Photonics Scotland
THE SCOTTISH OPTOELECTRONICS ASSOCIATION

PHOTONICS IN SCOTLAND

A VISION FOR 2030

CONTENTS

FOREWORD

Photonics is the critical enabling technology for the 21st century.

It underpins modern innovations that are fundamental across many aspects of modern life and business, from robotics and autonomous systems to connected living.

It enables step-changes in product performance, supports the adoption of digital manufacturing and delivers efficiency and productivity improvements in a diverse range of sectors from healthcare and transport, to agriculture and communications. The quantum technologies of tomorrow, including quantum computing and quantum imaging, will require further new advanced photonic technologies.

It facilitates the collection, transmission, storage and analysis of data to provide value-added information. The cloud - a critical enabler of digital technologies such as big data, artificial intelligence, cyber security, cloud computing, and the Internet of Things - is a global photonics network.

In the future, photonics will enable solutions to some of the greatest global challenges of our time: communications, public health, climate change, sustainability, energy production, and mobility.

Today, Scotland's Photonics Sector is a billion pound industry supporting 4,000 highly skilled jobs at a value-add per employee that is 3 times the national average. The sector is truly international, contributing significantly to Scottish exports and creating partnerships and collaborations across the globe. It is also supported by several world leading academic groups that provide a continuing pipeline of new technologies and skilled people. Scottish research excels and outperforms all other UK regions.

Yet, despite the significant contribution that photonics is making to global technological change, and the existence of a vibrant and world-leading cluster of companies and universities in Scotland, the sector remains unknown to most, developing invisible technologies that support our modern existence and drive innovation in the economy. This paper explores the world of photonics, discussing the ways in which it supports our current living and how it will impact our future lives.

This paper also highlights how Scotland is well positioned to make a significant contribution to future developments, and sets out a vision to treble the sector in Scotland by 2030, listing a set of recommendations that will be required to support this growth. These recommendations explore areas including skills, business support, cluster development, and international promotion.

PHOTONICS IN SCOTLAND:

A £1 BILLION INDUSTRY

4,000 HIGHLY SKILLED JOBS

EXECUTIVE SUMMARY

The global photonics market is set to grow rapidly over the coming decades, accelerated by unprecedented demand for photonics-enabled technologies across multiple market sectors.

Scotland has a long and distinguished history in this field, punching above its weight in a globally competitive market for over a century, built on an internationally recognised academic base and a thriving industry cluster. Today Scottish Photonics is a one billion pound industry supporting over 4,000 high-value jobs in a range of vertical sectors.

However, as the global demand for photonics grows, so too does the competitive landscape in which Scotland finds itself and we must ensure that the fundamentals are in place to allow the sector to exploit the opportunities that the coming decades will bring.

This paper sets out a series of recommendations that will secure Scotland's position on the future international stage. At the heart of these recommendations is a vision to **treble the size of Scotland's Photonics Sector by 2030**.

This vision will require efforts to ensure that Scotland continues to invest in and build a vibrant environment for future development and manufacture.

One built on skills, academic excellence, support infrastructure and global outlook.

One that will maintain Scotland's hard earned reputation built on 400 years of optical and photonics excellence.

SUPPORTING A VISION TO TREBLE THE PHOTONICS SECTOR IN SCOTLAND BY 2030

SUMMARY OF RECOMMENDATIONS

DEVELOPING A WORKFORCE FOR THE FUTURE

1. **Ensure 40% growth in the number of engineering and physical sciences undergraduate places at Scottish Universities by 2030**
   - Include greater emphasis on work-based learning
   - Ensure alignment between academic programmes and industry need

2. **Inspire the next generation of photonics professionals through a coordinated National Photonics Initiative**
   - Highlight the role of photonics in Scotland's society
   - Raise awareness of the diverse career opportunities in the sector

3. **Encourage greater diversity within Scotland's Photonics workforce through a new Women in Photonics initiative**
   - Identify barriers to female engagement with the sector
   - Provide employers and educators with recommendations and processes to encourage more women to pursue a career in photonics

4. **Establish a Scottish Photonics Academy to develop specific technical and commercial expertise identified by employers within the sector**
   - Upskill and retrain existing workforce
   - Provide hub for future collaboration

SUPPORTING BUSINESS GROWTH

5. Establish a Photonics Growth Pool to encourage early engagement between experienced market leaders and young entrepreneurial researchers

- Provide early stage enterprises with experienced input
- Create a database of mentors in areas such as exports, sales, supply chain and distribution

6. Maximise value from existing and future translational assets within the sector

- Improve visibility and access through creation of an asset database
- Ensure the sector achieves maximum benefit from future assets

DEVELOPING SCOTLAND'S CLUSTER

7. Create new partnerships and collaborations through improved access to key partners within Scotland's local supply chain

- Provide a catalyst for cluster activity through Photonics Scotland
- Create capability directory for all organisations, academic groups and translational assets within the sector

8. Accelerate product realisation by encouraging early engagement with Scotland's public sector

- Raise awareness within public bodies on the 'Art of Possible'
- Facilitate public-private partnerships by expanding existing funding models e.g. Small Business Research Initiative (SBRI), CivTech

GROWING SCOTLAND'S INTERNATIONAL POSITION

9. Promote Scotland's sector on an international level through the creation of a Photonics Scotland brand

- Work in partnership with Government, Scottish Enterprise and Scottish Development International
- Identify new export opportunities and attract talent and investment to Scotland

HOLYROOD SCOTTISH PHOTONICS RECEPTION

1. PHOTONICS: LIGHTING THE WAY

You may not know it, but photonic technologies already have significant impact on our lives today.

Whenever we use our smart phone, stream a video, turn on a light, drive our car or visit the hospital, we depend on products and services enabled by photonics. In future, photonics will help enable solutions to some of the major global challenges of our time: public health, climate change, sustainability, energy production, and mobility.

Yet, despite this, photonics remains an unknown to most, an invisible technology that supports our modern existence and drives innovation in our economy.

WHAT IS PHOTONICS?

Put simply, photonics is the technology of harnessing light. Indeed, the word 'photonics' is derived from the photon – particle of light – in much the same way as the word electronics derives from the electron. The field is focused on harnessing three inherent properties of light that make it advantageous for a multitude of applications – it is fast, it is clean, and it is precise.

These unique properties provide the basis for many of the recent advancements in technology that support today's society.

Arguably one of photonics greatest impacts has been to enable the communications infrastructure of today. Laser light and optical fibre underpin the internet, allowing business and consumers to access information and services that are now essential components of our everyday lives. The machines that connect to this infrastructure, smart phones, TVs and computers, are themselves reliant on photonics based display technologies such as LCD or OLED to improve our viewing experience.

In the world of healthcare, improvements to imaging technologies and non-invasive spectroscopic techniques are allowing better diagnostics, improving outcomes for patients and delivering savings for health providers.

The digitalisation of manufacturing, supporting productivity improvements in sectors as diverse as automotive and food production relies on laser technology to monitor and control key steps in the manufacturing process while 3D printing, set to play an increasingly significant role, requires lasers to operate.

In the future too we can expect photonics to play an increasingly important role.

Optical computing will provide significant advances in computing speed that will continue to revolutionise digital services. Sensor technologies will provide the eyes for a multitude of autonomous machines, from robotics in manufacturing to the cars and buses on our roads. In healthcare we can expect to see further improvements in non-invasive diagnostic procedures while light enabled pharmaceuticals provide the potential to target major disease states such as cancer in ways unimaginable until now.

PHOTONICS ENABLES SECTORS INCLUDING:

- COMMUNICATIONS
- LIGHTING AND DISPLAYS
- HEALTHCARE
- DEFENCE
- MOBILITY
- ENERGY

2. A GLOBAL OPPORTUNITY

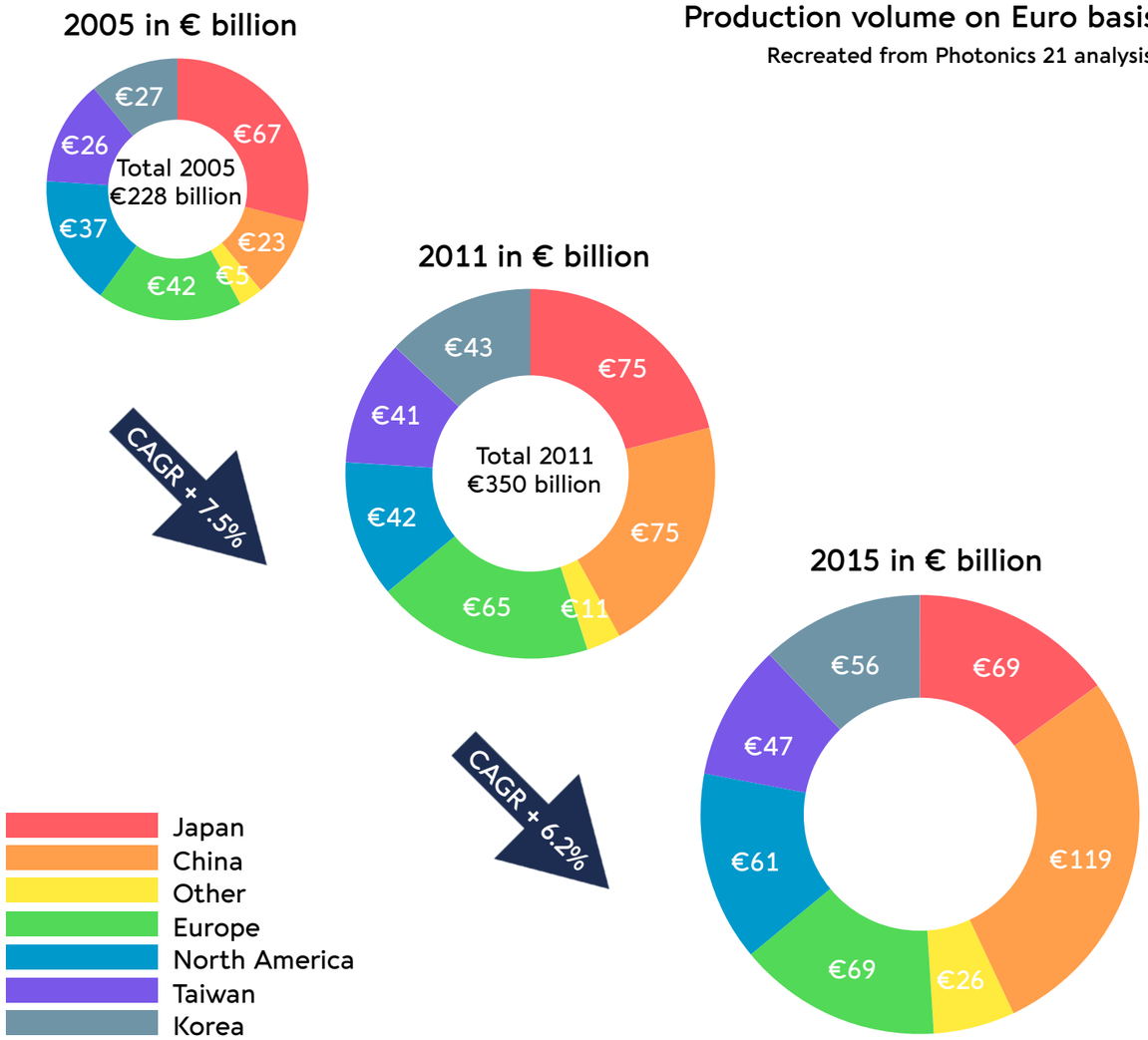
The global photonics market is set to grow rapidly over the coming decades, accelerated by unprecedented demand for photonics-enabled technologies across multiple market sectors.

Photonics 21, the European Technology Platform representing the European Photonics Community, recently conducted a thorough analysis of the global photonics market[1]. Their research concluded that the global photonics-enabled market had grown from €220Bn in 2011 to €447Bn in 2015 at a compound annual growth rate of 7.5%. The same research also forecast further growth to €615Bn by 2020.

This work also highlighted the emergence of China, now the world's largest producer of photonic products. This has created an increasingly competitive global market, one which will force the traditional photonics strongholds of Europe, North America, Japan and Korea to continually innovate and adapt to maintain growth.

Production volume on Euro basis

Recreated from Photonics 21 analysis



EUROPEAN AND UK MARKETS

The production volume of the European Photonics industry accounted for €69.2Bn in 2015, corresponding to a global market share of 15.5%. Growth in the photonics industry was much stronger than general industrial production across Europe which had essentially stagnated from 2011 to 2015. In contrast, the European photonics industry had grown over the same period and today directly employs some 300,000.

AREA	VALUE (€)
Production technology	13.1 Billion (19.2%)
Optical measurement and image processing	11.7 Billion (17.1%)
Photonics based medical technology	9.6 Billion (14%)
Optical communication	4.1 Billion (6%)
Information technology	2.5 Billion (3.5%)
Flat Panel Displays and display materials	1.7 Billion (2.5%)
Lighting	8.3 Billion (12%)
Defence and security	7.9 Billion (11.5%)
Components and systems	7.8 Billion (11.4%)
Photovoltaics	2.6 Billion (4%)

Recreated from Photonics 21 analysis

Closer to home, recent analysis by the UK Photonics Leadership Group (PLG) and Knowledge Transfer Network (KTN) estimated that there are at least 650 photonics companies in the UK contributing £12.9Bn to the economy per year and employing 65,000 people[2].

A regional distribution analysis conducted within the same report showed that the Scottish Photonics Sector generated just under:

£1 BILLION IN REVENUE

3. DRIVERS FOR GROWTH: ENABLING TOMORROW'S WORLD

HEALTHY LIVING

Photonics-enabled healthcare innovations are set to revolutionise the way we diagnose, monitor and treat patients. These developments will not only provide better outcomes for patients but also offer the opportunity to reduce costs to healthcare providers.

Photonics will support the development of non-invasive imaging, driven by clinical demand for safer and faster monitoring techniques that will allow improved patient diagnosis and treatment. These techniques will also allow an individualised approach to diagnosis and treatment, the foundation for the transition from conventional medicine to personal and precision medicine.

Advances in laser surgery techniques will continue to improve outcomes of complicated procedures. In future, such procedures will also be supported by augmented-reality surgical visors that will superimpose data and x-ray images onto the surgeon's field of vision, raising the efficiency and precision of surgical procedures.

Photonics will also support our continued efforts to monitor and support patients away from our primary care services and hospitals. From wearable photonic sensors that allow continuous home monitoring, to simple pre-clinical imaging techniques that allow early diagnosis of common conditions, photonics will provide opportunities for better care provision within our homes and communities.

FUTURE MOBILITY

The future of mobility over the next 10-15 years will be dominated by the emergence of connected and autonomous vehicles (CAVs). These vehicles will constantly communicate with their surrounding environment, initially to provide assistance and information to the driver before allowing full automation and driverless vehicles.

Photonic technologies will provide the 'eyes' of these future vehicles, using a series of cameras, sensors and laser measurements (LIDAR) to create a full three-dimensional picture of the vehicle's surroundings.

However, it is not just in CAVs that photonics will play an important role in future development. Photonics-enabled technologies are also supporting the electric revolution, with laser-based manufacturing an essential requirement for the production of batteries, fuel cells and lightweight materials.

CLEAN GROWTH

Governments around the world are under increasing pressure to achieve economic growth through sustainable methods. Central to this agenda is a reduction in greenhouse gas emission through cleaner and more efficient technologies and processes. Photonic innovations will continue to support solutions to this global problem.

Advances in sensor technology will improve the way we monitor toxic substances and other polluting materials. In addition to improving public health, this will lead to production of cleaner, more efficient industrial processes and transport. An intelligent network of these sensors will also support local authorities and industry alike to identify pollution hotspots, allowing them to take timely and appropriate action to reduce problems.

Smart lighting techniques will also support more efficient agricultural processes, providing methods to create perfect growth environments for important plants and crops. Such methods have already been used to improve yields by up to 60%. Imaging techniques will also allow rapid, non-damaging monitoring and measurement of food and drink production lines that will allow more efficient processes and higher productivity.

The next generation of solar panels and LED lights will continue to generate huge energy savings. By integrating these technologies with intelligent light management systems where the desired level of lighting is optimised, both the quality and efficiency of lighting will further improve.

QUANTUM TECHNOLOGIES

Quantum technologies have enjoyed an increasingly high profile, driven by the endless possibilities that the technology could bring to areas such as computing, communications and security.

However, in the context of this paper it is important to acknowledge that much of the quantum world is essentially a sub-sector of photonics, one in which the goal is to control individual quanta of light. Although in its commercial infancy, the applications for quantum technologies are broad.

Quantum imaging is expected to provide enhanced systems for scientific use within the next 5 years including microscopes and telescopes for defence applications. Looking further ahead, such techniques could provide a step-change in the way we visualise the human body for medical procedures and diagnostics.

Quantum sensors will allow the 3D mapping of dense materials, something that will have a significant impact on the construction and oil and gas industries. Such sensors would allow the underground mapping of existing infrastructure or the monitoring of oil and water movement.

Quantum technology will also have an important role to play in future communications, particularly in the area of security through advanced quantum encryption. While perhaps a little bit further off, quantum computers offer the possibility of tackling problems which cannot be addressed by classical computing.

COMMUNICATIONS

Photonic technologies enable the communication infrastructure of today and are critical to meeting the demand of the digital economy in future. They will continue to provide the fastest, most efficient way of gathering, transferring and storing data and the focus in future will be to do so in most efficient and secure way possible.

Data is being generated at an unprecedented rate and is forecast to accelerate further over the coming decades. To support this demand, huge data centres are being constructed around the world, each a large network of computing and storage equipment underpinned by fibre optics and optical transceivers. These data centres are significant consumers of energy and already produce more greenhouse emissions than all of the world's air travel. Photonics will play a key role in tackling this considerable issue, developing technologies that allow higher throughput, higher quality and lower cost optical transceivers.

Our demand for ubiquitous connectivity and networking technologies is likely to be met by a range of communications services and infrastructure in future. These will include fibre optics, WiFi, LoRa, LiFi, 5G, and virtual and augmented reality. All of these tools are enabled by photonic technologies and the delivery and security of our future communications framework represents a huge opportunity for the sector.

ADVANCED MANUFACTURING

Advanced manufacturing is a catch all term that describes the integration of new technologies to products and processes that deliver improved productivity and efficiency. This includes not only physical infrastructure but also the systems that are required for the automation and data exchange that underpins industry 4.0. In this regard, photonics will play two key roles.

Firstly, photonics will enable new technologies that directly improve the efficiency of manufacturing hardware. This includes further development of high power and ultra high intensity lasers that have already introduced a new level of precision to cutting, marking, monitoring and measurement. Lasers also enable additive manufacturing, also known as 3D printing, which allows the creation of complex and customised parts, from turbine blades on jet engines to dental implants for facial surgery.

Secondly, photonics devices will support the connectivity required for industry 4.0 applications. Through a series of advanced optical sensors and fibre optics, photonics will enable connected and interlocked production systems with the necessary high band-width and low latency for real-time industrial processes. Such systems will also allow further advancement in autonomous systems and predictive maintenance, laying the foundation for interruption free processes.

4. SCOTLAND'S PHOTONICS SECTOR

With total revenues nearing £1Bn, a significant focus on exports, and between 5% and 10% of revenue invested in R&D activities, photonics is one of the most innovative and internationalised sectors in Scotland.

Scotland has always enjoyed a pre-eminent position in photonics and optics, with a proud history that goes back to James Gregory in the 17th century (inventor of the modern reflecting telescope) and James Clark Maxwell who formulated the classical theory of electromagnetic radiation.

Scotland's modern optical industry was created with the founding of Barr & Stroud in the late 19th century, and throughout the 20th century, Scotland's prestigious universities became renowned for their ability to produce highly skilled optical and photonic engineers and scientists, providing the foundation for a new generation of photonics businesses.

This has created a cluster of innovative companies and internationally recognised academic centres that are developing and manufacturing cutting edge technologies and products which are exported the world over. Our flair for innovation and engineering endures, and Scotland continues to enjoy a leadership position in areas such as lasers, optical transceivers, Li-Fi and quantum technologies.

SCOTLAND'S INDUSTRIAL PROFILE

The photonics sector in Scotland is built around a vibrant industrial core of 60 companies developing and manufacturing a diverse range of photonic products from eye scanners and thermal cameras to LED lighting and micro displays. These companies are responsible for generating nearly £1Bn in revenues[2], with around 85% of output exported[3].

It is a sector driven by innovation, with over 5% of revenues invested in R&D activities[4] (cf. an average of some ˜0.5% across Scotland's economy). Indeed, some organisations spend in excess of 10% of revenues on R&D. These activities are supported by over 4,000 highly skilled staff of which up to 20% are trained to postgraduate level.

Consistent with patterns seen across Europe, Scotland's industry base is dominated by small and medium sized enterprises which make up over 75% of the commercial enterprises in the sector. However, the sector is bolstered by several large multinational organisations that have chosen to maintain a significant footprint in Scotland, attracted by the talent pool and supporting infrastructure available within the cluster.

ONE OF THE MOST INNOVATIVE AND INTERNATIONALISED SECTORS IN SCOTLAND

- £1bn — IN REVENUES
- 85% — OF OUTPUT EXPORTED
- Up to 10% — OF REVENUE INVESTED IN R&D
- 60 — VIBRANT COMPANIES AT ITS CORE
- +4,000 — HIGHLY SKILLED STAFF

RESEARCH AND ACADEMIA

The sector is supported by a number of universities across Scotland, where around 250 academics and researchers are working in the photonics field, including optical communication, quantum technologies, biophotonics, and sensors and imaging. Much of this research is internationally leading, evidenced by the fact that around 25% of all UK research funding in photonics goes to Scotland[5]. In addition, a recent analysis placed Scotland in the top three countries globally (alongside Switzerland and Singapore) when comparing photonics publications normalised to population[6].

Scotland's photonics research also benefits from two extensive research pooling initiatives – Scottish Universities Physics Alliance (SUPA) and Scottish Research Partnership in Engineering (SRPe). These organisations provide an integrated, collaborative community across Scotland's academic centres, capitalising on the breadth of expertise and cross-disciplinary experience to tackle some of the sectors biggest research challenges.

Photonics has also been one Scotland's most active areas for European collaboration with Scottish Universities and local partners participating in 100 different projects in FP7 and H2020 frameworks with a total value of €334M, from materials science to applications in life sciences and energy[5].

In addition to research, the universities provide a stream of new talent for industry as well as offering expert consultancy services and a wide variety of specialised facilities. They are also the birthplace of innovative spin-out companies that regularly provide new blood to the industrial landscape. Indeed, Scotland's Universities have produced a steady flow of spin-out companies over many years providing the seed for the majority of photonics manufacturers in Scotland.

RESEARCH AND ACADEMIA: THE LANDSCAPE

University of Aberdeen
University of Dundee
The University of Edinburgh
University of Glasgow
Heriot-Watt University
University of St Andrews
University of Strathclyde Glasgow
UWS University of the West of Scotland

SUPPORTING ASSETS

Scotland's photonics sector is further supported by an enviable array of translational assets providing research capability, access to funding and access to capital equipment that is vital to many within the sector. These resources often provide a focal point for collaboration, creating invaluable connections between local industry and academia as well as international partners.

SUPPORTING ASSETS: THE LANDSCAPE

AFRC Advanced Forming Research Centre, University of Strathclyde
CENSIS
CATAPULT We work with Innovate UK
Centre for Doctoral Training in Applied Photonics: industry inspired: imaging | sensing | analysis
CoB
EPSRC Centre for Doctoral Training in Photonic Integration and Advanced Data Storage
EPSRC Centre for Innovative Manufacturing in Laser Based Production Processes
Fraunhofer UK
Institute of Photonics
TFSI Institute of Thin Films, Sensors and Imaging
JWNC The James Watt Nanofabrication Centre
NPL
Organic Semiconductor Centre
QUANTIC
SMC Scottish Microelectronics Centre
STFC UK Astronomy Technology Centre

5. DELIVERING A WORKFORCE FOR THE FUTURE

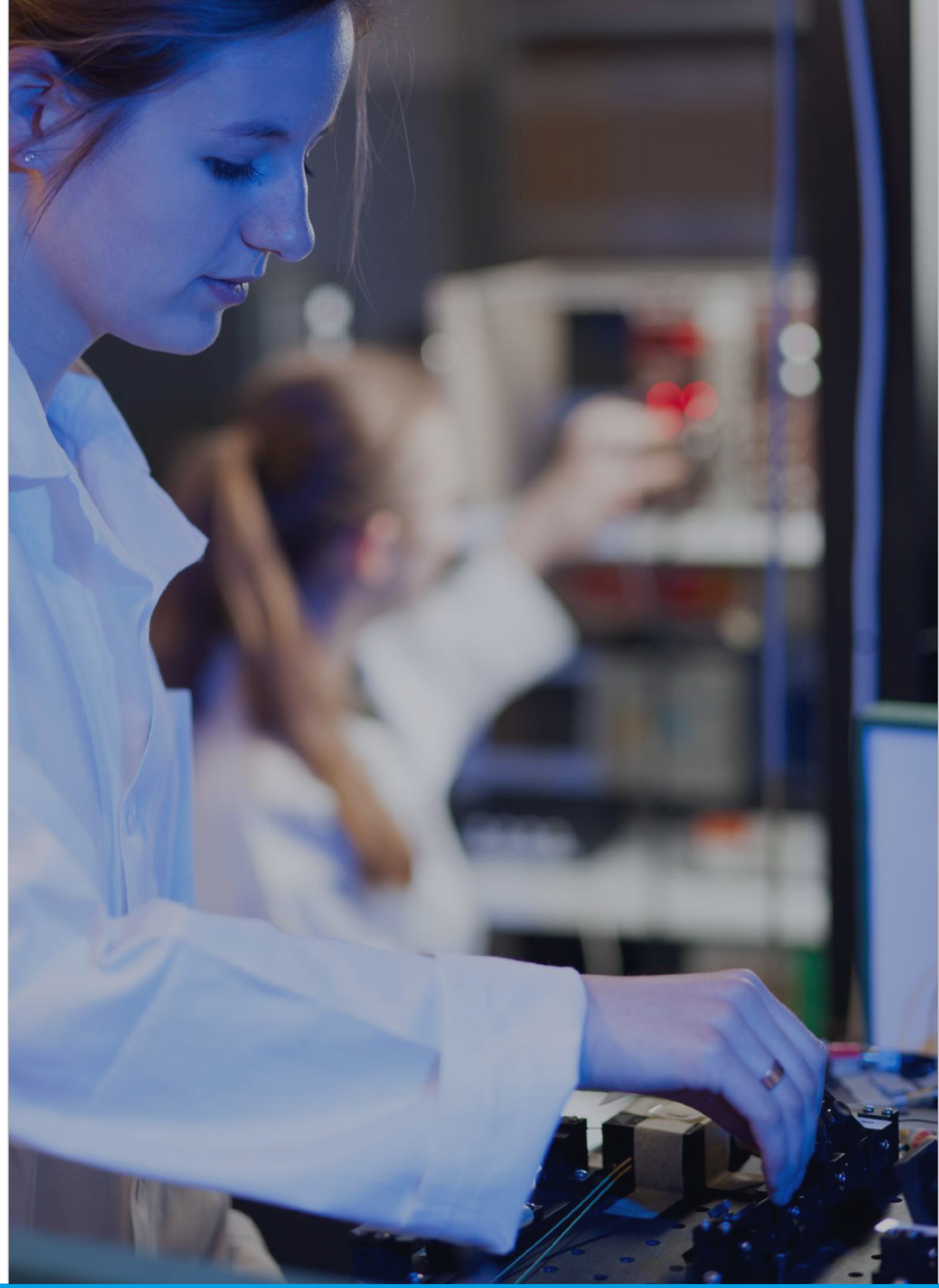
Access to high calibre talent has long been a key strength of Scotland's Photonics sector.

Driven by industrial demand since the late 19th century, Scotland's prestigious Universities have been delivering a conveyor belt of talent that has been stimulating new enterprises and encouraging international investment for over 100 years.

In the 21st century, Scotland's academic base continues to produce highly skilled engineers and scientists. However, with the projected rapid growth of photonics in the coming years, there will be increased pressure on Scotland's education system to produce a sufficient supply of qualified personnel to meet the demands of both the photonics industry and of academia.

It is vital therefore that Scotland takes measures to meet this future demand and cement its position as a leader in an increasingly competitive global market. These measures must address the development of talent across all levels, from PhD graduate to apprentice technician and should not only focus on technical knowledge, but also on the commercial skills that are so important to business growth.

The following section sets out a series of recommendations that will ensure that Scotland's talent pipeline is geared to meet future demand. While this includes proposals to ensure that there are sufficient graduates entering the potential talent pool, it also seeks to address challenges in attracting talent to the sector and increasing diversity. Finally, recommendations are set out to support the upskilling of the existing workforce, from early stage career professionals to experienced photonics practitioners.



GROWING THE SKILLS PIPELINE

Photonics is an industry that relies heavily on skilled individuals in the inter-related areas of Science, Technology, Engineering and Maths (STEM), particularly in physical sciences and electronics & electrical engineering.

However, as has been widely reported[7], there is a recognised shortfall in STEM skills across the UK's workforce with some estimates indicating that the UK is currently short of around 173,000 skilled workers at a cost to business of £1.5Bn per year[8]. In Scotland, demand for STEM skills is forecast to increase significantly over the next 10-15 years, driven by an unprecedented rate of technological change. This will put further strain on the emerging talent pool, with one report projecting that an additional 42,600 STEM jobs will be required in Scotland by 2027[7].

Given this rate of growth, it is important that our educational establishments continue to develop our future workforce at a rate that will meet demand. This paper recommends a 40% growth in the number of engineering and physical sciences undergraduate places at Scottish Universities by 2030. This represents an increase from recent growth rates across these subject areas which have been recorded at 35% and 24% respectively since 2006-07[9].

In addition, this paper also recommends that there is a greater emphasis on delivering these places through work-based learning schemes such as the Graduate Apprenticeship Programme run by Skills Development Scotland. These places, in which students benefit from significant time within industry, have been well received by employers who are eager to ensure that graduates are 'work ready' on transition to the employment market. The sector must work with Skills Development Scotland to include more specialised photonics activities within existing relevant graduate schemes.

Finally, the sector should also seek to ensure alignment between higher education programmes and industrial need. This will be critical to the development of a workforce that will support future growth. With the rapid pace of technological change in the sector, this must be done through continued engagement between academia and industry, identifying skills and training gaps to inform curriculum development and delivery. Photonics Scotland will play a key role here, aggregating the needs of the sector to ensure that higher education programmes are delivering value for the whole sector.

1. **Ensure 40% growth in the number of engineering and physical sciences undergraduate places at Scottish Universities by 2030**

    - Include greater emphasis on work-based learning
    - Ensure alignment between academic programmes and industry need

A NATIONAL PHOTONICS INITIATIVE FOR SCOTLAND

As outlined in the previous section, it is vital to the future of Scotland's Photonics Sector that we continue to grow the pool of STEM qualified professionals emerging from our universities and colleges. However, it is important to acknowledge that these individuals possess skills that are highly sought after in other sectors, not just in adjacent technical industries but across sectors as diverse as finance, health, education and energy. In this sense, a competitive landscape emerges, one that Scottish Photonics must address to ensure that future talent is not lost to the sector.

This is not an easy challenge with one recent study indicating that as many as 40% of engineering graduates and up to 60% of physical science graduates in the UK are not employed in highly skilled STEM careers[10]. The photonics sector has an additional challenge due to its relatively low profile within Scotland's education system and, indeed, Scotland's wider society. It is vital therefore, that the profile of photonics is raised with particular emphasis placed on the role of photonics in the modern world and the diversity of career opportunity available through our exciting sector.

This paper recommends that this awareness campaign be run through a coordinated National Photonics Initiative, to be delivered in partnership by Scottish Government, industry, and academia.

This initiative should raise the profile of Scotland's vibrant photonics sector to students, parents and education providers at all levels, from primary education to our university base. Industry must play its part, communicating the diverse range of career paths available and highlighting the opportunities that the sector supports, from school leaver to postdoctoral researcher.

Inclusivity must be at the heart of this activity, with increasing focus placed on those sections of society where engagement with photonics has traditionally been low. This will involve reaching out to schools in which take up of STEM subjects is known to be low as well as to those working in the Community Learning and Development Sector. Improving the gender balance must also be a key focus and will be discussed in more detail in the subsequent section.

Finally, the sector should seek support from other relevant organisations such as Skills Development Scotland, Institute of Physics, SUPA and SPRe to leverage complementary activities that would support the initiative.

2. Inspire the next generation of photonics professionals through a coordinated National Photonics Initiative

- Highlight the role of photonics in Scotland's society
- Raise awareness of the diverse career opportunities in the sector

HOLYROOD SCOTTISH PHOTONICS RECEPTION

PROMOTING GENDER DIVERSITY WITHIN THE SECTOR

The photonics industry has long struggled to increase the participation and engagement of women. A recent SPIE (the international society for optics and photonics) study indicated that, across Europe, female representation in the sector is as low as 20%[11].

It is clear, therefore, that Scottish Photonics will need to target greater engagement from this underrepresented group to ensure the future success of the sector. As well as unlocking the well documented commercial and cultural benefits of a more gender diverse workforce, this approach will be vital in securing the necessary number of skilled workers to support future growth.

The Scottish Photonics Sector is certainly not alone in addressing this challenge and it will be important to work with other relevant organisations such as SPIE, the Institute of Physics, Scotland Women in Technology, the Institution of Engineering and Technology, and Skills Development Scotland to find solutions. It will also be important to align future initiatives with the Scottish Government's STEM Strategy published in 2017.

However, there are actions that can be taken directly by the sector now, and this paper recommends a new Women in Photonics initiative to encourage and inspire more women into the industry.

Building upon programmes such as 'Opening Up Photonics', recently created in partnership between Photonics Scotland, The University of Glasgow, the Knowledge Transfer Network, and the Institute of Physics Scotland, this initiative will seek to identify barriers to female engagement in the sector. Working with both industry and academia, the initiative should then put recommendations and processes in place that will provide employers and educators with the necessary tools to encourage more women into photonics careers. For example, this may include recommendations to avoid unconscious bias during the end to end recruitment process.

3. **Encourage greater diversity within Scotland's Photonics workforce through a new Women in Photonics initiative**

   - Identify barriers to female engagement with the sector
   - Provide employers and educators with recommendations and processes to encourage more women to pursue a career in photonics

SCOTTISH PHOTONICS ACADEMY

A key consideration when creating a globally competitive talent pool is the upskilling and retraining of the existing workforce, from early career employees to technicians to experienced photonics researchers. This approach should not be limited to only technical requirements but should address key non-technical skills such as product management, sales & marketing, and leadership, so crucial in supporting the growth of the sector, particularly our SME base.

This paper recommends that a Scottish Photonics Academy be established to develop the specific technical and commercial expertise identified by employers within the sector. To be coordinated through Photonics Scotland, and with initial public and private sector investment, the academy would be scoped and delivered through partnership with industry and academia.

The Academy would build on a recent initiative between Technology Scotland and SUPA which created an Industry Skills Course for post graduate students across all 8 physics departments within Scotland's universities. This course focussed on key skills gaps identified by industry and included both technical and soft skills.

As well as forming an important teaching function, the Academy will also provide a hub for future collaboration within the sector. By bringing together photonics professionals across a variety of technical areas and market sectors, the academy would seek to cultivate an environment of knowledge sharing and cooperation.

4. **Establish a Scottish Photonics Academy to develop specific technical and commercial expertise identified by employers within the sector**

   - Upskill and retrain existing workforce
   - Provide hub for future collaboration

6. SUPPORTING BUSINESS GROWTH

The Scottish Photonics Sector is a fragmented one, dominated by a large number of small and medium sized enterprises (SMEs), a picture that is repeated across the UK photonics market where around 80% of revenues are generated by just 8% of companies[2].

However, this group of companies contribute significantly to the development of the sector in Scotland and will be critical to achieving our vision to treble the size of the sector by 2030. It is often from this base that exciting new technologies and enterprises emerge, those with the potential for rapid growth that will lead to significant contributions to the sector in future.

SMEs face many challenges in the sector. Success is often built on years of intensive research with long incubation times until development of commercial products. This can make access to some traditional finance routes difficult, at least until market potential can be established and prototypes developed. For this reason, support through initiatives such as the Scottish Investment Bank and Scottish Enterprise SMART grants is important and it is encouraging to note that Scotland's photonics sector maintains a relatively high share of investment through these routes.

In addition to finance, early phase development of photonics SMEs often requires access to expensive capital equipment. This is often well beyond the means of most small businesses meaning access to translational assets becomes critical. Be it prototyping, pilot manufacturing, or testing, the ability to operate at scale without significant upfront investment is a necessity for many in the sector.

However, the opportunities that access to finance and assets bring can only be maximised where commercial experience is readily available. It is often a lack of this experience that can inhibit growth and measures should be taken to ensure that the vast experience within the sector is disseminated to those at the beginning of their journey.

HOLYROOD SCOTTISH PHOTONICS RECEPTION

MAXIMISING THE KNOWLEDGE POOL

Scottish photonic spin outs and early phase SMEs are often technology driven, created from world-leading IP and years of research. However, there is an acknowledgement that while these enterprises benefit from substantial technical expertise, they often lack the type of commercial input that only significant industry experience can bring.

Scotland is fortunate to benefit from a cluster of world-leading photonic businesses which in turn have created a substantial knowledge pool in key areas for growth e.g. exports, supply chain management, marketing, IP and others. Ensuring that these expertise are shared where they are needed most will be important for future growth.

To facilitate this, this paper recommends the creation of a Photonics Growth Pool which will provide a central resource for SMEs to access important knowledge and advice. Central to this will be a categorised database of 'mentors' who would be willing to share their own experiences with young entrepreneurs. Such a service will provide early commercial input that has the potential to positively influence strategy, greatly reducing time to market and accelerating growth.

5. Establish a Photonics Growth Pool to encourage early engagement between experienced market leaders and young entrepreneurial researchers

- Provide early stage enterprises with experienced input
- Create a database of mentors in areas such as exports, sales, supply chain and distribution

TRANSLATIONAL ASSETS

Scotland's photonics sector is supported by an enviable array of translational assets providing research capability, access to funding and capital equipment that is vital to so many in the sector. Many of these assets, such as Fraunhofer CAP and the Scottish Innovation Centres enjoy a high profile within the sector and are utilised extensively. However, there are a range of assets, often contained within university departments or industrial enterprises that are available for use but are often under-utilised.

To ensure full visibility and maximum use of all assets, this paper recommends the creation of a Photonics Asset Database that will provide prospective users with an extensive, categorised list of available resources across Scotland.

Scotland is continually building its translational asset base, and it will be important that the photonics sector influences the activities of these resources where relevant. As an example, Scotland is soon to benefit from the £48 million National Manufacturing Institute for Scotland (NMIS), a joint skills academy and centre of manufacturing excellence. The photonics sector must work with the NMIS partnership to ensure that opportunities for the photonics sector are recognised and progressed. Similarly, the £56 million Medicines Manufacturing Innovation Centre (MMIC) could provide substantial opportunity for some in the sector and action must be taken now to ensure maximum benefit in future.

6. Maximise value from existing and future translational assets within the sector

- Improve visibility and access through creation of an asset database
- Ensure the sector achieves maximum benefit from future assets

7. DEVELOPING SCOTLAND'S PHOTONICS CLUSTER

With a diverse industry profile, world leading research base, and many supporting organisations and assets, Scotland can rightly claim to be home to a thriving photonics cluster.

Active clusters have been shown to increase the productivity of companies operating within them, supporting above average job growth, stimulating new businesses and promoting collaboration[12].

However, it is important that clusters are managed and developed to ensure that those operating within them realise these potential benefits. It is widely acknowledged that, without this management, clusters can remain fragmented and their visibility and influence reduced.

The development of Scotland's photonics cluster is facilitated through Photonics Scotland (formerly the Scottish Optoelectronics Association), a trusted partner to the sector for 25 years. The ultimate goal of Photonics Scotland is to maximise opportunities within the cluster and create a framework that will act as a catalyst for networking, collaboration and growth. In doing so, Photonics Scotland will raise the profile of the sector, creating an attractive environment for future investment and potential employees.

BUILDING THE ECOSYSTEM

A key prerequisite for any successful cluster is that those operating within it have full visibility of local skills, assets and potential partners. This visibility is vital when nurturing an environment that facilitates information exchange that will allow companies and organisations to benefit from combined resources and collaborative opportunities.

Photonics Scotland will continue to provide a catalyst for this, spearheaded by a series of conferences, workshops and networking meetings that bring together a diverse range of stakeholders to address specific technical or market challenges.

In addition, this paper recommends the creation of a Scottish Photonics Capability Directory that will provide those in the sector with a single database of industry, academia and shared assets, improving access to key partners within Scotland's local supply chain. Such a database would also provide a valuable marketing tool when promoting Scotland as a leading location for the development and manufacture of photonics products.

7. Create new partnerships and collaborations through improved access to key partners within Scotland's local supply chain

- Provide a catalyst for cluster activity through Photonics Scotland
- Create capability directory for all organisations, academic groups and translational assets within the sector

ENGAGING THE PUBLIC SECTOR

From lighting and connectivity to medical devices and autonomous vehicles, public bodies will have an important role to play when accelerating the utilisation of breakthrough photonics-enabled technologies. It is vital therefore that the photonics sector views such bodies, not just as integrators, but as development partners, regulators and funders. This paper recommends greater engagement with Scotland's public sector to accelerate product realisation.

Key to this is the alignment of civic challenges with technological development. In this regard, greater awareness of the 'Art of Possible' must be generated, and programmes that facilitate this communication by bringing together technology suppliers and public bodies should be encouraged.

Funding initiatives committed to this approach, such as the Small Business Research Initiative and CivTech®, should be expanded to facilitate greater public-private partnership and provide opportunities for the utilisation of pioneering technologies.

8. Accelerate product realisation by encouraging early engagement with Scotland's public sector

- Raise awareness within public bodies on the 'Art of Possible'
- Facilitate public-private partnerships by expanding existing funding models e.g. Small Business Research Initiative (SBRI), CivTech

8. INTERNATIONALISATION: THINKING GLOBAL FROM BIRTH

Photonics is a truly global market and those participating in Scotland's Photonics sector must often negotiate complex international supply chains, even those in early phase development. In this sense it is important that Scotland's Photonics companies think global from birth.

In Scotland this has created a sector that has a strong emphasis on international markets, with the majority of companies exporting upwards of 85% of their output[3]. Indeed, for some in the sector, international exports account for 100% of revenue.

Scottish companies look further afield to attract talented individuals with specific expertise to augment the skills pool in Scotland. International collaboration is also vitally important, with Scottish companies and universities participating in European projects worth some €334 million in recent years[5].

Finally, the Scottish Photonics sector has benefited from significant foreign direct investment over the last 20 years, establishing footprints for a number of multinational companies bringing significant capital and capability to Scotland.

Whether it is securing future business or investment, attracting skills, or developing partnerships, Scottish Photonics must look to grow its reputation and profile on the international stage. Scotland has much to offer but we must build on a Scottish brand that has been established over the last century to ensure our position in an increasingly competitive global market.

PHOTONICS SCOTLAND

As one of the world's oldest photonics clusters, The Scottish Optoelectronics Association has an enviable global reputation. The Scottish Optoelectronics Association, recognising that optoelectronics is now considered an outdated term, has taken the decision to rebrand as Photonics Scotland.

To ensure that Scotland maintains its profile on the international stage, this paper recommends a series of promotional initiatives based around this new brand. This will build on the efforts of the Scottish Optoelectronics Association over the last 25 years, providing a focal point for the sector to identify new export opportunities and attract talent and investment.

These initiatives should be built on a coordinated, cross-platform promotional campaign to be delivered through Technology Scotland, The Scottish Government, Scottish Enterprise, Skills Development Scotland and Scottish Development International. This will include: creation of new promotional materials, attendance at key international conferences and events, trade missions to key and emerging markets, and a talent attraction programme.

In a political climate characterised by uncertainty, it is more important than ever that Scottish Photonics establishes itself as a secure home for investment and future career opportunities.

9. Promote Scotland's sector on an international level through the creation of a Photonics Scotland brand

- Work in partnership with Government, Scottish Enterprise and Scottish Development International
- Identify new export opportunities and attract talent and investment to Scotland

Photonics Scotland
THE SCOTTISH OPTOELECTRONICS ASSOCIATION

9. CASE STUDIES

COHERENT

Founded in 1966, Coherent Inc. is one of the world's leading providers of lasers and laser-based technology for scientific, commercial and industrial customers.

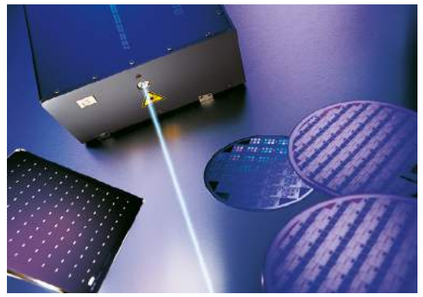
With headquarters in the heart of Silicon Valley, California, and offices spanning the globe, Coherent offers a unique and distinct product portfolio that touches many different markets and industries.

Since 2000, Coherent Scotland (a subsidiary of Coherent Inc.) has operated from a purpose built laser design and manufacturing facility within the West of Scotland Science Park. The subsidiary has grown strongly and consistently over the past ten years and develops products that are deployed in a wide variety of markets including industrial microelectronics, materials processing and scientific research.

One area fuelling Coherent' s laser development is the growing requirement for laser enabled manufacturing to meet the demand of the smartphone and tablet revolution. The latest of these devices pack fantastic processing power, combined with sophisticated touch screen displays, into a compact, rugged package. Laser manufacturing processes play an essential role in almost all significant components in these products, which is increasing as the drive for miniaturization continues. With a higher density of circuitry in a smaller package, the move to flexible substrates, rather than rigid materials, enables greater freedom in terms of phone size and shape. This advance is enabled by multiple laser processes.

Phone manufacturers are also moving to increasingly thin display glass. Mechanical glass cutting has limitations and so glass cutting has moved, in great part, to processes using laser cutting. Combined with the laser techniques in semiconductor manufacturing, such as lithography, inspection and via drilling, the laser is a core manufacturing tool.

Modern smartphones are the manufacturing marvel of the age, and the laser enables almost every step of its production.



INTELLIGENT GROWTH SOLUTIONS

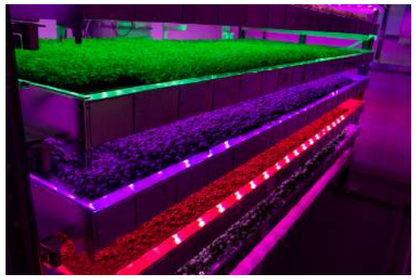
Intelligent Growth Solutions (IGS) was established in 2013 as an indoor horticulture business with a vision to deliver commercial viability to the vertical farming model through Totally Controlled Environment Agriculture (TCEA).

It has developed a ground-breaking patented power and communications technology deployed in vertically stacked Growth Towers at its Scottish demonstrator farm in Invergowrie to address the key challenges facing the global farming industry.

Fundamental barriers including the cost of power and labour have inhibited the spread of digital indoor farming technologies to date. The ability to produce consistent and quality produce at scale across a wide range of crops is the single pivotal factor governing the mass adoption of these products. IGS technology has been designed to overcome these barriers.

In vertical farming it is particularly important to control the intensity, spectrum and method of delivery of light provided to the plants, at various levels throughout the crop growth cycle. Being able to alter the wavelengths of light, removing or varying the spectrum at different stages of growth is important in significantly improving crop yield. Building in this capability has been a key focus for IGS and is unique among currently available indoor farms. The exact optimum light levels for each crop and stage of growth are less well understood and is now a key focus for the development of IGS' Artificial Intelligence capabilities.

The location of IGS' first vertical farm at the James Hutton Institute, a world leading crop research facility, was deliberately chosen to enhance collaboration opportunities. Scientists and researchers at the Institute are working with the team at IGS to better understand how growing under lights can impact different varieties of crop growth, as well as drive increased productivity. This is bringing excellent results with the synergy between the technology systems and the Hutton's cutting-edge plant science knowledge and experience.



LEONARDO

Leonardo is a global high-tech company and one of the key players in aerospace, defence and security. Leonardo is the largest inward investor in the UK defence sector and one of the biggest suppliers of defence equipment to the UK Ministry of Defence.

The company works with governments, armed forces, institutions and citizens to design and realise a wide range of products, systems, services and integrated solutions to meet their customers defence, protection and security needs.

For more than 40 years, portable infrared guided Surface-to-Air Missiles (SAMs) have been spread throughout the world. This has driven the need for an effective countermeasure to protect helicopters, aircraft and particularly their crew and passengers. Used by both the military and terrorists, SAMs have been used in every conflict area around the world.

Traditional countermeasures for IR SAMs involve the use of flares, but only limited numbers can be carried on an aircraft, and they have become less effective as missile technology has evolved. The use of flares over towns also leads to fire risks. The need to provide effective and inexhaustible protection has driven the requirements for Directed Infrared Countermeasure (DIRCM) Systems.

Miysis is an advanced DIRCM System. Developed over the last decade, it is sold throughout the world to protect aircraft from SAMs.

Designed and built in the UK, it encompasses advanced technology, exploiting more than 30 years of domain knowledge and expertise in infrared countermeasures. The smallest and lightest DIRCM available today, Miysis is fully qualified and in production.

The performance of Miysis has been shown to have a 100% success rate during UK Government and NATO tests against a range of real SAM threats.

Business Innovation Award 2018

IOP Institute of Physics

M SQUARED LASERS

M Squared is a leading photonics and quantum technology company headquartered in Scotland. The company has provided the world's purest light, in the form of advanced laser technology, to academia and industry for over a decade and its dedicated quantum division is responsible for several quantum firsts.

Last year, M Squared developed the UK's first quantum accelerometer for inertial navigation in collaboration with Imperial College London.

The exceptional accuracy and low drift of such a system could see it eventually replace GPS entirely.

Current global navigation satellite systems such as GPS, send and receive signals from satellites orbiting the Earth whereas a quantum accelerometer can provide precise locations based on inertia without the need for any external system. This is particularly useful because satellite signals can be damaged, blocked, or destroyed. It can be costly too - one day of denial of the satellite service would cost the UK £1 billion.

The quantum accelerometer is heavily reliant on lasers and photonic control systems to harness the quantum effects on which it relies. M Squared developed a universal laser system for cold atom-based sensors that it implemented in its quantum gravimeter in 2017. Used in the quantum accelerometer, this laser system's high power, exceptionally low noise and frequency tunability means it can cool the atoms and provide the optical ruler for the acceleration measurements. Commercially viable quantum devices, such as this, will put Scotland at the heart of the coming quantum age.

Given the widespread interest in its quantum technology systems, M Squared is scaling up its quantum business to accelerate the commercialisation process. Its dedicated quantum centre at Inovo in the Glasgow City Innovation District is set to become the focal point for the majority of the company's quantum efforts. M Squared will focus on the commercialisation of many new technologies including quantum computers, inertial sensors (gravity, acceleration and rotation) as well as timing (strontium lattice clocks).

OPTOS

In 1992, Optos was founded and incorporated in Scotland. Our vision is to be The Retina Company and recognised as a leading provider of devices to eye care professionals for improved patient care.

Our core devices produce ultra-widefield (UWF™), high resolution optomap images of approximately 82% or 200° of the retina, something no other device is capable of doing in a single capture. An optomap image provides a bigger picture, which facilitates the early detection, management and effective treatment of disorders and diseases evidenced in the retina such as retinal detachments and tears, glaucoma, diabetic retinopathy and age-related macular degeneration. Millions of eyes are imaged every year with our technology world-wide.

Optos is committed to utilising the latest technology to manufacture new products and software that support optomap as a standard of care therefore helping eye care professionals around the world save sight and lives. Optos requires access to the latest development in photonics to deliver its advances in technology. We collaborate with many local companies and universities to achieve these advances in our medical devices and remain the leading provider to eye care professionals.

PURE LIFI

Imagine a world where high-speed connectivity is as pervasive as the lights in our ceilings, our streets and our homes. Imagine, billions of connections powering billions of smart devices unlocking unprecedented productivity, autonomy and powering the next generation of high-bandwidth disruptive applications. Imagine LiFi.

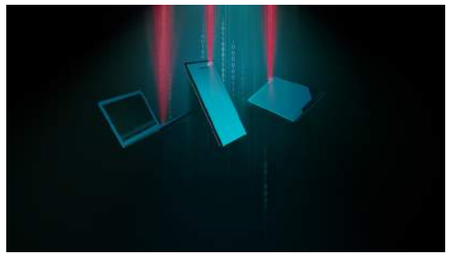
Established in 2011, pureLiFi is a spin-out from the University of Edinburgh. The company was founded by Professor Harald Haas and Dr Mostafa Afgani, after Professor Haas's famous Ted Global talk where he demonstrated Light Fidelity for the first time and coined the phrase LiFi. Harald Haas is now broadly known as the "Father of LiFi". However, the founding team have been pioneering research into LiFi communication since 2003, work which was begun at the Jacob University, Bremen.

LiFi is high speed bidirectional networked and mobile communication of data using light. LiFi has the ability to turn any LED light into a high speed and secure wireless access point. The company's vision is simple, pureLiFi believe one day LiFi will be in every light and every device, connecting everything and everyone.

pureLiFi brought the first commercial LiFi product to the world in 2013 and continue to lead the advancement of this ground-breaking technology. In February 2019 pureLiFi debuted the world's first optical LiFi components designed for mobile integration at Mobile World Congress. The new optical components enable high-speed LiFi with Gbps connectivity. offering fast, secure mobile communications via light.

Since the company's inception pureLiFi has become a global leader in the development and innovation of Light Fidelity (LiFi). They have pioneered the technology adoption globally seeing more than 130 deployments across more than 24 countries. pureLiFi's international customer base includes major influencers in the lighting and communications ecosystem such as Cisco, Wipro, Zumtobel and O2 Telefonica.

LiFi adoption is on the rise and transforming our lighting infrastructures into inherently secure, high-speed and reliable wireless communications. With 1000 times the capacity of the entire radio spectrum, LiFi will be the greatest carrier of data in our not so distant future.



ABOUT PHOTONICS SCOTLAND

This paper has been prepared by Photonics Scotland (formerly the Scottish Optoelectronics Association) in consultation with its members and would like to thank them for their continued support.

Photonics Scotland is a community for all photonics and photonics-enabled organisations in Scotland. We are the focal point for the sector and a trusted partner to our members allowing us to represent their views to a number of key stakeholders. We also facilitate a cohesive sector, providing a range of events, working groups and networking opportunities that help to drive collaboration between industrial and academic partners.

Ultimately, our goals are simple: to raise the profile of the sector, help grow this thriving cluster, and drive innovation in photonics in Scotland.

Founded as the Scottish Optoelectronics Association in 1994, it is one of the oldest national photonics organisations in the world and remains one of the largest technology communities in Scotland.

Photonics Scotland is a network managed by Technology Scotland, the trade association for Enabling Technologies in Scotland.

ABOUT TECHNOLOGY SCOTLAND

Technology Scotland is the representative body for the Enabling Technology Sector in Scotland.

We support a vibrant community of industrial and academic organisations who are developing technologies to deliver product advancements in markets from healthcare and communications to manufacturing and mobility.

Technology Scotland delivers clear business value to members, providing a catalyst for growth and supporting the community through networking, collaboration, lobbying and thought leadership.

- Representing industry interests to government
- Promoting Scottish technology capabilities within the UK and internationally
- Influencing policy at both Scottish and UK government level
- Supporting the community through events, workshops and forums
- Interfacing to key national and international stakeholders

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