy efficiency improvements, reductions of greenhouse gas and pollutant emissions, in this field are:

1. Novel Infrared Photonics Technologies

Technologies such as high-power continuous wave quantum cascade (QC) and tunable diode lasers (TDLs) that can be applied to multi-species greenhouse gas and pollutant sensing to provide better sensitivity and selectivity than at present. These must have wavelengths that are selected for use in these applications. QC lasers in particular are evolving rapidly in terms of their relevant infrared wavelength coverage for gas and vapour detection, their reliability and robustness, capability for operating with new efficient mini-coolers, and at reduced costs. These laser systems will be used increasingly for in-situ monitoring and open atmospheric fenceline monitoring. Further potential applications include measurements of emissions from marine transport, where new international legislation is being introduced

2. New and Enhanced Detection Techniques

Techniques such as cavity ring-down spectroscopy, cavity enhanced spectroscopy, and long-path laser absorption spectrometry, that are robust, can be reduced in size and can be incorporated into multispecies sensors with good detection sensitivities. Such technology would have application in biomass burning and other combustion measurements. It would provide accurate information in support of greenhouse gas emission trading, and enhanced waste management. These techniques, when used with suitable wavelength lasers, are capable of monitoring a wide range of gases and vapours, including greenhouse gasses, and of detecting different isotopes near simultaneously to identify, for example, whether the sources are natural or anthropogenic

3. High Power LEDs

High power pulsed and continuous-wave LEDs (including organic LEDs) in suitable infrared visible and ultraviolet spectral regions that can be used as multi-wavelength sources for the parallel sensitive detection of a number of greenhouse gas and pollutant species simultaneously with suitable detector arrays (similar ultraviolet LEDs have a wide range of other applications e.g. water purification); These, when used together, are considered as a new exploitable technology for multispecies gas detection, which, in some applications, will replace more complex techniques such as FTIR

4. Solid State Lasers

High pulse energy robust fixed-wavelength solid state lasers that can be applied to lidar wind sensing and process control (e.g. flow) applications; Once this technology has been demonstrated to be robust and cost-effective, a wide range of flow sensing applications will open up that are not easily achievable at present. These include a combination of flow and speciated gas monitoring of effluent pipes and flare emission sources for the chemical and other industries

5. High Pulse Energy Solid State Lasers for Advance Dial Systems

High pulse energy robust solid-state laser systems wavelength tunable in the infrared visible or ultraviolet regions used for advanced DIAL system applications (carbon capture and storage, greenhouse gas and pollutant loss detection in industry). These include broadband optical parametric amplifiers, new periodically-poled nonlinear materials diode-pumped solid state lasers, and frequency-agile laser systems. These sources also have applications to chemical agent detection in the atmosphere

6. New Photonics Technology for the Real Time Monitoring of High Temperature Gases and Vapours

There are opportunities for new photonics technology for the real time monitoring of high temperature gases and vapours such as those emitted by the exhausts of aircraft engines. A number of trials have been carried out worldwide by research groups, but the complexity, the costs, and the difficulty of using existing technologies means that the requirement has not yet been commercially exploited, although developments are being undertaken with new multi-wavelength sensing systems with improved photonic detection systems to bring this closer to fruition. The cost benefits are related both to improved efficiency of the aircraft engine and reduced air pollution with cost savings related to improved human health and the environment

7. Infrared Detectors

Improved infrared detectors such as quantum-well devices and mid infrared avalanche photodiodes (e.g. InAsSb) can be used to increase detection sensitivity and/or to enable photon counting

8. Detector Arrays

Detector arrays in the infrared visible and ultraviolet spectral regions with one or two dimensions with the required detection sensitivities, by integrating miniaturized closed cycle cooling units, of application to multi-wavelength sensors and for hyperspectral image sensing; Quantum well arrays allow imaging spectroscopy to be achieved. It is recognised by experts contacted[9] that these detector arrays are growing in performance and reliability, their costs are reducing and the applications foreseen in the near future are increasing as a consequence. They can also be combined with multispectral techniques to provide imaging inside industrial processing plants

9. Broad Bandwidth Sources

The application of broad bandwidth sources and detector arrays into robust solid-state spectrometers (e.g. Fourier-transform) to develop lower cost sensors for the measurement of multiple greenhouse gases and pollutants; These are currently being trialled at different industrial plants as whole fence-line monitors for the detection and identification of accidental leakages of harmful and/or expensive industrial products. This applica-

[9] As part of the stakeholder consultation programme carried out as part of this study

tion is estimated by the industry as having a potential EU wide market of > 6000 instruments with a market value ~€29 million.

10. Broad Spectral Bandwidth Sources

These are high energy photonic sources and array detectors for measurements of particulates in pollutant emissions and in process control and quality control in manufacturing processes; Industry sources have identified that the market for particulate monitoring in the EU could grow by a factor of five in the next ten years, based on their estimate of the current market, provided that the technology is robust and cost- effective

11. Novel Optics

Infrared fibre optics and Bragg diffraction gratings can be used to provide more efficient and more robust sensing systems for use in combustion efficiency monitoring and control

12. Optoelectronic Materials

New solid-state optoelectronic materials will be utilised to offer more efficient and robust nonlinear optical generation of different wavelength sources

13. Imaging Cameras

New detection systems will be developed to offer improvements to imaging cameras for loss detection

14. Detection Technologies

Simpler vehicle roadside screening using photonic sources and detection technologies and improved solid state sensors for better vehicle engine management.

Overview of Major Research Programmes and Deployment Initiatives outside Europe

4

4. Overview of Major Research Programmes and Deployment Initiatives outside Europe

Formal initiatives outside of Europe are restricted to the USA, Japan, Korea and Saudi Arabia, and to a lesser extent China, and are described below. These are limited in comparison to other technologies, particularly photovoltaics and energy efficient lighting, which is entirely consistent with the earlier comments on advanced sensors and instrumentation for emission monitoring being a small niche sector, which depends on other sectors for product development.

4.1 USA

The US is spending significant sums on technology research as a way of stimulating the economy (The American Recovery and Reinvestment Act of 2009 (ARRA), also known as the stimulus act or stimulus package). Millions of dollars are being spent on climate change mitigation technologies. The Department of Energy's (DOE) Office of Fossil Fuel is overseeing a number of projects investigating various issues associated with the sequestration of carbon dioxide. In order to promote rapid demonstration, the US government is assuming all liabilities for the first five demonstration units. These and related initiatives will stimulate the market for control and environmental instrumentation in a low carbon economy. The US MACT program mentioned earlier has had a significant impact on innovation and developments in the US.

4.2
Developing Economies

Developing economies, which have amassed income from trading (China and Far East) and natural resources exploitation (Middle Eastern countries), are seeking to invest this money to build an economy based on technology development. Photonics based technologies are likely to be part of this activity. The King Abdulaziz City for Science and Technology in Saudi Arabia has published a strategy document 'Strategic Priorities for Electronics, Communications and Photonics Technology Program' (http://www.kacst.edu.sa/en/research/Documents/ECP.pdf), which outlines priority areas for development including lidar (laser radar) and instrumentation for oil and gas pipeline surveillance.

In Jan 2008, the UK and China signed a Joint Declaration on Climate Change to further strengthen co-operation on adaptation to climate change, low carbon technology development and transfer, clean energy, energy efficiency, research on programmatic clean development mechanisms (CDM) and the Near Zero Emissions Coal Project. The aim is to promote new technology development, of which instrumentation will be part.

In 2005, Korea created a "photonics town". The town, called Gwangju (or "village of light"), is home to more than a dozen research institutes, government agencies investing in photonics R&D, and photonics trade associations promoting the industry's development. Companies locating in the Gwangju photonics cluster receive generous tax incentives.

Japan has a long-standing and successful instrumentation industry. Hamamatsu and Horiba are large suppliers of emissions monitoring and other gas sensing equipment. Japan also has numerous successful engineering companies that supply to the energy sector and stimulate demand for Japanese instrumentation. These and similar companies fund large research projects in collaboration with Japanese universities and other state-funded research institutions.

Based on the above analysis, there is limited value in assessing transferability of initiatives developed elsewhere to Europe.

Europe's Current and Future Perspectives for Market Positioning in Identified Green Photonics Areas and Related Applications

5

5.1
SWOT Analysis – Current Perspectives for Market Positioning

A SWOT analysis of the current position for the European sensors and instrumentation industry for emissions monitoring and energy is shown in Figure 2.

Strengths	Weaknesses
• Existing market position • Large established companies and smaller innovative companies • Type approval systems respected worldwide • World leading companies in related areas, e.g. power generation technology and oil field services	• High cost base • Perceived lack of government investment compared with US and other large economies
• Low carbon economy, and related regulation will drive new technology development • Biomass and biofuel use will create a market for new products	• Focus of energy sector shifting to the Far East • Lower cost base countries developing instrumentation capability • Takeover threat from larger non-European companies
Opportunities	**Threats**

Figure 2: SWOT Analysis for the European Advanced Sensors and Instrumentation Industry – Current Position

5.2
Market Development

The market for on-line sensors and instrumentation in the environmental, vehicle, industrial and power sectors is largely driven by regulation. The equipment is used almost exclusively to demonstrate compliance with environmental legislation, although it does have a secondary use in process control and optimisation. In the EU, a number of Directives regulate emissions to air and water and provide a statutory framework, which lays down the requirement for continuous emissions monitoring of all large sources of pollution. This regulation has been reviewed over the recent past with the outcome that pollutant emissions will be more comprehensively abated in the immediate future.

The market for CEMs measuring traditional pollutants will grow with GDP in the developed world (as increased industrial activity will require a concomitant increase in monitoring equipment), while increased demand for environmental controls in industry in the developing world, as the standards applied in the developed world are adopted, will lead to faster worldwide market growth for CEMs. Greenhouse gas (GHG) emissions and energy saving are increasingly the focus of attention in the developed world. The market for instrumentation to monitor emission of GHGs is currently small compared with that for other pollutants, but is likely to grow as industry adapts to a low carbon economy.

New EU Regulation is being introduced to limit emissions of GHGs - such as the Emissions Trading Scheme Directive[10] (all GHGs), the Carbon Capture and Storage Directive[11] (carbon dioxide) and the Landfill Directive[12] (principally methane); these will create a market for infra-red instrumentation to measure the carbon content of the fuel and flow rate, the emissions of GHGs and sensors that can optimise the fuel burning process to reduce overall fuel use. A large proportion of these CEMS will be photonics based.

Elsewhere, beginning in 2011, the U.S. Environmental Protection Agency will require operators of large carbon-emitting operations such as refineries, chemical facilities, and cement plants to submit annual emissions reports for carbon dioxide, methane, nitrous oxide, and other GHGs.

Carbon Capture and Storage (CCS) is seen as a key technology that will enable adaptation of fossil fuel derived energy into a low carbon economy by retro-fit to existing power stations and by new process design for new builds. The technology has also recently been accepted for inclusion in clean development mechanism projects, which should increase demand. The global market for new and replacement thermal power plants is currently about 140 Giga Watts (GW) p.a. (90GW p.a. of new capacity and 50GW of replacement capacity, assuming a replacement rate of 2%). The International Energy Agency in looking at future global scenarios, projects that a

10 http://ec.europa.eu/clima/policies/ets/index_en.htm
11 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF
12 http://ec.europa.eu/environment/waste/landfill_index.htm

large part of this thermal plant build will be fitted with CCS. Looking out to 2030, the IEA "450 stabilisation" case, suggests that 310GW of coal-fired and 170GW of gas-fired plant will be fitted with CCS by 2030[13]. This would imply an average construction of c.40GW p.a. between 2020 and 2030 .The IEA has extended this case out to 2050 in a 'Blue Scenario' in response to the G8 and EU targets of reducing emissions by 50% from current levels by 2050. Under this scenario, 700GW of coal-fired plant and 817GW of gas-fired plant would be equipped with CCS by 2050.

CEMS spend on a typical 500MW power plant is about €200,000, which is likely to double for CCS[14]. This gives an expected global market value, based on industry estimates[15], of €400 million for all emission monitors in the first instance. Scenario analysis by the IEA[16] indicated that CCS would mainly be used in industrialised countries, although by 2050, use of CCS in developing countries may reach comparable levels. Countries such as China and India already recognise the need for highest efficiency and are interested in understanding the potential for CCS against possible limits posed by local geology.

There is also the potential for innovation in existing products; lighter weight, cheaper CEMS that are more temperature stable, would take market share. Technology innovation is expected to follow developments in telecoms or military applications. These sectors offer much larger markets and historically have led technological innovation with components crossing over into the (smaller) instrumentation markets.

Integrating emissions monitoring with process control activities represents a potentially large new market but quantitative data on market size is not available. This would involve embedding multispecies, optical sensors in processes, enabling optimisation of the process and determination and control of emissions. This is being done in China already with embedded sensors being used to control abatement technologies i.e. tuning electrostatic precipitators, controlling ammonia slip in SCRs, and monitoring the mercury content in gypsum. Substitution of fossil fuels by biomass and waste, to reduce GHG emissions, will also act as a driver for market growth as these fuels generate

[13] Energy Technology Perspectives 2006 scenarios and strategies to 2050, International Energy Agency (2006), OECD/IEA, Paris

[14] http://www.cemtrex.com/news/59-cemtrex-secures-order-to-supply-continuous-emission-monitor-for-power-plant-in-india.html

[15] Input from stakeholder interview programme, carried out as part of this study

[16] Towards a Sustainable Future, IEA, 2008

more particulate matter and toxic VOCs (waste burning) than gas and oil. Investment into biofuels production capacity probably exceeded €3.1 billion worldwide in 2007 and seems to be growing rapidly[17]. It is not possible to estimate how much of this investment will be directed towards new sensors. In addition, the use of wind power will also drive the market for different types of sensors (e.g. Doppler Lidar).

Financial incentives to replace fossil fuels with biofuels are providing other technically challenging opportunities. Power companies see the need to differentiate fuel origin in a mixed fuel stream. One application is to quantify the biomass fraction of a mixed waste stream and photonics sensors may be able to differentiate based on visual characteristics. A different approach is to measure the percentage of the isotope C14 in the emitted carbon dioxide. This is essentially carbon dating the carbon dioxide and distinguished recent carbon (biomass) from fossil carbon. Offline analysis is currently required but future advances in sensing technology may provide the sensitivity for on-line analysis.

As the reporting of greenhouse gas emissions in company literature becomes more widespread, some organisations believe that a requirement for accurate measurements of carbon dioxide and methane in ambient air will emerge. Such measurements would parallel the air quality networks set up in urban population centres throughout Europe and the US in response to regulation. This would provide a new niche market for equipment based on laser cavity ring-down spectroscopy. There is as yet no definitive evidence to suggest that this market will develop in response to public demand ahead of any regulation.

5.3
Future Market Potential – Key Technologies

The commitments for more comprehensive industrial monitoring and improved abatement require the implementation of new continuous moni-

[17] "Towards Sustainable Production and Use of Resources: Assessing Biofuels". United Nations Environment Programme. 2009-10-16. http://www.unep.fr/scp/rpanel/pdf/Assessing_Biofuels_Full_Report.pdf

toring techniques to detect lower concentrations, generally using new/advanced infrared sources and detectors within more advanced and cost effective instrumentation – a number of these technologies were highlighted in Section 2 above. Companies are investing now in new products to address these new opportunities. However this is part of the normal product renewal cycle, as older instrumentation is rendered obsolete if it is not compliant with new EU Directives. Some extra demand is being created, as already highlighted, as developing countries seek to protect their environment.

Carbon capture and storage market development will offer significant opportunities for improved non-dispersive infra-red technology, open-path tunable diode laser spectrometers, differential absorption lidar and infra-red cameras.

Recently introduced incentives and regulation to stimulate biomass as an energy source is also providing a stimulus for new photonics based sensors. Updating existing equipment is the typical approach taken but a requirement to differentiate fossil fuel derived carbon from biomass derived carbon is also emerging. There is also a large emphasis, however, on employing new photonic technologies in this field to provide tools that make significant improvements to the economic efficiency and/or reducing the environmental impacts of industries in a number of ways that are difficult to achieve with previous technologies. Examples include:

- Remote sensing of greenhouse gas and pollutant emissions from industrial combustion processes etc, to optimise the performance of the process and thereby reduce the emissions
- Remote sensing of the emissions from landfill and similar sources in order to identify areas where gas recovery is most cost effective
- Remote sensing or semi-quantitative imaging of fugitive emissions from industrial plant to reduce the costs of the lost products. This includes, for example, losses from petrochemical processes where the products themselves are expensive, as well as being harmful to the environment, or having potential for greenhouse gas production in the environment (e.g. by formation of ozone from volatile organic compounds)
- Replacement of existing optical technologies by more powerful and robust photonics technologies to increase their measurement capabili-

ties and applications, increase the product's lifetime, reduce ownership costs, and reduce energy consumption

5.4 Future Market Share for Europe

The consensus view of industry experts is that European industry will retain its current market position, based on the activities of larger global companies and innovative SMEs as discussed in section 2, above.

5.5 SWOT Analysis – Future Perspectives for Market Positioning

A SWOT analysis of the future market position for the European sensors and instrumentation industry for emissions monitoring and energy is shown in Figure 3. The EU has developed the first Emissions Trading Scheme and London is the centre of carbon trading and clean development mechanism products. This has created an advantage for European instrumentation companies who are responding to these developments with new products. Renewable incentives are also creating a market for wind power, biomass and other renewables which is creating a new market for instrumentation. The weaknesses listed in Figure 2 are largely unchanged.

Strengths	Weaknesses
• Existing technology can be applied to new products; European companies are at the forefront. • Early adoption of GHG controls. • Development of Emission Trading Scheme and Clean Development Mechanisms	• High cost base; • Liability issues hindering CCS development compared with the US.
• EU investment is directed towards low carbon economy. • Renewable incentives will stimulate this market.	• Focus of energy sector shifting to the Far East; • Lower cost base countries developing instrumentation capability; • Takeover threat from larger non-European companies
Opportunities	**Threats**

Figure 3: SWOT Analysis for the European Advanced Sensors and Instrumentation Industry – Future Position

Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

6

6. Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

The EU has already put in place regulation to reduce greenhouse gases and energy consumption at the industrial level for large emitters. Improved sensor capability will allow the impact of this regulation to be demonstrated. Sensors and instrumentation uptake is largely confined to the industrial sector and is not expected to lead to reductions in domestic energy consumption. Key benefits are summarised in the tables below.

6.1 Economic Impact

Economic impacts are summarised in Figure 4:

IMPACTS	New Technology	Realisation
Economic	• New CEMS should be more robust and require less servicing • New CEMS should incorporate process control technology • New CEMS with process control will control pollutants more effectively • New CEMS should be lighter weight	• Lower servicing and operational costs • Will save energy during operation of power plant • Less expenditure on pollution abatement • Less raw material use

Figure 4: Economic Impacts and Benefits of Emission Monitoring Sensors

The worldwide growth in market and for sensors and instrumentation should yield an increase in GDP to the EU at least in line with existing market share. Published data on the European market share is not available so it is not possible to quantify the number of jobs that this will sustain/provide. A larger increase can be expected if member states pursue carbon capture and storage and renewable energy faster than the rest of the world. Although components and raw materials may be imported from outside the EU, most assembly, testing and development is carried out within the EU leading to an expected increase in jobs created.

6.2 Social Impact

Social impacts are linked to quality of life and the introduction of new processes as shown in Figure 5:

IMPACTS	New Technology	Realisation
Societal	• Enhanced environment – improved air quality • Better greenhouse gas sensing technology will increase public acceptance of carbon storage. • Better pollutant sensing may increase public acceptance of waste incineration and combined heat and power plants.	• Better quality of life for the individual • Less resistance to local carbon storage. • Less resistance to waste processing facilities.

Figure 5: Social Impacts and Benefits of Emission Monitoring Sensors

6.3 Environmental Impact

The environmental impact of advanced control and instrumentation is well established through the control of emissions. This will be continued and extended as shown in Figure 6:

IMPACTS	New Technology	Realisation
Environment	• Better greenhouse gas sensing will focus attention on high emitting facilities and countries. • Lower detection limits for pollutant detection will differentiate cleaner processes.	• Reduction in greenhouse gas emissions in urban areas. • Best available technology (BAT) will move forward and pollutant emissions will be reduced.

Figure 6: Environmental Impacts and Benefits of Emission Monitoring Sensors

Contribution to 2020 Low Carbon Energy Targets

7

7.
Contribution to 2020 Low Carbon Energy Targets

The low carbon economy targets set for Europe[18] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020 compare to a baseline of 1990 levels
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

Advanced sensors and instrumentation will be critical in achieving these targets. However, it will be an enabling technology, supporting users to contribute to these targets. It will enable energy consumers to monitor performance in a more and more accurate manner and thus identify opportunities to reduce consumption and/or greenhouse gas emissions.
It is, therefore, considered to be making a minor contribution to meeting these 2020 targets.

[18] EUROPE 2020, A European strategy for smart, sustainable and inclusive growth, European Commission, March 2010

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

8

8. Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

Key barriers to the uptake of novel photonics technologies for advanced sensors and instrumentation, particularly related to the role of sensors in environmental monitoring in industrial and power generation sectors include:

Legislative Barriers/ Inertia

One of the primary barriers to the uptake of new technologies is related to the primary driver for the measurements – which is regulation. Increasing regulation and market interventions worldwide, to reduce emissions of pollutants and force change to a low carbon economy, is driving growth but also creating barriers to entry. Type approval or independent assessment of technology is often required by regulators in Europe and the US to ensure compliance with the relevant regulation. Different regions of the world can require different testing regimes and this creates a barrier to entry for small companies or entrepreneurs with new ideas. Approvals gained in Europe or the US can, however, often facilitate sales in other regions of the world. This trend is expected to continue with the EU piloting the Environment Technologies Verification scheme, which, although voluntary at present, aims to cover all technologies which claim improved environmental performance.

Environmental controls and legislation provide the main drivers for monitoring environmental parameters. In general the legislative requirements, which are usually implemented as emission limit controls, lead to requirements on the methods used to measure and control compliance. These, in turn, lead to requirements for standardised measurement methods, and performance requirements. For example, in Europe, emission controls are enacted through Council Directives, such as the Industrial Emissions Directive. Such Directives place requirements on industrial plants, and national authorities, to report emissions. The Directives define limit values for controlled pollutants, and specify minimum monitoring requirements.

Within the framework of emissions monitoring, automated measuring systems (AMS), also known as Continuous Emissions Monitors (CEM) are prescribed for certain pollutants. There is a further requirement that the CEMs shall be calibrated against standard reference methods, and that a quality assurance system shall be in place.

The important role that standardised methods have in emission monitoring can present a barrier to innovation, as the existing techniques have an advantage in not having to be shown to be equivalent, and in some cases, if a novel approach is fundamentally different, it may be hard to demonstrate equivalence. An example is the monitoring of hydrogen chloride (HCl). The standard method EN 1911 is a wet chemical method, in which a sample of the stack gas is passed through liquid impingers that absorb the HCl for subsequent analysis by ion chromatography, titrations, or spectrophotometry. A number of optical based methods have been developed, which are able to directly measure HCl in the stack gas, and provide real-time data. However, the wet chemical reference method actually determines the total soluble chloride content in the stack gas, and, therefore, may give a different answer to the instrumental method, even though it could be argued the instrument method is providing a better measurement of HCl. This represents a barrier to the take up of improved sensors, which is being addressed jointly by the relevant Directorate, DG ENV, and CEN TC 264. However, the process takes some time, during which national regulatory authorities make independent decisions whether to accept instrumental techniques.

For the AMSs/CEMs used continuously to monitor industrial emissions, the requirement for a quality assurance framework was met by the development of a further European Standard – EN 14181. This standard defines the calibration methodology and other ongoing quality control methodologies. It also defines a requirement for the performance of the AMSs to be assessed and quantified by laboratory and field assessment. This assessment led to the development of a further set of European standards EN 15267 Parts 1-3, which define a testing and type approval process for instrumentation.

Within Europe, this standard has harmonised a number of existing national certification programmes, in particular the UK Environment Agency MCERTs product certification scheme and the German UBA type approval scheme. The impact of this certification process is discussed in the next section.

Instrument Type Approval Requirements

Within Europe and at a wider level, there are a number of national instrument approval and certification programmes, which regulatory authorities require instrumentation to have passed in order to be used for environmental monitoring. Two prominent schemes within Europe are the MCERTS and UBA schemes. Such schemes present three barriers to innovation, these are;

- the slow adaptability of both the performance requirements and the testing process to novel sensors, and in particular to novel sensor configurations. For example the use of cross duct analysers (which measure the average concentration across the stack) requires specific testing and validation capabilities
- inconsistencies between different national schemes can mean technologies have to be tailored to specific markets, adding to the cost of implementing new measurement innovations
- the presence of a certification scheme can distort the market, removing quality differentiators, as the performance requirements of the certification process represent minimum requirements and all instruments that meet these requirements are perceived as being equal. Cost then becomes the only differentiator. This can support innovation in photonics technologies, which reduces the cost of sensors, but can act against innovations that improve capabilities

Additional barriers can exist through additional performance requirements being developed within the same markets. An example is the development of performance standards for certain emissions monitoring instrumentation by OIML, the legal standards body, which are not equivalent to CEN and ISO standards.

The issues of inconsistent requirements across member states has been addressed by CEN TC 264, by the development of a harmonised European standard for instrument type approval, EN 15267, which implements common performance specifications and testing requirements across Europe.

The type approval regime in Europe may be helping to support certain European manufacturers by adding an entry burden to what is a fairly small market for non European suppliers.

Although type approval adds a delay and cost to innovation, it also has driven some aspects of innovation, improving the quality of systems and requiring, for example, calibration methodologies to be developed.

Market Size

The market size for individual gas sensing instruments is fairly small, when compared to communications or ICT markets. In addition, many instrument manufactures are SMEs who do not have the resources to develop novel photonics systems themselves.

Consequently, the development of the principle photonics components is usually reliant on technology drivers outside the environmental field. For example, environmental sensors are often based on available laser wavelengths developed for communications or military purposes, which are not necessarily the optimum for the sensing application. This is particularly the case where novel technologies come on to the market, for example quantum cascade lasers (QCL). Initially the high volume markets will drive the development of the sources. Once the technology becomes more mature, and production costs are lower, niche producers may begin to develop specific detectors or sources that directly meet the requirements of environmental sensing. A supply chain issue will then be that such producers make low volumes of the components, or are single suppliers, which can introduce a risk in terms of commercial production of sensing instrumentation relying on these sensors. Another issue that can arise is that for sensing applications, high specification sensors or sources are required, which need specific selection from higher volume production runs. For example the specification of a detector may be more stringent than a standard production line component, but it may be achievable by selecting a good chip from standard production runs. The supply of such components is often a high risk, as the availability of sensors with the correct specification may be dependent on factors outside the control of the component supplier.

European Initiatives to Overcome Barriers

While there are a large number of initiatives relating to the support of photonics in general, and some of these encompass sensing and instrumentation within their scope, there are relatively few initiatives directly aimed at supporting improved photonics based technologies for environmental sensing. There are, however, initiatives to encourage transition to a low carbon economy, which will indirectly stimulate the market for sensors and instrumentation. The support for Carbon Capture and Storage technology via the NER 300 initiative and the Environmental Technologies Verification Scheme (ETV) will both increase the demand for photonics based instrumentation.

Within member states, a number of the photonics clusters address the requirements of the companies developing novel sensors. In addition some initiatives, for example, the UK Sensors KTN (which is linked to but separate from the Photonics and Plastic Electronics (PPE) KTN), exist which support the sensing and application aspects, without specific focus on the photonic aspects of the market.

Within the UK, tax credit schemes are used to support innovation and R&D and it is considered by SMEs that these can be preferable to grant based schemes.

These barriers can be classified and summarised as shown in Figure 7:

Barrier Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
Legislation	Regulatory	High	Immediate	Low	The establishment and use of standardised methods is a barrier to adoption of innovative technologies.
Instrument Type Approval Regquirements	Regulatory	Medium	Immediate	Low	These approval systems are a barrier to innovation and inhibit the opportunities to exploit novel photonics (and other) technologies.
Market Size	Market	High	Immediate	€10's millions	The relative small market size means that there is little dedicated product development and that new technologies from other applications are adapted. A dedicated product development programme would lead to investment in application specific products which should lead to market growth.

Figure 7: Classification of Barriers

Potential Intervention Options

9

9.

Potential Intervention Options

The major barriers (ranked as high in Figure 7, above) to the development of the European advanced sensor and instrumentation industry have been assessed and the following actions to address these barriers have been identified:

1. **Legislation** is identified as a barrier to the adoption of innovative sensor and instrumentation technologies, such as some of those listed in Section 3, above. This barrier can be overcome by
   - Prototype development and demonstrator programmes that show the performance and suitability of innovative technologies, e.g. DIAL systems and multispecies detection instruments.
   - Rationalisation and simplification of the regulatory requirements to demonstrate "equivalence" of innovative technologies

These two interventions will ensure that the measurement performance of novel technologies is demonstrated and that there is then a streamlined mechanism for these new technologies to be adopted in regulations.

2. **Market Size,** being such that it will not support any significant dedicated product development activities.
   This barrier can be overcome by a dedicated research, development and innovation programme focusing on developing technologies (e.g. lasers and detectors) that are optimised for sensing applications. It must be noted that due to the small scale of the market the economic impact accrued is likely to be modest. However, such an intervention would underpin Europe's leading position in a key enabling technology for the low carbon economy.

These interventions are summarised in Figure 8:

		Intervention Options			
		R&D and Commercialisation Programmes			Regulation
		RD&I Programmes	Prototype Development	Demonstrator Programmes	Rationalisation and Simplification
Key Barriers to Market Development	Legislation		●	●	●
	Market Size	●	●		

Figure 8: Potential intervention Options to Address Barriers

PHOTONICS TECHNOLOGIES and Markets for a Low Carbon Economy

Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066

Annex 5:

Clean Manufacturing Technologies and Applications

17th February 2012

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Prepared by

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Executive Summary

Executive Summary

This document reviews clean manufacturing using lasers, summarises relevant technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity. Applications where a laser beam interacts with materials in a production process to change the form of the material or its shape, and the technologies associated with producing and forming laser beams for manufacturing operations were analysed in this study. The terminology 'lasers for materials processing' is used to generically describe this area of manufacturing.

The most important current technologies are diode lasers, disc lasers, fibre lasers, carbon dioxide lasers, high peak power and high pulse energy lasers and beam delivery systems.

The global industrial laser **systems** (defined as a machine tool incorporating a laser source) market was valued at almost €4.5 billion in 2010[1]. The global sales of laser **sources** included in these machine tools were estimated at €1.1 billion in 2010 with Europe's share estimated at €600 million[2]. Europe's share of the predicted market for laser sources is expected to be at least €850 million per annum in 2020, an increase of €250 million from its current position. The main market segments were metal processing (dominated by metal cutting but including welding and surface engineering), marking and engraving. Europe plays a major role in both manufacture of laser materials processing equipment and its use. A number of the major global companies are either European owned (e.g. Trumpf and Rofin Sinar) or have major facilities in Europe (e.g. Coherent). The key future technologies are expected to be high beam quality diode lasers, high power single mode fibre lasers and kilowatt class ultrafast

[1] Industrial Laser Solutions for Manufacturing (ILS) (www.industrial-lasers.com), January 2011. Industrial Laser Solutions for Manufacturing has been publishing an annual economic review of industrial laser markets for 25 years. These figures are constructed in terms of sales of laser sources used in manufacturing applications and then in terms of processing systems which include these laser sources. The data is assembled using information from about 30 publicly listed companies, known to be important players in the area. This is further supplemented by discussions with other companies as felt relevant in any particular year. The figures quoted for 2010 are listed as estimated, only because some organisations 4th quarter results for 2010 are as yet not known. No data are currently available which relate these figures specifically to the sub-set, aspects of clean or green manufacturing.

[2] Power Laser Trends, Dr Ch. Harder, Swiss Photonics and Laser Network, July 2009. Data is compiled from IOA, Laser focus World and OIDA sources

lasers. Green and dual wavelength lasers, UV laser sources and fibre optic and beam delivery systems are also expected to be important in the future. These new laser sources and their associated equipment, such as beam delivery systems, are becoming significantly more efficient in the way they convert electrical energy into optical energy. For example original laser welding lines in the automotive industry employed many lasers with efficiencies of only 3%. These can now be replaced by laser sources capable of the same manufacturing process but operating at efficiencies of up to 40%.

No specific initiatives to support the development of lasers in clean manufacturing were identified in other global regions. Clean (or green) manufacturing is being developed at a global level, with environmentally benign manufacturing emerging as a significant competitive factor between companies. However, there is no evidence to date that this has included the specific use of lasers in manufacturing.

Europe currently has a strong position in the global lasers industry based on its historic leading position in the industry and its continuing strong industrial and research base. Most of the world's major laser companies have their headquarters in Europe. There are, however, concerns that Europe's high cost base may affect its position in Far East markets that will lead, over time, to a weaker position in Europe, particularly if Far East companies actively seek to expand their own production of lasers for materials processing.

The global market for lasers in materials processing is expected to grow by over 40% in the period to 2020, with the Far East being the most attractive regional market. Fibre and solid state pumped lasers are expected to demonstrate the largest growth over this period. It is expected that Europe will retain its current strong market position over this period, particularly if it can successfully exploit Far East markets. This will provide added employment but the levels could not be quantified. Economic benefits will be offered to user sectors through lower materials, operational and maintenance costs. An estimate of the potential value of this was not available.

Laser processing offers a wide range of environmental benefits to users, which include:

- Reduced electrical consumption of more efficient lasers
- Reduced GHGs equivalents
- Production of less toxic by-products
- Less use of helium and other rare gases, which are currently used in laser based manufacturing systems
- Reduction in fumes generated during cutting processes
- Reduced use of raw materials in production
- Zero defect manufacturing will reduce scrap and waste
- Laser processes offer the potential of repair rather than scrap and replace, particularly for high value products
- Use of laser based solvent free cleaning techniques
- Removal of fouling in marine environments
- Efficient methods of assisting nuclear decommissioning
- Use of lasers for production of hybrid structures
- Manufacture of nano-particles
- Use of lasers in aspects of manufacture involving 'light-weighting'
- Use of lasers in battery applications for electric vehicles
- Efficient manufacture of photovoltaics

The main barriers to maintaining and expanding Europe's position in green manufacturing with lasers were cited by key industry stakeholders as a lack of awareness of the capability of the laser as a manufacturing tool, a lack of product design capability using laser manufacturing and the fact that economics, rather than 'greening', is the major industry driver.

These barriers can be overcome by a combination of demonstrator and capital grant programmes, as follows:

1. **Insufficient awareness by those implementing manufacturing solutions of the potential of lasers in clean manufacturing,** leading to the selection of alternative approaches.

   This barrier can be overcome by education and demonstrator programmes to show the potential of lasers in sustainable manufacturing. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the green, technical and business benefits of using lasers. Such applications might include aspects of light-weighting in the automotive industry showing how the benefits might be applied to other products. Other possibilities include the use of lasers in the production of photovoltaics, quantifying the benefits offered for replacing toxic chemical processes.

2. **Insufficient product design capability.** Product designers have little knowledge of the capabilities (and constraints) of laser based manufacturing technologies, which inhibits the application of these technologies in industry.

   This barrier can also be overcome by education demonstrator programmes that show the potential of lasers in a range of sustainable manufacturing roles. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the design, technical and business benefits of using lasers as well as the green manufacturing potential.

3. **Economics drives industrial decisions.** These typically focus on the initial capital costs only and neglect longer term operational and environmental benefits.

   A capital grant or equity/loan programme for the introduction of laser based clean manufacturing technologies will address this barrier. Furthermore, the scale of the grant available should be linked to the expected environmental benefits of adopting the laser based manufacturing technologies.

In summary, Europe has an established and strong laser industry and it is expected that it can retain this position in the future. There are a number of new technologies under development to extend the potential applications of lasers and Europe is in a strong position to exploit these. These all offer a range of competitive and environmental benefits to users, although these could not be quantified.

Table of Contents

Glossary

Acronym	Description
µm	Micrometre
µS	Microsecond
2D	Two Dimensional
3D	Three Dimensional
AlN	Aluminium Nitride
AMOLED	Active Matrix Organic Light Emitting Diode
AMEPD	Active-Matrix Electrophoretic Display
AMS	Automated Measuring System
APD	Avalanche Photodiode
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act (2009)
a-Si	Amorphous Silicon
ASP	Average Selling Price
AWG	Arrayed Waveguide Grating
BAT	Best Available Technology
BIPV	Building Integrated Photovoltaics
CAGR	Compound Annual Growth Rate
CALiPER	US Department of Energy Commercially Available LED Product Evaluation and Reporting Programme
CCS	Carbon Capture and Storage
CCT	Correlated Colour Temperature
CD/M^2	Candela per Meter Squared
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformité Européenne
CELMA	Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires
CEM	Continuous Emissions Monitors
CEMS	Continuous Emissions Monitoring Systems
CEN	European Committee for Standardisation
CEN TC 264	CEN Standards Committee
CFL	Compact Fluorescent Light
CFP	C-Form Factor Pluggable
CIE	International Commission on Illumination
CIGS	Copper Indium Gallium Diselenide
CIP	Centre of Integrated Photonics
CO	Carbon Monoxide
CO_2	Carbon Dioxide

CPV	Concentrator Photovoltaics
CQS	Colour Quality Scale
CRI	Colour Rendering Index
CRT	Cathode Ray Tube
CSM	Sustainable Manufacturing
CuZnSnSe	Copper Zinc Tin Selenide
CVD	Chemical Vapour Deposition
CW	Continuous Wave
DCICC	Dynamic Coalition on Internet and Climate Change
DFB	Distributed Feedback
DG ENV	Environment Directorate, European Commission
DIAL	Differential Absorption Lidar
DLP	Digital Light Projection
DMD	Digital Micro-mirror Device
DOE	Department of Energy
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electroabsorption Modulator
EBM	Environmentally Benign Manufacturing
EC	European Commission
EC JRC	European Commission Joint Research Centres
EDFA	Erbium Doped Fibre Amplifier
e-ink	Electronic Ink
EISA	Energy Independence and Security Act
EL	Electroluminescent
ELC	European Lamp Companies Federation
EML	Electroabsorption Modulated Laser
EMS	Environmental Management System
EN 15267	European Standard for Instrument Type Approval
EN 1911	Standard method for monitoring HCl
e-paper	Electronic Paper
EPA (US)	Environment Protection Agency
EPI	Epitaxy
EPIA	European Photovoltaic Industry Association
ESL	Electronic Shelf Label
ETV	Environmental Technologies Verification Scheme
EU	European Union
EU-ETS	European Emissions Trading Scheme
FBG	Fibre Bragg Grating
FEC	Forward Error Correction
FED	Field Emission Display

FP	Fabry Perot
FP8	Framework Programme 8
FPD	Flat Panel Displays
fs	Femtosecond
FTIR	Fourier Transform Infra red
FTTC	Fibre to the Kerb or Building
FTTH	Fibre to the Home
GaN	Gallium Nitride
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GDP	Gross Domestic Product
GE	General Electric
GEPON	Gigabit Ethernet Passive Optical Network
GHG	Greenhouse gas
GLS	General Lighting Service
GPON	Gigabit-Capable Passive Optical Network
gw	Gigawatt
HB-LED	High Brightness Light Emitting Diode
HCl	Hydrogen Chloride
HDTV	High Definition Television
HTPS	High Temperature PolySilicon
IALD	International Association of Lighting Designers
ICT	Information and Communications Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ILS	Industrial Laser Solutions for Manufacturing
InAsSb	Indium Arsenic Antimonide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infra Red
ISO	International Standards Organisation
ISO 14001	International environmental quality standard
ITO	Indium Tin Oxide
ITRI	Industrial Technologies Research Institute, Taiwan
ITU	International Telecommunications Union
JRCM	Japan R&D Centre of Metals
kg	Kilogramme
KOPTI	Korean Photonics Technology Institute

KTN	Knowledge Transfer Network
kW	Kilo Watt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LED	Light Emitting Diode
LEP	Light Emitting Polymer
LIDAR	Light detection and Ranging
lm/W	Lumens per Watt
LTE	Long Term Evolution
LTPS	Low Temperature PolySIlicon
MACT	Maximum Achievable Control Technology
MCERTS	UK Product Certification Scheme
MEMS	Microelectromechanical Systems
MIIT	Ministry of Industry and Information Technology
MOVCD	Metal-Organic Chemical Vapour Deposition
MP3	Media Player
Mtoe	Million tonnes oil equivalent
MW	Megawatt
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
NEDO	New Energy and Industrial Technology Development Organisation
NER 300	Support Programme for Installations of Innovative Renewable Energy Technology and CCS in the EU
NGLI	Next Generation Lighting Initiative
NGLIA	Next Generation Lighting Industry Association
NGO	Non Governmental Organisation
NGPON	Next Generation Passive Optical Network
NMP	Nanotechnology, Materials and Production Technologies
nm	Nanometre
NO_x	Nitrous Oxide
NPL	National Physical Laboratory
NREL	National Renewable Energy Laboratories
NRZ	Non Return to Zero
ns	Nanosecond
OEM	Original Equipment Manufacturer
OIML	International Organisation of Legal Metrology
OLED	Organic Light Emitting Diode
OLT	Optical Line Terminal
ONU	Optical Network Unit

OPV	Organic Photovoltaics
OVPD	Organic Vapour Phase Deposition
OXC	Optical Cross Connect
PDA	Personal Digital Assistant
PDP	Plasma Display Panels
PIC	Photonic Integrated Circuit
PLED	Polymer Light Emitting Diode
PM	Particulate Monitoring
PMEPD	Passive Matrix Electrophoretic Display
PMLCD	Passive Matrix Liquid Crystal Display
PMOLED	Passive Matrix Organic Light Emitting Diode
PMP	Portable Media Player
PON	Passive Optical Network
POP	Point of Presence
POS	Point of Sale
PPE KTN	Photonics and Plastic Electronics Knowledge Transfer Network
ps	Picosecond
PSD	Power Spectral Density
p-Si	Polycrystalline Silicon
PV	Photovoltaics
PVI	Photovoltaic International
PVTP	Photovoltaic Technology Platform
QC / QCL	Quantum Cascade (laser)
QPSK	Quadrature Phase Shifting Keying
R&D	Research and Development
RDI	Research, development and Innovation
REACH	European Community Regulation on chemicals and their safe use. It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RGB	Red, Green Blue
RMB	Chinese currency
ROADM	Reconfigurable Optical Add Drop Multiplexer
R2R	Roll to Roll
RoI	Return on Investment
SCR	Selective Catalytic Reduction
SED	Surface-conduction Electron-emitter Display
SEMI	Global Industry Association Serving the Manufacturing Supply Chain for the Micro- and Nano-electronics Industries
SERDES	Serilaiser/Deserialiser
Si	Silicon

SiC	Silicon Carbide
SME	Small and Medium Enterprise
SMOLED	Small Molecule Organic Light Emitting Diode
SOA	Semiconductor Optical Amplifier
SONET/SDH	Synchronous Optical Network/ Synchronous Digital Hierarchy
SSL	Solid-State Lighting
STN	Super-Twisted Nematic
SWOT	Strengths, Weaknesses, Opportunities and Threats
Tb	Terabyte
TCO	Transparent Conducting Oxide
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing Passive Optical Networks
TEC	Thermo-Electric Cooler
TFT	Thin Film Transistor
TDL	Tunable Diode Laser
TN	Twisted Nematic
TV	Television
TWh	Terra Watt Hour
TWI	The Welding Institute
UBA	German Type Approval Scheme
USD	United States Dollar
USP	Unique Selling Proposition
UV	Ultra Violet
VCSEL	Vertical Cavity Surface Emitting Laser
VDSL	Very-High-Bit-Rate Digital Subscriber Line
VFD	Vacuum Fluorescent Display
VOC	Volatile Organic Compound
WDM	Wave Division Multiplexing
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
WOLED	White Organic Light Emitting Diode

Notes:

Exchange rates of €1 = £0.87 and €1 = $1.3 have been used throughout this study (based on http://www.ecb.europa.eu/stats/exchange/eurofxref/html). Exchange rates used for other currencies are also from this source

Clean Manufacturing

1

1.
Clean Manufacturing

This document reviews clean manufacturing using lasers, summarises relevant technology, assesses its current and potential future markets and identifies potential intervention options to maximise development of European activity. It has been prepared to address the following specific objectives and to underpin a summary report on the potential of green photonics technologies in Europe:

1. Overview of existing green photonics technologies and today's related markets and market players
2. Identification and analysis of promising new green photonics technology developments for market deployment in the period 2011-2015
3. Overview of major research programmes and deployment initiatives outside Europe (North America, Japan, China, Korea, Taiwan)
4. Analysis of Europe's current and future perspectives for market positioning in identified green photonics areas and related applications
5. Assessment of the potential socio-economic and environmental impact of green photonics technology take-up assuming that the previously described market perspectives will be realised
6. Assessment of how photonics can contribute to the low-carbon policy targets defined in the EU2020 strategy and provide data and further inputs for the Digital Agenda for Europe
7. Identification and analysis of the barriers to be overcome to translate the deployment of promising new green photonics technologies into significant market shares
8. Recommend possible fields of action from an innovation and policy perspective at European and Member State level that would permit to address existing barriers and further develop the innovation capacity and opportunities of Europe's photonics industries.

Each of these objectives is addressed in turn in the following eight sections of this report.

1.1 Definition – Clean Manufacturing

This section will describe the contribution of lasers in 'clean' or 'green' manufacturing. It will be restricted to applications where the laser beam interacts with materials, in a production process, to change the form of the material or its shape and to the technology associated with producing and forming laser beams for manufacturing operations. The terminology 'lasers for materials processing' is used to generically describe this area of manufacturing. It is useful to look at the manufacturing processes that lasers can perform as falling into two categories. The first, pyrolytic processes, in which the interaction of the laser with the material causes a temperature rise, and the second, photolytic processes, which involve direct breaking of chemical bonds to produce changes in the structural form or chemical composition of the material. Figure 1 shows how these two categories are further subdivided to produce a wide range of possible processes.

Pyrolytic			Photolytic	
Heating	Melting	Vaporisation	Ablation	Curing
Transformation Hardening Forming Marking Scabbling	Soldering Cutting Conduction Welding Cladding Marking Surface Alloying Net Shaping Additive Manufacturing	Drilling Scribing Keyhole Welding Texturing Marking Caving Shock-Peening	Micro-Machining Wire Stripping Marking	Stereolithography Photo-Resist Production

Figure 1: Different Categories of Laser Process

Each of the above processes can be used to manufacture a range of different products.

The choice of laser depends on the material being processed and the required wavelength and power density of the applied light. The combinations available offer the breadth of possible applications of lasers in material processing. Laser light can be used to drill through diamond, whilst on the other hand; it has the control to perform very delicate corneal surgery.

In this section, 'green' and 'clean' manufacturing will be taken as synonymous and will be manufacturing that conserves energy, reduces green house gases (GHG), reduces pollution; improves public health and yields an environmentally sustainable outcome, the latter including repair and recycling. Whilst lasers have been in constant use as manufacturing tools since the 1970s, in terms of clean manufacturing as defined above, most laser sources used have an obvious downside, in that their conversion efficiency of electrical to optical power (wall-plug efficiency) is very low. In this context it is interesting to note that one of the major uses of high power lasers is for welding in automotive 'body-in-white' production. When this process was pioneered on production lines in the 1990s, over 100kW of optical power was introduced using laser sources with wall-plug efficiencies of the order of only 3%. Clearly the process advantages of laser welding were considered to be very significant at that time, particularly when one considers the capital expenditure required to install and manipulate 100kW of laser power. In Figure 1 above, almost all the laser processes cited have some potential for producing greener products.

One of the areas regularly cited as being particularly 'green' is that of solar cells, and the laser will have a growing part to play in the manufacture of photovoltaic components. This important topic has been described separately in a sister report of this study, so the use of lasers in photovoltaic production will not be described further here, other than to say that in section 6.2 below, the figures quoted include laser systems for photovoltaic manufacture. It should also be noted that in conducting the interviews for this section of the report, there were many comments on the important and growing part lasers play in the manufacture of photovoltaic systems.

Overview of Existing Green Photonics Technologies and Today's Related Markets and Market Players

2

2.1 Existing Technologies

Diode Lasers

Diode lasers are a key enabling technology, not only in their own right but also because these lasers are used as optical pumps in other types of solid state, fibre and disc lasers. The advancements in diode lasers for material processing applications have been significantly fast, both in terms of available output power, but also in terms of available beam quality. The latter is a complex function but relates to the capability to focus the laser light to a small spot (thereby allowing higher power densities on the material being processed). Most current industrial applications of diode lasers use light in the wavelength range 800-1000nm and use diode laser chips assembled into diode laser bars (up to about 200W per bar). The diode laser bars can then be coupled together to make a diode laser stack (up to about 2.5kW per stack). For higher powers, individual stacks are combined (for example using polarisation coupling) to form powers as high as 10kW. In use the light from these lasers is either formed into an energy distribution for direct interaction with the material being processed, by a set of external optics, or focused into the end of an optical fibre for transmission of the optical power to a remotely positioned set of beam forming optics.

Key technological and economic issues that have been addressed in recent years but are still ongoing, involve the beam quality as a function of laser power, the lifetime of the diodes, the efficiency of converting electrical input power to optical output power, the available power to footprint ratio and the cost per watt of diode power. Diode lasers have the highest wall plug efficiencies of any of the lasers used for materials processing and can reach 40%. One of the key challenges met recently has been to improve the beam quality of diode lasers to the point where the beam can be focussed to a spot size comparable to lamp pumped Nd:YAG rod lasers, which have a wall plug efficiency of the order of only 3%. Another advantage of the diode laser lies in the fact that shorter wavelengths of light are better absorbed by metals, leading to potential efficiency benefits in processes such as transformation hardening or welding. A recent example of the latter, is the use of diode lasers for welding of the aluminium tailgate on the Audi Q5. The world leaders in production of high power diode lasers for manufacturing applications are based in Germany.

Disc Lasers

To overcome the problem of thermal lensing (difficulties caused by excessive heat generation in optical components) with Nd:YAG lasers (and their low efficiency), the disc laser was developed. In it, instead of a crystal rod with a low surface to volume ratio, a very thin crystal disc of Ytterbium doped Yttrium-Aluminium Garnet crystal is used as the lasing medium. The disc, generally of only a few hundred microns in thickness but several millimetres in diameter, is coated at one end with a reflective surface (which acts as the rear mirror in the laser resonator) and mounted to a heat sink. The very small thickness of the disc (and therefore its high surface to volume ratio), its contact with a large heat sink, and the fact that the diameter of the laser light source used to pump the crystal is much greater than the disc thickness, means that axial cooling can be achieved. This axial temperature profile reduces thermal lensing to a minimum, thereby promoting good beam quality. In addition, the level of pumping (and thereby the power level of the laser beam generated) can be regulated through simultaneous variation of the pumping power level and the area of the disc that is pumped. This means the crystal can be pumped at a constant intensity whatever the power level, further improving the beam quality.

Although the fact that the disc is very thin and allows very efficient cooling, it also means that only a small fraction of the pump light (created using diode lasers) is absorbed as it passes through the disc. Therefore, to increase the efficiency of the pumping action, the pump light is reflected at the coated rear face of the disc. Around the disc, a sophisticated optic causes the pump light to pass through the disc many times (generally ~16 times), increasing its absorption. In this way, powers generally up to ~1kW may be achieved from a single disc. To generate multiple kilowatt sources, several disc units are combined. Currently the maximum commercially available output power is 16kW (Trumpf) and such lasers have wall plug efficiencies of the order of 20%. Disc lasers have beam qualities suitable for laser cutting and the flexibility of fibre optic beam delivery and high available cutting speeds for thin materials has resulted in these lasers being used recently on 2 axis flatbed laser cutting systems.

Fibre Lasers

Fibre lasers are part of the family of solid state lasers, although some manufacturers of fibre lasers prefer to look at them as a separate class. These lasers have been used for materials processing only relatively recently, although fibre lasers (more strictly fibre amplifiers) have been used in the telecommunications field for many years. However, the number of high power fibre lasers used in materials is increasing faster than any other type of laser. In the fibre laser, the lasing medium is an optical fibre doped with low levels of a rare earth element, such as Yttrium, Erbium or Thulium, which determine the wavelength of the output light. Diode lasers are used to couple infrared light into the cladding of the doped fibre and act as the pump source. This pumping action excites the dopant atoms, stimulating them to emit photons at a specific wavelength. Diffraction gratings are used as the rear mirror and output coupler, which form the resonator.

It is possible to use the doped fibre, acting as the laser resonator, also as the beam delivery fibre, using appropriate beam shaping and focusing optics at its end. Such an approach will maximise the useful beam quality of the laser. However, for materials processing at high powers, it is usual to de-couple the beam delivery fibre from the laser, in case of damage. To maintain high beam quality, the way the diode laser pumping source is coupled to the fibre is critical, especially at high powers. The most usual method employed is the so-called cladding-pumping technology. Cladding-pumping enables the use of high-power, low-cost and long life, laser-diodes to pump the fibres. A cladding-pumped fibre has an inner core doped with the chosen rare earth element. The inner core is surrounded by an inner cladding with a lower refractive index, so that the inner core can propagate the output laser beam. The inner cladding is then surrounded by the outer cladding composed of an even lower-refractive index material. In this way, the inner cladding becomes a waveguide for the pump light. The long, thin, fibre geometry is ideal to minimise thermal effects due to the pump light, and the inherently high gain of the fibre system means that high efficiencies are possible. Another benefit of this type of laser is that it is possible to produce single mode laser beams, (i.e. capable of focusing down to the minimal spot sizes) at powers up to 5kW. Multimode versions of fibre lasers are available at powers up to 100kW. The high power scalability is a clear advantage of the fibre laser design. The technology produces fibre laser modules of the order a few hundred watts in power. The fibres from many of these modules are simply spliced together, into a single fibre, in order to create the power required. Using this concept a 10kW fibre laser can be produced with a footprint of less than $1m^2$. The combination of inherent ruggedness, small size, scalability, the real lack of any user maintenance and high efficiency, makes the fibre laser an attractive choice for materials processing applications. IPG Photonics, the major producer of fibre lasers, claims wall plug efficiencies greater than 30% for its products. Because of the very high beam quality offered by these systems, high power density in the beam focus can be obtained using long focal length optics, (>1m). Passing such beams through rapidly scanning galvanometer driven mirrors has resulted in a new type of welding operation, currently in use in the automotive industry, called 'remote' welding. Here, components such as car doors are stitch welded together at very high speed, by manipulating the laser beam via the oscillating mirrors.

Carbon Dioxide Lasers

The carbon dioxide laser, first demonstrated as long ago as 1965, has been the workhorse laser for manufacturing applications for many years. Its classic designs are power limited, high maintenance, low efficiency and consume large amounts of gas, including helium, a diminishing reserve. However, over the years, as solid state lasers of various sorts have begun to eat into its markets, manufacturers of CO_2 lasers have responded with more reliable and sealed versions of the laser, which also do not require gas circulating pumps. Such lasers can run for long periods on a single 'charge' of pre mixed gas. They are still of low efficiency, (of the order 6%) compared to modern diode and fibre lasers, but they are reliable and less expensive. As a result there is still a growing market for what is known as the diffusion cooled CO_2 laser in laser cutting and other sealed CO_2 types that offer lower powers, used for example in laser marking, as the beam quality of these lasers is high.

High Peak Power and High Pulse Energy Lasers

The types of lasers described above generally produce high output powers in a continuous fashion (cw). They are usually used for the processes involving heating and melting of material and to an extent for the processes which involve vaporisation. It is also possible to produce laser light as a stream of pulses and although in any pulsed laser the average power available will be less than with a cw laser, pulsing the laser beam has been found to have many useful features for materials processing applications. Introducing pulsing introduces many more process variables, in terms of pulse repetition rate, pulse duration, peak power in the pulse, and mean power, as well as the laser wavelength. It has been found that for different materials, the process can depend significantly on any of these parameters. It has become the norm to describe pulsed laser systems generically by the available pulse duration, so they fall into the classes of microsecond (μs), nanosecond (ns), picosecond (ps) and femtosecond (fs) lasers. The terms 'ultra-short' pulse length laser and 'ultra-fast' laser are also used to describe the latter two pulse ranges. There are many different approaches to design of a pulsed laser. Individual designs tend to be optimised in terms of one of the critical parameters but are less optimised in others. It is also found that in pulsed lasers, generally, not all combinations of the available ranges for individual parameters are available at the same time. As the pulse duration shortens, the complexity and hence reliability and the price of system increases. A main driver for the manufacturer of a ps laser, for example, would be to produce this with the reliability and cost of ownership of a ns laser. Pulsed lasers are used for a wide variety of production applications, particularly in the area of micromachining. As the pulse width decreases various processes involving ablation become possible, as well as conventional cutting, drilling and joining. Because different wavelengths are involved, many different materials can be processed. Pulsed lasers are mainly used in the following sectors:

- Semiconductor - for cutting and drilling of wafers and thin film ablation
- Flat panel displays - cutting of thin glass
- Photovoltaics - for thin film ablation and cutting/scribing of silicon
- Medical- for stent manufacture
- Automotive - for drilling of injectors and structuring metal surfaces
- Aerospace - For drilling of turbine blades
- Electronics - For drilling of via holes, scribing of substrates and resistor trimming
- General engineering - for cutting and welding of small scale and intricate components

Laser Beam Delivery Systems

Laser beam delivery systems play a very important role in the use of lasers for material processing. A key enabling technology in this respect has been the development of fibre optics capable of delivering very high average and peak powers. 20kW of optical power can be delivered safely through a 200µm diameter fibre and much development is ongoing in optical fibre design. Currently, intensity dependent non-linear effects limit the maximum length of a beam delivery fibre that can be used at a given fibre diameter. The smaller the diameter, the larger the problem and for potentially beneficial remote (distant) laser applications, long beam delivery fibres will be needed. At the end of the beam delivery system, the beam has to be shaped, regardless of the laser source used, and in the majority of cases, wavelength dependent reflective or refractive optics are used. For some applications, holographic or diffractive optical element are beginning to be used, which ‘tailor’ the energy distribution in the focused laser beam to that specifically required for the particular process.

Process Monitoring and Control

Much information on the quality of a particular process can be obtained by observation of the electromagnetic emissions arising from the interaction of the laser light with the material. As the optical arrangements for forming the laser beam transmit a wide range of wavelengths, it is possible, via back reflections from the process, to use cameras mounted on the welding head for example, to monitor disturbances in the process. Such signals are in use in the process of car body welding with lasers, where the magnitude of the signals is recorded and stored for a weld of acceptable quality. In production, all the signals received from all other welds are compared to the ‘reference’ signals, and if any signal in any part of the weld exceeds a ‘boundary’ set with the reference at its centre, an alarm is triggered. After the weld is complete, on the return of the welding head to its home position, the position of the recorded anomaly is marked on the car body for subsequent inspection and possible repair. In this process, there is no adaptive, on-line control of the weld, but this is an area of current research, which moves towards the goal of ‘zero defect manufacturing’

2.2
Current Market

The growth in the global market for industrial lasers has, more or less, been consistent for over 30 years. Figure 2 shows the trend in industrial laser sales since 1970, reproduced from Industrial Laser Solutions for Manufacturing (ILS)[1]. The continuous upward trend is marked by the clear evidence of the effects of the very global recession that began in 2008. However, the figures for 2010 show some recovery of this position and ILS predicts this trend will continue for 2011.

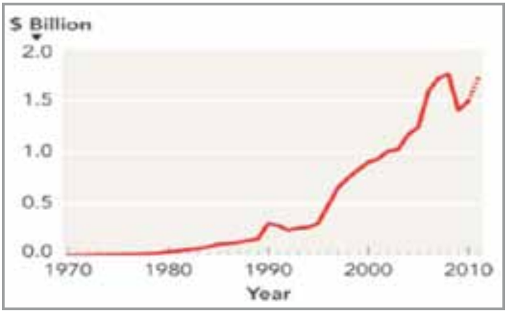

Figure 2: Revenues for Sales of Industrial Lasers as a Function of Time[1]

The figure below lists, by type of laser used, the revenues for industrial laser systems for 2009, 2010 and estimates for 2011[1]. It should be noted that in this table, the excimer laser, (used in many laser lithography systems) is not included. This is because ILS regards the use of lasers for lithography as a special case and does not include these systems in their analysis. However, this market segment is large and may add another €2 billion to the figure for the total revenues from laser systems for manufacturing.

	Revenues ($ million)		
Laser Type	2009	2010 (estimated)	2011 (projected)
CO2	3.022	3.560	4.050
Solid state	1.276	1.490	1.680
Fibre	430	608	720
Other	137	180	206
Totals	4.865	5.838	6.656

Figure 3: Global Industrial Laser System Revenues

This shows that the largest growth is predicted for manufacturing systems that use fibre lasers.

Figure 4 opposite, shows how the market is broken down by application and compares 2010 results with those from 2009[1]. In 2010, 54% of lasers sold were used for metal processing and of these 65% were employed in metal cutting. These numbers, plus the cost of the higher power lasers used in this application, show why the metal cutting market is so important, not only in terms of lasers sold but also in terms of the value of system sales. In terms of units of lasers sold, marking and engraving are the industrial processes that lead the way. After the first dip in sales for over 10 years in 2009, sales increased by 21% in 2010, with the major contributor to this growth being increased sales of fibre lasers.

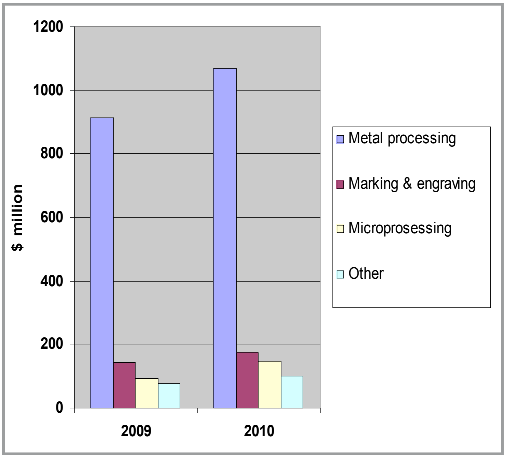

Figure 4: Revenues for Industrial Laser Sources by Application

The biggest increase in laser system sales since the dip in 2009 has been in the area of micro-processing. Lasers are used in this area for drilling 'via' holes on printed circuit boards, machining flat panel displays, machining photovoltaics and in the production of LEDs and OLEDs. More conventional micro-processes, such as cutting, are also performed in the medical sector, in particular for the manufacture of stents. The rapid expansion of this area in 2010, a 55% increase in system sales, is largely due to the rapidly expanding market for mobile communications devices and focused on China, Korea, Taiwan and Japan.

ILS includes in its 'other' category, (see Figure 3) laser systems used for additive manufacture, heat treatment, 'desktop manufacturing' and laser systems for photolithography, which do not use excimer lasers. This area also grew in 2010, and the figures showed, once again, an increasing use of fibre lasers in these applications.

Figure 5 shows where the industrial laser systems supplied in 2010 are installed[1]. The expanding market is East Asia, and if these figures are added to those of Japan, Asia currently dominates Europe, with 47% of the total system installations. However, it is clear that a large proportion of laser systems manufactured in Europe are also put to work in Europe.

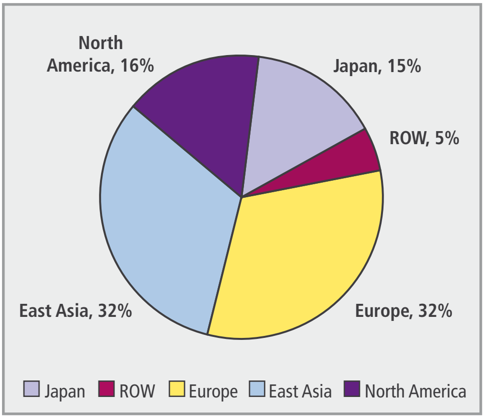

Figure 5: Global Installations of Industrial Laser Systems in 2010

In terms of future projections, ILS indicates a 16% increase in laser revenues and a 14% increase in system revenues for 2011. Focusing on future revenue, fibre laser sales are expected to increase significantly (21%) compared to other types of laser.

It is almost impossible to establish the market value for products manufactured using lasers. This is because, very often, the laser is only a part in the manufacturing cycle and many different processes are utilised. An example of a minimal use of lasers in production of a product is in part marking. Almost any part manufactured today, which has a permanent mark will be marked by a laser. At the other end of the spectrum, in laser based additive manufacturing using the powder bed technique, manufacture of the product from start to finish is by laser. The same thing is true for other laser processes. The Welding Institute (TWI) has in the past been unable to assemble figures for the size of the market for laser welding, due to the diversity of resulting products and the many industry sectors which use this technique.

2.3
Important Market Drivers and Challenges

As a result of the interview process, the main drivers and challenges for manufacturers of lasers and laser systems and the users of such systems to produce manufactured product, have been established and include:

Market Drivers	Challenges
• Introduction of cheaper but more reliable products • Introduction of maintenance free lasers and laser systems • The increasing domination of East Asia in product manufacture • The stagnant economies in Japan and the USA • Increased laser sub-component manufacture in East Asia • Increasingly short time to market • Product design requiring new or novel manufacturing procedures • Enhanced product quality	• Introduction of equipment with a greener footprint • Optimised consumption of resource • Enhanced safety of manufacture and product use • Requirement for re-configurable and adaptive production systems • Increased re-usability • Production of fewer scrapped parts or parts having to be re-worked • The growing realisation that products should be manufactured, and work, with a reduced carbon footprint • European current and future legislation

Figure 6: Key Market Drivers and Challenges

2.4
Market Players

Europe is a key location for international laser companies. Many of the commercially exploitable advances in laser materials processing, including laser sources, have been made in Europe and many companies have adopted manufacture of equipment related to laser materials processing and many others have been formed to specifically exploit this technology. Some of these companies focus on a specific limited range of technologies and products and others provide complete turn-key manufacturing solutions, including initial process development. It is generally accepted that Europe plays a very major role in both manufacture of laser materials processing equipment and its use. Figure 7 shows the world's leading

Laser Type	Manufacturer	Primary Base
CO_2 lasers	Synrad, Inc.	Mukilteo, Washington, USA
	Coherent Inc.	Santa Clara, California, USA
	Rofin Sinar	Hamburg, Germany
	El.En. S.p.A.	Firenze - Italy
	PRC Laser Corporation	Landing, New Jersey, USA
	TRUMPF GmbH	Ditzingen, Germany
	Han's laser	Shenzhen, PR China.
	CVI Melles Griot	Albuquerque, New Mexico, USA
Solid state lasers	JDS Uniphase Corporation	Milpitas, California, USA
	Apollo Instruments, Inc.	Irvine, California, USA
	Coherent Inc.	Santa Clara, California, USA
	Laserline GmbH	Mülheim-Kärlich, Germany
	High Q Laser	Rankweil, Austria
	Klastech	Dortmund, Germany
	CVI Melles Griot	Albuquerque, New Mexico, USA
	GSI Group	Rugby, Warwickshire, UK
	DILAS Diode Laser	Hamburg, Germany
	Powerlase-photonics (E O Technics Co., Ltd.)	Crawley, UK
	Rofin	Hamburg, Germany
	TRUMPF GmbH	Ditzingen, Germany
	EdgeWave GmbH	Würselen, Germany
	Lasag (Rofin)	Thun, Switzerland
Fibre lasers	SPI lasers (TRUMPF)	Hedge End, Southampton, UK
	IPG Photonics	Burbach, Germany
	Apollo Instruments, Inc.	Irvine, California, USA
	Raycus Fibre Laser Technologies Co.ltd.	Hubei Wuhan, China
	GSI Group	Rugby, UK
	Fianium Ltd.	Southampton, UK
	Rofin Sinar	Hamburg, Germany
Excimer lasers	Coherent Inc.	Santa Clara, California, USA
	Gam Laser, Inc.	Orlando, Florida USA
	LightMachinery	Ontario, Canada
	ATL Lasertechnik GmbH	Wermelskirchen, Germany
	GSI Group	Rugby, UK
Disc lasers	Jenoptik	Jena, Germany
	TRUMPF GmbH	Schramberg, Germany
	Solus Technologies Limited	Glasgow, UK

Figure 7: Notable Manufacturers of Lasers for Materials Processing

manufacturers of lasers for materials processing, in line with the technology categories presented in Section 2, and where these companies are based. Organisations in italics are based in Europe. It should be noted that some of these companies are now 'global' with manufacturing bases in several countries and some of them also supply industrial laser processing machines.

A laser based manufacturing tool includes a wide range of technologies. For the laser itself, these include but are not limited to, electronic power supplies, control circuitry, optical materials, lasing materials, cooling equipment and the different technologies involved in optical pumping, such as diode lasers or flashlamps. To this must be added the beam delivery systems, which include optical materials, electronic control systems and monitoring devices. These are then assembled into the machine tool, which may be small and simple, such as a laser marker, or large and complex, such as a 6 axis gantry type device for cutting holes in car bodies. The technologies included in machine tools embrace motion control, systems engineering, mechanical positioning technology and component fixturing and handling. Europe has assembled a wide range of companies skilled in these areas, including both SMEs and large companies. Some organisations manufacture complete turnkey systems, including lasers, others supply just the lasers. Some concentrate only on beam delivery and focusing systems and others on process monitoring systems. Others act as 'system integrators', buying in a laser and perhaps other components and developing the system and its control around these parts. In many cases these are bespoke systems, particularly for the automotive, aerospace and shipbuilding sectors and in some cases, these are standard processing machines targeted, for example, at the semiconductor industry. Of particular interest is the 'flatbed laser cutting machine', of which there are probably over 30 manufacturers, in one form or another, in Europe.

Some of the largest of these companies publish annual reports and Figure 8 indicates the scale of the turnover, in the area related to materials processing, of some of these[3]. In some instances, these companies have a greater product range than lasers in manufacturing, so the figures should be used with caution.

[3] Company annual reports

Company name	Estimated turnover in 2010 in the area of laser materials processing	Range of business in aspects of laser materials processing	Approximate number of employees in European Union	R&D costs	Estimated sales in Europe
IPG Photonics	€192 million	Manufacturer of fibre lasers and diode pumps	600	€14.6 million	€86 million
Rofin Sinar	€323 million	Manufacturer of several types of laser sources and systems	600		€154 million
Trumpf	€769 million	Manufacturer of several types of laser and laser machine tool supplier	6500	€99 million	€462 million

Figure 8: Major European Players in the Area of Lasers for Materials Processing

Many other key European players, such as Laserline, that manufactures high power diode lasers are SMEs, whose annual turnovers are not made public.

Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

3

3.
Promising New Green Photonics Technology Developments for Market Deployment in the Period 2011–2015

High Beam Quality Diode Lasers

Diode lasers will be a key enabling technology for the foreseeable future. This is because, not only do they have the highest wall plug efficiencies, but they also form the pump base in several other types of laser source, such as fibre and disc lasers. Key challenges include improvements to the beam quality (thereby allowing these lasers to replace less efficient types in existing manufacturing applications), electrical to optical efficiency, cooling, output power per single emitter, output power per bar, method of manufacture, increasing the output wavelengths available, particularly into the visible part of the spectrum and cost per device. An additional key challenge will be the number of diode laser producers/users in the world market, as it is estimated that the current capability to produce diode wafers exceeds predicted demand[4]. This technology is currently split relatively equally between Europe and North America, however, Europe plays a larger role in using diodes as pump sources in other lasers. Europe is in a world leading position with respect to high power diode laser technology and production. In terms of green potential the diode laser also succeeds because of its leading wall plug efficiency. One manufacturer of diode lasers recently indicated that diode bar efficiency could increase to over 75% by 2020.

High Power Single Mode Fibre Lasers

The main technical advantage in manufacturing for this type of laser is that, because the extreme power densities (sometimes also referred to as brightness) available, offer process speeds that are extremely high. In many cases it is expected that these speeds might be orders of magnitude larger than those available by any other methods. The main key challenge here, is not particularly the production of the single mode light, but controlling

[4] Bonati.G 'Prospects of the diode laser market' Aachen International Laser Congress AKL 2010

its interaction with the material during the manufacturing process. Once again, green benefits will be in the use of an efficient high power laser but manufacturing benefits are expected, for example, in cutting, the kerf width will be extremely small, so that a minimal amount of resource is lost and resulting vaporised material is minimal.

Kilowatt Class Ultra-Fast Lasers

Although the introduction of pulse parameters complicates development of process parameters, the potential for the resulting additional process control should offer better process performance and this is the primary reason for including this generic class of laser source here. Advanced control systems should be able to modulate pulse width and duration and also the brightness of the processing spot. This will allow the laser to be 'tailored' to a specific manufacturing problem and pave the way for 'application' specific ultra-fast lasers. Typical green application areas are in the production of photovoltaics.

Green (~500nm Wavelength) and Dual Wavelength Lasers

In the manufacture of fuel cells and batteries there are many applications where metallic materials that are highly reflective in the 1-10µm wavelength range have to be cut or joined. In these applications, process speeds are paramount. Aluminium and copper, in particular, absorb better in the visible part of the spectrum. Green (~500nm wavelength) lasers are potentially beneficial in this area. Advances will have to be made in the average power available from these lasers and there are indications that wavelengths might have to be combined in order to reach the process performance required. However, the market for the applications discussed will clearly be an important one in years to come. In addition, less expensive laser sources with wavelengths in the range 2-5nm, will also be used for niche applications on special materials.

UV Laser Sources

Lasers that radiate in the ultra-violet part of the spectrum play an important part in many aspects of semiconductor processing. Historically these lasers have been excimer gas lasers, spectacularly un-green in terms of efficiency, waste products and use of noxious gases. Steps will be made to produce solid sate UV lasers. This can be done at the moment by using a technique known as frequency doubling (equivalent to wavelength halving), which can be performed two or even three times. The down-side to this technique is that it is a very inefficient process, resulting in more complexity of design and a much reduced efficiency. In terms of market, however, because of the size of the semi-conductor industry, revenues could be large. Europe with its sound structure in laser R&D and established major players, in terms of both source and systems development would be expected to play a major role.

Fibre Optic and Beam Delivery Development

New beam delivery products will be needed and these will be subject to the 'optical' loads available using the new laser products. In particular the incident energy on the optical surfaces is likely to increase. Efforts will be required to reduce power and time induced beam focus shift and spherical aberration in fibre termination systems. It is likely that optical fibres below 50µm in diameter will be introduced and this could cause problems in preservation of the beam quality through the optics. Diffractive optical products will become available as well as new optical systems using conventional refractive elements. Advanced beam scanning systems will be developed driven by applications in the automotive industry but these will also find new processing applications. It is likely that additional standards will need to be introduced for measurement of small and non-circular beam profiles and this will happen in conjunction with the development of new instrumentation for characterisation of laser beams. Europe has a leading position in all the above and would be expected to maintain this in the future.

Photonics Based Methods for Manufacturing Quality Control

Part of greening involves better utilisation of resource, reduced wastage and production of less scrap during manufacturing. Laser materials processing offers significant potential to move towards the concept of 'zero defect manufacturing'. This is based on its capability for on-line process monitoring. Products are already available using optical techniques, to implement process monitoring of several laser processes. In the future, these technologies will be used in real-time adaptive control loops to ensure product quality. Once again, Europe leads the way in this field and would be expected to maintain this position in the future.

A New Disruptive Laser Technology

Considering the market penetration achieved since the launch of high power fibre laser systems and the projections for future sales, it would be remiss not to conclude this section without stating that a new equally disruptive laser technology for materials processing, that to date is not clearly identified could be developed before 2020.

Overview of Major Research Programmes and Deployment Initiatives outside Europe

4

4.
Overview of Major Research Programmes and Deployment Initiatives outside Europe

Research to identify formal initiatives outside Europe has been carried out. For lasers in green manufacturing, when compared to other technologies, particularly photovoltaics and energy efficient lighting, a very different situation is apparent, with no formal initiatives identified. This finding is consistent with the observations above on the barriers to deployment of laser based manufacturing.

However, it is clear that the approach to green manufacturing has been addressed on a global level but this analysis has yet to drill down to the specific use of lasers in manufacturing applications. A good starting point for the former is a paper - 'Environmentally Benign Manufacturing: Observations from Japan, Europe and the United States', Gutowski et al[5]. This analysis (one of the few which is specific to different countries) finds the internationalisation of environmentally benign manufacturing (EBM), emerging as a significant competitive dimension between companies. It found the drivers (in the 28 organisations in the analysis) for introduction of EBM to vary, but included the following:

Regulatory Mandates

- Emissions standards (air, water, solid waste)
- Worker exposure standards
- Product take-back requirements (EU, Japan)
- Banned materials and reporting requirements e.g. EPA Toxic Release
- Inventory

Proactive Green Behaviour

- Corporate image (including avoiding embarrassment by NGO's and others) and employee satisfaction
- Regulatory flexibility
- ISO 14001 Certification
- Market value of company
- Green purchasing, Eco-labelling

Competitive Economic Advantage

- Reduced waste treatment and disposal costs (€131 billion/year in US)
- Conservation of energy, water, materials
- Reduced liability
- Reduced compliance costs
- First to achieve product compliance and cost-effective product take-back system
- Supply chain requirements

Figure 9: Drivers to the Introduction of Environmentally Benign Manufacturing

[5] Gutowski et al, Journal of Cleaner Production 13 (2005)1-17

The paper includes a large amount of information and data but attempts to 'score' the geographical areas with respect to the above and other criteria, with the overall ranking; Europe 87, Japan 75 and USA 55. More specifically, the study found among Japanese companies visited, an acute interest in using the environmental advantages of their products and processes to enhance their competitive position in the market. In the European countries visited, the authors saw what could be interpreted as primarily a protectionist posture; that is, the development of practices and policies to enhance the well-being of EU countries that could act as barriers to outsiders. In the USA, the authors found a high degree of environmental awareness among the large international companies, but mixed with scepticism.

The paper also introduces the use and benefits of life cycle analysis (LCA) in introducing and quantifying green manufacturing. This latter subject is taken up in a more recent paper - 'The Incoming Global Technological and Industrial Revolution towards Competitive Sustainable Manufacturing'[6]. This proposes a reference model for proactive action to develop and implement sustainable manufacturing (CSM) at national and global level. Figure 10, reproduced from the above reference, explains how the processes involved in CSM are being implemented in various countries in terms of the generation, adoption and use of strategic initiative lifecycle, for various categories of stakeholders, including industry. It is interesting to note that in this figure, under this heading, involvement can be seen for 'big' industries, significantly less for 'medium' industries but none at all for 'small' industries. A similar ranking to that cited above (made by counting evidence of strong and normal involvement, as indicated in Figure 10) in terms of EC – Japan - USA, appears evident. The paper goes on to show how the EU Manufuture platform has played a fundamental role in establishing the mechanisms for the pursuit of CSM, including a strategic initiative vision, roadmaps and framework. It concludes that different countries are moving at different speeds in the direction of CSM. Another conclusion to be drawn from this paper is that implementing a CSM strategy at country level is likely to be a complex task.

Research to date has found that, although the use of lasers in manufacturing has been cited as being potentially beneficial in CSM, there is little or no information publicly available quantifying this, other than the

[6] Jovane et al. CIRP Annals - Manufacturing Technology 57 (2008) 641-659

rather obvious example of changing many high power, 3% efficient lasers in car body applications, for newer and more efficient, fibre, disc and diode lasers.

Another useful and newer reference, 'Integrated Sustainable Life Cycle Design: A Review'[7], concludes that effective CSM can only be introduced if a product is initially designed for sustainability. Due to the length in some industry sectors of introducing new product and manufacturing processes, it is perhaps understandable that, currently, few obvious links to CSM and lasers in manufacturing have been quantified.

There has also been some analysis[8] of the participation of key stakeholders in different stages of the lifecycle of sustainable product development, as shown in Figure 10. This Figure highlights the need for consideration of sustainability at the generation, adoption and use stages of the life cycle and indicates variable involvement of stakeholders in different regions.

During the course of interviews with key industry players, it became clear that there was little awareness of major initiatives in the use of lasers in green manufacturing, either in Europe or in the rest of the world. However, green manufacturing initiatives appear to exist in Japan, in the USA and in Europe. In Japan, the web-sites promoting these were in English but little direct involvement of lasers in manufacturing could be found. Questions solicited via these web-sites produced no responses. TWI has representatives in China, Japan, Korea and the USA. All of these were asked to perform web-searches relating to green use of lasers in manufacturing but no concrete information was forthcoming. Several of the interviewees, currently involved in business ventures in China, pointed out that although China has a very poor record in green/clean issues, it does have a very strong governmental policy in place to change this. For example, processes involving adhesive joining have been changed for laser welding due to environmental concerns. In Europe, perhaps the current initiative with the greenest relevance to the use of lasers in manufacturing is the European 'Clean Sky' project. This is an ambitious aeronautical research programme, with a mission to reduce significantly detrimental environmental aspects of air travel, such as noise and fuel consumption. Laser additive manufacturing and laser welding are expected to contrib-

[7] Ramani et al. Journal of Mechanical Design 132 Sept 2010 091004-1
[8] The incoming global technological and industrial revolution towards competitive sustainable manufacturing' Jovane et al. CIRP Annals - Manufacturing Technology 57 (2008)

Stakeholders / SI Life Cycle		Püblic Administrations/Entities						Associations			Universi-ties		Industrial Research		Industry			
		Governament	Gov department	Research national organization	Regionalresearch organization	Local authorities	Other entities	Manufacturing association	Industrial Associations	Local Industrial and manu-facturing Associations	Technical Universities	Other Universities	Excellence Tecnoloical research centres	Research national organization	Big manufacturing industries	Knowledge intensive industries	Medium manufacturing industries	Small manufacturing industries
Generation	EU	strrongly involved		strrongly involved	involved			strrongly involved	involved		strrongly involved		strrongly involved		strrongly involved		involved	
	Japan	strrongly involved	strrongly involved					involved	strrongly involved		strrongly involved		strrongly involved		strrongly involved			
	USA		strrongly involved					strrongly involved	strrongly involved		strrongly involved		strrongly involved		strrongly involved			
	China	strrongly involved	involved								not planned							
Adoption	EU	strrongly involved		involved		strrongly involved	strrongly involved			strrongly involved	strrongly involved		strrongly involved		strrongly involved			
	Japan	strrongly involved	strrongly involved						strrongly involved		strrongly involved		strrongly involved		strrongly involved			
	USA		strrongly involved	involved				strrongly involved	strrongly involved		strrongly involved		strrongly involved		strrongly involved			
	China	involved	strrongly involved								not planned							
Use	EU	strrongly involved			involved	strrongly involved	strrongly involved			strrongly involved	strrongly involved		strrongly involved		strrongly involved	strrongly involved	involved	
	Japan	strrongly involved	strrongly involved								strrongly involved		strrongly involved	involved	strrongly involved	strrongly involved	involved	
	USA					strrongly involved					strrongly involved		strrongly involved	involved	involved			
	China					strrongly involved					strrongly involved							

● strrongly involved
● involved
○ not planned

Figure 10: Strategic Initiative Life Cycle for the EU, Japan, USA and China

ute to this, specifically in the areas associated with benefits due to light-weighting. Other European initiatives, relating to more efficient ground transport, will also benefit from the light-weighting aspects of laser welding and advanced laser surface engineering, which will enhance engine performance.

Europe's Current and Future Perspectives for Market Positioning in Identified Green Photonics Areas and Related Applications

5

5.1 SWOT Analysis – Current Perspectives for Market Positioning

The SWOT analysis below was conducted in 2010 by the Photonics 21 Working Group 2 'Industrial Production, Manufacturing and Quality'. This is considered to be a European perspective.

Strengths

- Skilled specialists and institutes in Europe
- High quality of European products and processes
- Cutting edge technology origins in Europe and USA (i.e. pico + femtosec laser, multi kW laser)
- Close link between optic, laser and production engineering technologies
- Industrial laser technologies are present and accepted in the public
- Very good price/performance ratio for European products

Weaknesses

- Cost competitiveness for European products
- Language and cultural barriers to Asia
- Research efforts are unbalanced in Europe (concentration in Germany)
- Non-uniform standards for safety requirements worldwide
- European State Aid Rules (not valid for competitors outside Europe)

Opportunities

- High number of laser research institutes in Europe
- Good cross-link between research institutes
- Good national funding structures
- Integration of application know-how into the products (as an USP)
- Leverage new East European production (automotive, electronics)

Threats

- Know-how transfer from Europe to Asia (e.g. through Asian students in Europe)
- Suppliers' locations differ from users' locations (Micro applications in particular)
- Growing share of Asian components in lasers (Crystals, Semiconductors, etc.)
- Duty and tax barriers especially on spare parts (outside Europe)

Figure 11: SWOT Analysis – Clean Manufacturing

Europe is generally understood to have a very strong position both in the manufacture of lasers and laser systems, and in terms of companies who employ laser technologies in their manufacturing processes. Most of the world's major laser companies have their headquarters in Europe. Historically, much of the development of lasers, the necessary optical and associated components, plus the process development, has been undertaken in Europe. This is particularly true in the area of high power laser developments and associated production processes, such as cutting and welding. Europe continues to maintain a world leading position in innovation and technical excellence in laser materials processing. It is also accepted that Germany, with very active national and regional governmental support in this area, leads the field. The European position is strengthened, in that the workforce it has, is both well educated and well trained and the number of universities and research institutes, working in fields aligned to the manufacture of laser systems and their use in manufacturing, is large. A major current concern, however, is that it is becoming increasingly difficult in Europe to persuade young people to adopt a career associated with manufacturing.

The EC is currently in the process of introducing legislation and directives related to green issues and sustainability[9]. The two directives most related to the potential use of lasers in manufacturing are Directive 2009/33/EC - Clean and Energy Efficient Road Transport Vehicles and Directive 2005/32/EC - Energy Efficient Products. The former aims at a broad market introduction of environmentally friendly vehicles. It requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in all purchases of road transport vehicles, as covered by the public procurement Directives and the public service Regulation. The latter provides a framework for the establishment of coherent EU-wide rules for eco-design. It ensures that disparities among national regulations do not become obstacles to intra-EU trade. The Directive does not introduce directly binding requirements for specific products. However, it does define conditions and criteria for setting requirements, through subsequent implementation measures, regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently. In addition the Environmental Management Systems (EMS) approach, has led to the development and implementation, at a company level, of ISO 14001. All interviewees were asked if their organisations had any internal policy regarding greening, and whether they had implemented ISO 14001. Only 50% of organisation had either of these in place.

[9] A summary of the current position in this area can be found at http://ec.europa.eu/environment/gpp/related_policies_en.htm.

5.2

Market Development

The predicted growth of laser source sales related to the materials processing, and other key markets for non-diode lasers is shown in Figure 12[10]. This shows that the global market for lasers for materials processing is expected to grow from over €1500 million in 2011 to €2,150 million in 2020. Market growth for all non-diode lasers, by laser type, is shown in Figure 12 below.

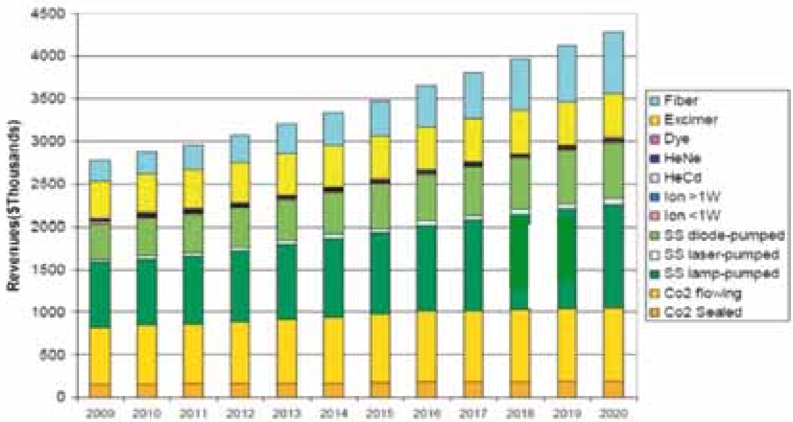

Figure 12: Forecasted Growth in Non-Diode Laser Systems to 2020

From the interviews carried out as part of this study it is clear that most manufacturing organisations are expecting growth in the period to 2015 to be centred on Asian markets, primarily China and to some extent India.

The countries in Asian markets are known to be actively engaged in the introduction of high technology manufacturing processes and the laser is an ideal tool for this. However, it was felt that economics rather than green issues will dominate sales growth.

[10] Power Laser Trends, Dr Ch. Harder, Swiss Photonics and Laser Network, July 2009. Data is compiled from IOA, Laser focus World and OIDA sources.

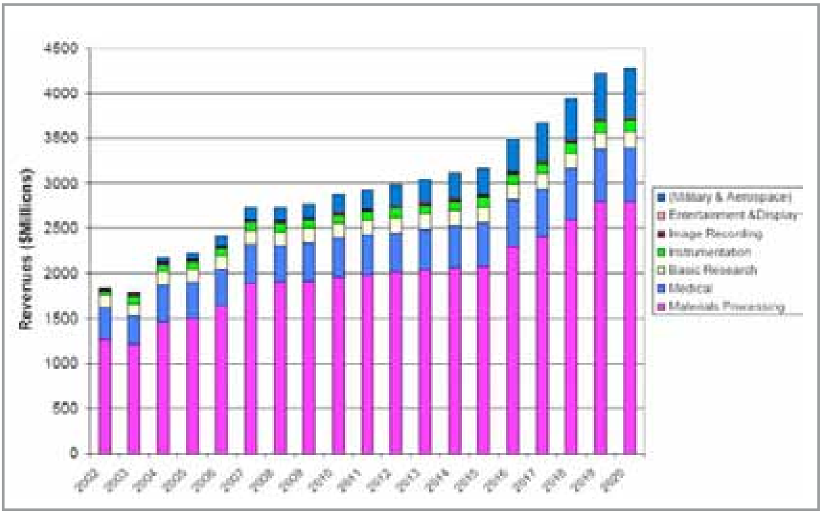

Figure 13: Market Growth for Key Laser Technologies

Several interviewees also felt that there was no longer sufficient manufacturing in Europe to sustain market growth and this is another reason why the Asian market is now so important.

5.3
Future Market Potential – Key Technologies

Predictions of future market developments for key laser technologies in materials processing applications alone were not readily available. Thus the figure opposite shows the situation for all non-diode laser applications, although as shown in Figure 12 above, materials processing accounts for around 70% of the total non-diode laser market. This figure shows that fibre lasers and solid state pumped lasers are expected to demonstrate the largest market growth to 2020, which is consistent with 2009 to 2011 data shown in Figure 2.

5.4
Future Market Share for Europe

As already indicated in Section 2.4, Europe is a key location for internationally competitive laser companies and for research and development activities in new laser systems (e.g. TWI, Laser Centrum Hannover, Fraunhofer ILT and Fraunhofer IWS).

It is, therefore, expected that Europe will retain its current market position.

5.5
SWOT Analysis – Future Perspectives for Market Positioning

The future perspectives for market positioning are not expected to change significantly from the current SWOT presented in Section 5.1, Figure 11.

Assessment of the Potential Socio-Economic and Environmental Impact of Green Photonics Technology Take-up

6

6.1
Economic Impact

The global sales for lasers for materials processing applications were estimated at €1.5 billion and €2.15 billion for 2011 and 2020 respectively as shown in Figure 12. Europe is estimated to have a 40% share of this market, a value of over €600 million per annum in 2011 and over €850 million per annum in 2020 respectively. No evidence of employment in the manufacture of lasers for materials processing was available.

Novel laser technologies will enable lower operational and maintenance costs. This will provide a number of benefits to downstream users, including:

- Products will be manufactured with less waste and less scrap therefore reducing cost
- A move towards zero defect manufacturing therefore reducing cost
- There will be less use of raw material (e.g. up to 75% less prime material use for some laser based additive manufacturing)
- Cost reductions due to manufacture of 'lightweight' products with equivalent performance (e.g. laser welded stiffened structures for air frame manufacture)
- Less rework in manufactured parts due to the use of low heat input processes reducing residual distortion (e.g. use of laser welding in shipbuilding)

An estimation of the economic impact to Europe of these developments was not available during this study.

6.2
Social Impact

Based on the analysis carried out direct social impacts will be accrued through the increase in employment in the laser manufacturing and material processing industries. Indirect impacts will be enjoyed by a number of beneficiaries. These include:

- The use of lasers in products designed to help mankind will in-

crease. For example, personal communications devices, displays, automobiles, aeroplanes, solar panels, fuel cells, batteries and domestic white goods
- Tailored implants for humans will be made from laser powder bed technology
- Manufacture of medical instruments using lasers
- Use of lasers to produce bio-functional surfaces
- Promotion of a safer working environment (because of the safety issues using lasers, its operating environment has to be carefully controlled and this should, by definition, provide a safe working environment and in addition the laser lends itself to full automated production)

6.3
Environmental Impact

Development of new photonics technologies for materials processing will offer numerous environmental benefits. These include:

- Reduced electrical consumption of more efficient lasers
- Reduced GHGs equivalents
- Production of less toxic by-products
- Less use of helium and other rare gases, which are currently used in laser based manufacturing systems
- Reduction in fumes generated during cutting processes
- Reduced use of raw materials in production
- Zero defect manufacturing will reduce scrap and waste
- Laser processes offer the potential of repair rather than scrap and replace, particularly for high value products
- Use of laser based solvent free cleaning techniques
- Removal of fouling in marine environments
- Efficient methods of assisting nuclear decommissioning
- Use of lasers for production of hybrid structures
- Manufacture of nano-particles
- Use of lasers in aspects of manufacture involving ‘light-weighting’
- Use of lasers in battery applications for electric vehicles
- Efficient manufacture of photovoltaics (covered further in the sister report to this study)

Due to the diversity of laser and laser systems and the product manufactured using such systems, it is not possible to fully quantify the impact of current and future solutions for all aspects of materials processing. In addition it is extremely difficult to find in the public domain, documentation which quantifies this. For example in the 'Journal of Cleaner Production', (www.sciencedirect.com), it is estimated that significantly less than 1% of the papers included to date, relate to the use of lasers for manufacturing, as defined in Section 1.1.. As a result, in this section, three examples will be provided. The first relates to the potential green benefits in laser cutting of metal that might be introduced by the future large scale use of fibre lasers instead of CO_2 lasers. The second, an analysis which compares two specific processes for enhancing the performance of aeroengine turbine blades, one laser and one not, in terms of environmental impacts and the third, which discusses the use of lasers to replace wet chemical etching in the area of flat panel production.

Fibre Laser vs CO_2 Laser Cutting

Laser cutting plays an important role in sheet metal fabrication. The high value laser sheet metal cutting industry is vital for Europe, serving its thriving automotive, aerospace, construction and general manufacturing industries. Currently, laser sheet metal cutting systems, powered by high-power CO_2 lasers, total more than 50,000 units installed worldwide since 1980. Annual sales are in the 3500-4000 unit range, with over 1,500 sold in Europe. The CO_2 laser has high running costs because of the poor efficiency of converting electricity into laser light for this particular type of laser and the fact that these lasers consume large amounts of gas in operation, including helium, a decreasing resource. Newer 1µm wavelength lasers, e.g. fibre lasers, are now available with significantly better wall plug efficiencies and other green benefits such as minimal maintenance. These are currently being introduced into laser systems for the cutting of sheet metal below about 3mm in thickness. There are just two high power (>1kW) 1mm laser source suppliers (more predicted to emerge in the near future) and both are based in Europe. In addition, 70% of the world's laser cutting system suppliers are also European. In 2010, it was estimated that 240, 1kW plus fibre laser cutting systems were sold (private communication David Belforte ILS). It is estimated[11] that the saving in electricity costs (using typical European rates) which might be expected by using these fibre laser systems for one year, in a jobbing shop type environ-

[11] Internal TWI estimates

ment, when compared to the same cost if the systems had been supplied with CO_2 lasers, would be ~€18m. At the same time, this would reduce green house gas emissions by an amount equivalent to some 15,000 tons of carbon dioxide.

Laser Shock Peening vs Shot Peening

This example is based on a 'Journal of Clean Production' paper[12]. It is interesting to note that in the introduction to this paper, the authors can only cite previous reference to four other publications on the environmental impact of lasers in manufacturing. In order to increase the resistance of metallic components to the initiation and growth of fatigue cracks, mechanical surface treatments are widely used. Shot peening, in which the surface of the product is bombarded by small round particles, which can be steel, glass or ceramic, is such a technique, used in the automotive, aerospace, and marine industries. Laser shock peening, is a competing process, whereby a plasma shock wave is generated by the application of a short, high density pulse of focused laser light. The plasma produces a compressive shock wave, which induces beneficial residual stress. In the comparison, LCA is used to compare the two processes. Figure 14, summarises the results of the comparison in terms of LCA for nine different ecological factors, based on equivalent functional performance.

It can be seen quite clearly that in all the impacts categories, there is a significant benefit (55-58%) by use of the laser-based process. It is unfortunate that there are not more of these detailed process comparisons available showing the green benefits of laser based manufacturing.

Impact category	Unit	Shot peening	Laser shock peening
Global warming	Kg CO_2 eq.	63	34.6
Acidification	H+ moles eq.	11	6.1
Cancer effects	Kg benzene eq.	0.32	0.18
Noncancer effects	Kg toluene eq.	3800	2128
Respiratory effects	Kg PM2.5 eq.	0.073	0.04
Eutrophication	Kg N eq.	0.026	0.015
Ozone depletion	Kg CFC-11 eq.	3.1E-06	1.8 E-06
Ecotoxicity	Kg2.4-D eq.	230	128
Smog	Kg No_x eq.	0.082	0.046

Figure 14: Life Cycle Impacts - Comparison of the Shot Peening Process with the Laser Shock Peening Process

[12] Fu Zhao, William Bernstein, Gautam Naik and Gary Cheng. 'Environmental assessment of laser assisted manufacturing: case studies on laser shock peening and laser assisted turning'. Journal of Cleaner Production. 19 (2010) 1311-1319).

Rapid Laser Patterning Versus Wet-etch Lithography for Flat Panel Displays

Until relatively recently the standard industrial method for patterning thin films on glass or other substrates has been wet-etch lithography. The primary applications for this have been in manufacturing flat panel displays and more recently, the new generation of thin film solar cells. Wet-etch lithography has benefits in terms of achievable feature size and quality and its development has been largely driven by the semiconductor market, where it is also used to pattern transistors on silicon chips. However, this technology also has serious disadvantages: it employs toxic chemicals, creates contaminated effluent, requires multiple process stations per manufacturing step and has a large footprint. The alternative is to use a laser beam to directly pattern a thin film on a transparent substrate by selective vaporisation. This technique has become known as rapid laser patterning. Most types of commercially available pulsed laser have been investigated for this process: Excimer, ultra-fast, solid state (of high average power), Q-switched and nanosecond pulse duration and diode-pumped solid-state lasers. The largest industrial uptake for this process has been in patterning indium tin oxide (ITO) thin films on the glass front plate of plasma display panels. This requires the creation of repeating patterns in the ITO film of around 100nm thickness on a glass substrate. Rapid laser patterning has been in volume production in Asia for this process for several years – replacing
wet-etch lithography and offering significant cost and environmental benefits, as the single laser process replaces a resist coating, photo-mask production, photo-mask exposure, development, washing, etching, washing and finally resist stripping. The resulting reduction in the use of corrosive chemicals and their disposal is very significant.

To summarise, the environmental benefits of the key promising new photonics based products described in Section 3 above are tabulated in Figure 15.

Published quantitative data on reductions in electrical consumption by using lasers in manufacturing was not available.

Key New Technology	Expected Impact
High beam quality diode lasers	The high efficiency of these lasers will reduce electrical consumption in laser processing machines. High beam quality will introduce new applications
High power single mode fibre lasers	The high efficiency of these lasers will reduce electrical consumption in laser processing machines. Extreme power densities involved will greatly enhance process speeds
Kilowatt class ultra-fast lasers	These lasers will be used to improve efficiency in manufacture of photovoltaics, other semi-conductors and flat panel displays, through high speed machining replacing wet chemistry processes. They could also be used for the safer manufacture of nano-particles
Green and dual wavelength lasers	These lasers will be used to weld copper and aluminium, mainly associated with aspects of electrical mobility, in motor and battery technology
New improved UV lasers	These lasers will be used to improve efficiency in manufacture of photovoltaics, other semi-conductors and flat panel displays, through high speed machining replacing wet chemistry processes
Photonics based methods for manufacturing quality control	These will improve product quality and in doing so, will reduce product scrap and re-work

Figure 15: Key Promising Technologies and Expected Impacts

Contribution to 2020 Low Carbon Economy Targets

7

7. Contribution to 2020 Low Carbon Economy Targets

The low carbon economy targets set for Europe[13] are:

- A reduction of at least 20% in greenhouse gas (GHG) emissions by 2020
- A 20% share of renewable energies in EU energy consumption by 2020
- A 20% reduction of the EU's total primary energy consumption by 2020 through increased energy efficiency

As stated above, development of new photonics technologies for materials processing will offer reduced electrical consumption through the use of more efficient lasers and reduced GHGs equivalents. However, quantitative data on the scale of these benefits is not available.

[13] EUROPE 2020, A European strategy for smart, sustainable and inclusive growth, European Commission, March 2010

Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

8

8. Barriers in Translating the Deployment of Promising New Green Photonics Technologies into Significant Market Share

Input to this section is taken mainly from the results of the interview process carried out as part of the study.

Experts were selected from universities and contract research and development organisations working in the field of laser materials processing, organisations engaged in technology transfer activity, laser equipment manufacturers, laser systems suppliers and industrial laser users, the latter including both SMEs and large companies.

The main barriers to maintaining and expanding Europe's position in green manufacturing with lasers were cited as:

- A general perception that the capabilities of the laser as a 'green' manufacturing tool are not well documented. (Result is that these activities get little promotion)
- Insufficient product designers with a fundamental knowledge of the capability of the laser as a manufacturing tool, let alone its potential for green manufacturing. (Result is that lasers are not considered at an early design stage)
- Insufficient legislation forcing green manufacturing. (Result is that manufacturers often use the cheapest solution).
- Unclear current legislation relating to green manufacturing. (Result is that manufacturers are confused about which manufacturing processes to adopt)
- Economics, rather than 'greening', drives most industry. (Result is that green issues take a back seat)

Additional issues highlighted were:

- Lasers are currently chosen because they perform the task required, any green issues are side benefits only
- Market issues, including protectionism by Asian countries, understanding emerging markets, current export regulations for high technology manufacturing products and how they function and a lack of market pull for advanced technology
- Only very large organisations can now self fund the investment needed in product R&D to maintain a leading 'green' supplier position. Smaller companies cited the need for government incentives to help them offset the costs of implementing and developing green policies, green manufacturing and green products.
- Adherence to traditional forms of manufacturing in industries that are slow to change and a view that green activities are seldom self supporting.

Analysis of the main barriers can be presented as follows:

Barrier Description	Barrier Classification	Importance	Action Timeline	Relative Cost to Implement	Explanation
Insuffiicent Awareness of the Potential of Lasers in "Green" Manufacturing	Technical	High	Immediate	Low	It is not clear in manufacturing industry how lasers can be used to deliver high quality and green manufacturing - so alternative approaches are usually selected.
Insufficient Product Design Capability	Technical	High	Immediate	Low	The lack of knowledge of laser manufacturing at the product design stage is inhibiting its application.
insufficient Effective Legislation	Regulatory	Medium	Immediate	Low	There is no driver for green manufacturing - the low cost option is typically used, whether it is sustainable or not.
Economics Drives Industrial Decisions	Financial	High	Immediate	Medium	The competitive market place means short term economic considerations is the dominant factor in manufacturing technology decisions.

Figure 16: Classification of Barriers

Industry must take prime responsibility for addressing three of these barriers while public sector organisations need to address the other (insufficient effective legislation). However, evidence to date indicates that industry is not acting independently to overcome the barriers.

The industry is very unsure about current initiatives to address the above, particularly in the area of green manufacturing, apart from some national government competitive collaborative funding opportunities in the general area of 'sustainability'. However, during the interviews, it became apparent that some of the laser manufacturers now offer 'new for old' deals, to help previous customers switch from using very inefficient lasers to more modern lasers with increased electrical efficiencies.

To overcome these barriers the following initiatives were suggested by industrial stakeholders:

- Place the topic of green technology as part of the school curriculum (primary, secondary and above), thus creating new levels of responsibility
- Place more emphasis on the capability of lasers as a green manufacturing tool in university courses
- Establish more public sector funded technology transfer activities in green aspects of laser materials processing
- Extend government/supplier/end user relationships for products/processes shown to be beneficially green
- Establish case studies, quantifying green benefits in specific examples, arising from the above
- Establish true 'European' centres of excellence in laser development, supported internationally in similar ways to 'big science' projects

Potential Intervention Options

9

9. Potential Intervention Options

The major barriers (ranked as high in Figure 16, above) to the development of the European clean manufacturing industry have been assessed and the following actions to address these barriers have been identified:

1. **Insufficient awareness of the potential of lasers in clean manufacturing,** leading to the selection of alternative approaches.

   This barrier can be overcome by demonstrator programmes to show the potential of lasers in sustainable manufacturing as the industry itself has been unable to achieve this. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the technical and business benefits of using lasers.

2. **Insufficient product design capability.** Product designers have little knowledge of the capabilities (and constraints) of laser based manufacturing technologies, which inhibits the application of these technologies in industry.

   This barrier can also be overcome by demonstrator programmes that show the potential of lasers in a range of sustainable manufacturing roles. These demonstrator programmes should focus on a number of potential applications of lasers in manufacturing and show the design, technical and business benefits of using lasers.

3. **Economics drives industrial decisions.** These typically focus on the initial capital costs only and neglect longer term operational and environmental benefits.

   A capital grant programme for the introduction of laser based clean manufacturing technologies will address this barrier. Furthermore, the scale of the grant available should be linked to the expected environmental benefits of adopting the laser based manufacturing technologies.

It may be argued that the first two intervention options are unnecessary as industry should deal with this itself. However, smaller companies simply don't have the time to seek this information or they can't employ persons who know it already.

Of course it is important that these near market interventions are complemented by continued support to laser research and development programmes.

These interventions can be summarised as follows:

<table>
<tr><th></th><th></th><th colspan="2">Intervention Options</th></tr>
<tr><th></th><th></th><th>R&D and Commercialisation Programmes</th><th>Subsidised Market Development Programmes</th></tr>
<tr><th></th><th></th><th>Demonstrator Programmes</th><th>Capital Grant Programmes</th></tr>
<tr><td rowspan="3">Key Barriers to Market Development</td><td>Insufficient Awareness of the Potentials of Lasers in Clean Manufacturing</td><td>•</td><td></td></tr>
<tr><td>Insufficient Product Design Capability</td><td>•</td><td></td></tr>
<tr><td>Economics Drives Industrial Decisions</td><td></td><td>•</td></tr>
</table>

Figure 17: Summary of Potential Intervention Programmes

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