

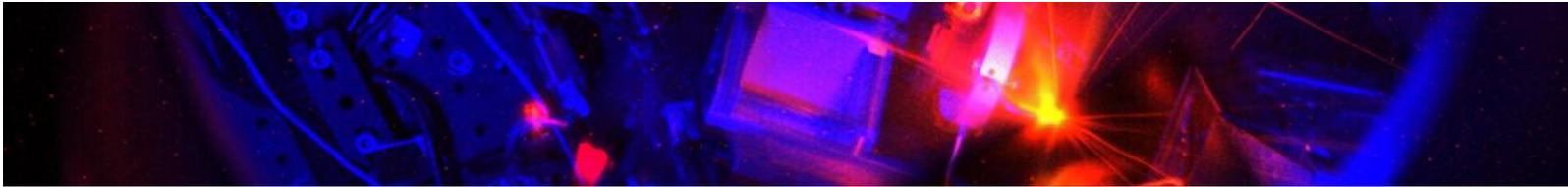
Central Laser Facility Impact Study

Summary Report for



know.consulting

29th November 2024



About the CLF

The CLF is a global leader in laser science that works to enable and sustain the development of skilled people and the application of laser technologies by supporting the UK academic community and industry, connecting researchers across the world and training the next generation of scientists.

“

“From drug discovery to imaging viruses in action, from greener chemical synthesis to better batteries, from light sources for national security to liquid scanners at airports, from determining the fate of microplastics to studying environmental emissions, from AI driven lasers, to recreating conditions in stars, the CLF develops laser technologies that advance our fundamental understanding and tackle pressing societal challenges impacting health, security, energy, and climate change.”

”

About know.consulting

know. /nəʊ/v.

to understand clearly and with certainty

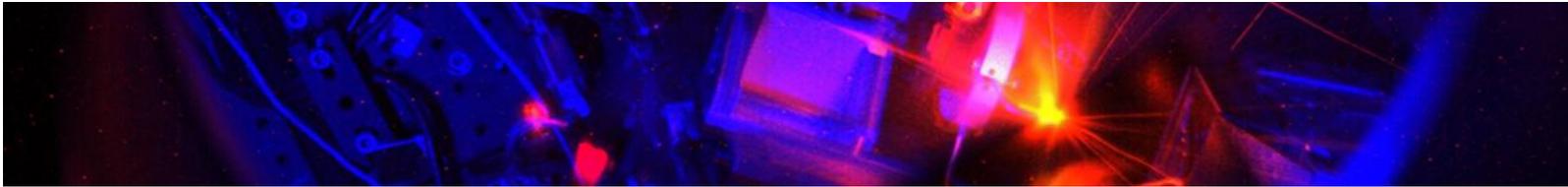
know.consulting¹ is a specialist economic and strategy consultancy, based in London and Edinburgh. We are motivated by a single mission: to provide **trusted expertise in the analysis of research & innovation**. We combine cutting-edge analysis with deep understanding of R&D investments to help our clients navigate hype, risk and uncertainty.

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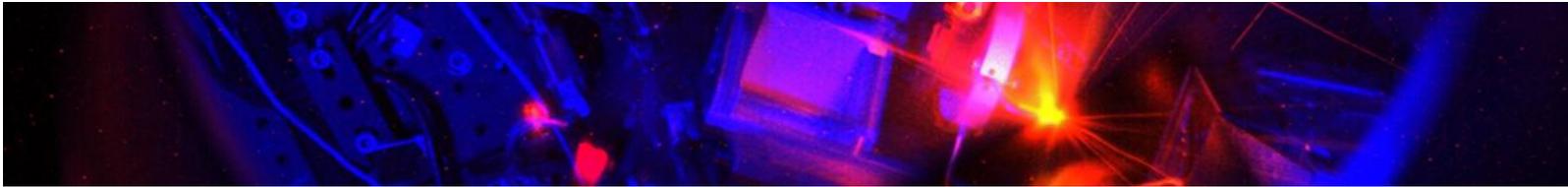
STFC CLF X/Twitter post, available at: https://twitter.com/CLF_STFC/status/170697440292186150

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Executive Summary

The Central Laser Facility (CLF) has generated **significant socio-economic impacts**, benefiting UK researchers, industry, and society. Its international leadership and influence in laser technology, built over decades, **positions the UK at the forefront of global research.**

know.consulting were commissioned by STFC to study the impact of the CLF over the past decade. We present analysis across four impact categories:

Science

- The CLF generates **close to 150 peer reviewed publications a year**, averaging 27 citations per publication.
- The CLF supports multi- and inter-disciplinary research, with publications spanning **at least 39 different (2nd level) subject areas.**
- Publications from the CLF have amassed over **33,300 citations** over the last decade, and **they are cited twice as much as the global average.**
- The top 150 cited publications are referenced in at least **325 news articles**, on sites such as BBC News and Forbes, and are **linked to 16 patents.**
- Cutting edge research at the CLF has contributed to advances in nuclear fusion, astrophysics, climate change, viral research, and 3D printing.

Competitiveness & Reputation

- The CLF supports UK research organisations from every area of the UK.
- Over 60% of CLF supported publications are internationally collaborative.
- The CLF has **collaborated with over 220 international organisations since 2019**, from all continents except Antarctica.
- The CLF is **regarded as world leading** by stakeholders, and the next generation of facility upgrades will help to secure this status in the future.
- CLF staff hold positions on numerous international scientific advisory boards and groups, helping to boost UK reputation and influence.

Skills, Knowledge & Inspiration

- Technical and scientific expertise of CLF staff is a **key enabler of upskilling.**
- **Around 150 PhD students** are trained at the CLF annually, **maintaining the research pipeline** and spilling over knowledge to a range of industries.
- The CLF **boosts technical and soft skills** at a range of seniority levels, through apprenticeships, training, outreach and industry placements.
- **112 industrial placement students** were hosted over the past decade, and **14 apprentices are currently being hosted.**

- The CLF has published **350+ news items and articles** over the past 10 years, and has a long tradition of engaging with the public and young people.

Innovation & Commercialisation

- The CLF **supports innovative research**, with many invention disclosure forms, proofs of concept (PoC), and patents generated in recent years.
- There are **23 active patent families** within the CLF portfolio, which have attracted **£15m+ in income** to the CLF over the last decade.
- CLF has **spun out two companies**, leveraging in-house capabilities to meet commercial demand: **Scitech Precision Limited** and **Cobalt Light Systems**
- These companies have led to societal and commercial benefits for the UK, including **around 200 person-years of employment & ~£45m in revenue**
- Industry users leverage the CLF's expertise and technologies to support internal R&D, leading to improved production techniques and products.

As part of the study, we conducted **27 interviews with key stakeholders**. These included representatives from the UK user community (including academia and industry), representatives from CLF spin-out companies, key strategic partners, and directors at other international laser facilities.

Stakeholders stressed that the CLF offers a **catalogue of cutting-edge capabilities, expertise, support, and outreach which is internationally leading**. These capabilities and services have underpinned impacts for the wider community, and supported the UK (and international) academic and industrial research base.



*"In enabling user-led science, **the CLF is world leading.**"*



*"**The CLF's reputation is really respected.** The UK is the technological leader in the field"*



*"The staff are incredible... they are incredibly friendly and approachable, and have **incredible expertise**"*



*"[in-house technology development at the CLF] **drives companies to improve** existing products, or supply new ones."*





1 Introduction

1.1 Context

In over 40 years of operation, **the Central Laser Facility (CLF) has become a globally leading hub for laser research.** The CLF is a world leader in laser-driven interdisciplinary science and innovation. It operates five advanced laser facilities, delivering cutting-edge research capabilities for the UK. Supported by state-of-the-art engineering, the CLF also develops next-generation high-power laser technologies to maintain its scientific edge. Additional support is also available for the laser research community, such as access to high performance computing and modelling capabilities through the theoretical plasma physics group.

know.consulting was commissioned by STFC to study the socio-economic impact of the Central Laser Facility (CLF) over the past decade, to enhance the evidence base and inform funding decisions. This report presents analysis across four impact categories: **Science, Competitiveness & Reputation, Skills, Knowledge & Inspiration, and Innovation & Commercialisation.** Evidence was gathered through 27 interviews, a site visit, desk-based research, and bibliometric analysis.

The CLF is made up of five laser facilities, which are split between two classifications: High-Power Lasers (HPL) and the Lasers for Science Facility (LSF). Additional areas of activity include applications, target fabrication, and in-house laser development.

The CLF hosts two HPL facilities:

- **Vulcan** is the most powerful laser at the CLF, and supports research in extreme conditions and laser-driven accelerators. Following an £85m upgrade, Vulcan 20-20 will be the world's most powerful laser, enhancing capabilities in a range of fields that include plasma physics, astrophysics, and laser fusion. The upgrade will enable twice the number of experiments each year.
- **Gemini** is a versatile high-power laser with dual synchronized beams, operating at one shot every 20 seconds. Its twin lasers can be used to produce bright and intense X-rays, or beams of electrons or protons, and it supports research into some of the fundamental aspects of the Universe. Eventually, Gemini will be replaced by the Extreme Photonics Applications Centre (EPAC), which will enable both high-power laser experiments and precise imaging using laser sources, benefiting commercial and research applications.

The CLF's LSF located in the Research Complex at Harwell, includes three facilities:



- **Artemis** provides high repetition rate and high average power laser systems, enabling studies of ultrafast dynamics and diffractive imaging from XUV to far-infrared. Along with Ultra, Artemis will benefit from the £18m HiLUX upgrades, significantly enhancing power and repetition rates.
- **Ultra** focuses on ultrafast molecular dynamics using pump-probe spectroscopy, applicable in chemistry and biology. It boasts unique combinations of laser amplifiers, detectors, and optical tweezers for advanced time-resolved spectroscopy.
- **Octopus** is comprised of a suite of imaging and laser trapping capabilities, including super-resolution microscopy and scanning electron microscopy for life, environmental, and materials sciences.

2 Science

This section outlines the scientific impacts of the CLF over the past decade, highlighting contributions from the five facilities across diverse research fields. Using a range of bibliometric and altmetric tools, along with qualitative insights and desk-based evidence, we demonstrate evidence of high impact 'in the round'.

Stakeholders view **the CLF as an internationally leading facility**, supporting a **high volume of researchers** conducting **cutting-edge experiments** across fundamental and applied research, enabled through **its highly skilled staff**.



"The CLF allows us to take science in directions that wouldn't be possible anywhere else."

"There have been many scientific discoveries that could not have been done anywhere else, as well as key auxiliary advancements in laser development."

"The CLF supports areas of science where the activation barrier is high, but the impacts are too. They have kept cost per scientific output low though, thanks to the staff who are well trained and technically proficient."

"Techniques developed at the CLF have had a range of applications, from verifying pharmaceuticals, to detecting explosives and narcotics"



2.1 Research output

Our analysis shows that the CLF has consistently supported **high research output over the past decade**, in both the HPL and LSF divisions, demonstrated by the number of experiments and related academic publications from the user community and CLF staff.

Since 2013, the CLF has supported...



1242 peer-reviewed publications
100-150 publications a year



The equivalent of 50+ years of facility access
825 experiments

While these numbers do not account for the quality of research undertaken, the high-impact journals in which the research is published provides an indication of **the global reputability of CLF research**. These journals include: *Nature Communications*, *Physical Review Letters*, *Science*, and *Cell Reports*.

The CLF offers unique capabilities, ranging from high-intensity petawatt facilities, to super-resolution microscopic imaging. Stakeholders noted that **no other facility matches the CLF's breadth of capabilities**. For example, Vulcan's powerful laser can replicate the high temperatures, pressures, and magnetic fields found in outer space for a split-second, while Octopus enables multidimensional molecule imaging and tracking at the cellular level. Combined with leading staff support, the CLF provides cutting-edge techniques essential for **both fundamental and applied research**.

The following figures only measure peer-reviewed publications, and therefore underrepresent the wider pool of industry users, engineering services, and target fabrication operations.

CLF supported publications cover a range of disciplines...



44% of publications are in **Physics**



30% of publications are in **Chemistry**



13% of publications are in **Engineering**



8% of publications are in **Biology**



4% of publications are in **Biomedical & Clinical**



1% of publications are in **Earth Sciences**

The breadth of disciplines which the CLF supports is also reflected at the sub-discipline level, where **the CLF has supported publications from at least 39 different second-level research areas**. Nuclear and plasma physics is the most common subject for CLF publications, comprising approximately 22% of publications, followed by physical chemistry at 16%. Inorganic chemistry, and particle and high energy physics are the next most common fields of research at around 8% each, followed by biochemistry and cell biology, and materials science. Although less common, **CLF publications encompass a far wider range of subjects, including atmospheric sciences, nanotechnology, and applied computing**.

2.2 Research impact

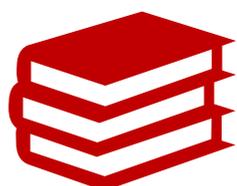
This section highlights the scientific impacts of the CLF. Using citation-based and altmetric analysis, desk research, and interview insights, we show how CLF-supported research has been received globally and provide key examples of its scientific contributions over the last decade.

2.2.1 Citations

Publications developed using the CLF's facilities have **recorded consistently high numbers of citations**. For example, the mean number of citations for a physics paper (disciplinary average, i.e. not specifically related to the CLF) is 17, whereas publications linked to CLF-enabled research over the last decade register an average of 27 citations per publication.

57 publications in the time series amassed more than 100 citations, reaching as high as 613 citations for one publication. However, there is a wider base of moderately cited papers, including **733 publications which have amassed more than 10 citations**. Notably, there are only 56 publications over the last decade that have not accumulated a citation, and these are generally either very recent publications (which have not had sufficient time to be cited), or are peer-reviewed conference abstracts, which typically are cited less frequently.

The CLF supports highly cited research...



27 citations per publication on average

3500 citations a year between 2012/13 and 2018/19

33,300+ citations since 2012/13

57 publications have amassed **100+** citations

Comparing citations over time and across disciplines can be misleading (e.g. some disciplines tend to attract more citations, all else being equal), so we have analysed CLF supported publications by using a relative citation ratio for each publication. This is calculated as follows:

$$\text{Relative Citation Ratio} = \frac{\text{\# of citations}}{\text{Average citation rate for publications in the same sub-discipline from the same year}}$$

For context, a relative citation ratio (RCR) of 1 indicates that a publication has received the average number of citations for its corresponding sub-field of research in the same year, while an RCR of 1.2 would for example mean that a publication has received 20% more citations than average.

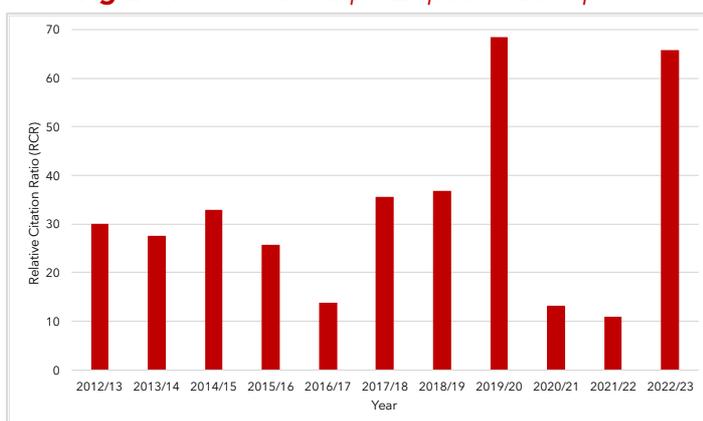
Overall, publications developed from work conducted at the CLF have an average RCR of 2 across the time series. This indicates that CLF publications are cited twice as much as the global average, across the sub-fields in which the publications sit.

CLF publications are cited **2x** the **global average**

Beyond the average RCR figure, some of the top performing CLF supported publications have accumulated far higher RCRs. **Figure 1** illustrates the RCR for the top-performing publications per year, **including a publication cited 66 times more than the average in that field in the same year**. Some of these publications have been developed in collaboration with authors from other global facilities, illustrating that CLF staff and the user community are working on research of international significance. These partnerships span across well established and emerging fields of research.

The majority of the highest RCR publications are in nuclear and plasma physics, although other subjects with high RCRs include materials science, inorganic chemistry, atomic, molecular and optical physics, condensed matter physics, biotechnology, microbiology, and history.

Figure 1 RCR of the top CLF publications per



Source: know.consulting analysis of CLF publications

2.2.2 Altmetrics

Altmetrics are a tool that can help identify activity around publications which can **demonstrate research impact beyond citations**, as articles are often shared, mentioned and discussed in many different fora and contexts. They are not a method to replace traditional citation-based metrics, but act as a complementary approach to show interest in research that cannot be measured in a citation count.

Our sample includes the **top 150** cited CLF publications over the last decade. We found these papers had been referenced in at least **325 news articles, including BBC News, BuzzFeed, and Forbes**, and were linked to **approximately 16 patents**.

2.2.3 Shaping the leading edge of research

CLF staff and the wider user community have conducted experiments which have **shaped the global direction of research**, leading to an improved understanding of key societal challenges, and how they can be tackled. We found evidence of cutting-edge research underpinning many areas of research, including: **quantum**

physics, astrophysics (including replicating a supernova in a lab), **shrinking km-long accelerators to cm-scale, AI applications** in their exploitation in a variety of fields including additive manufacturing (3D printing), **and understanding how COVID-19 replicates**. Below, we highlight two experiments which relate to climate change, to provide some examples:

A breakthrough in fusion energy²



This experiment was conducted at the National Ignition Facility (USA), but featured contributions from **CLF staff in the HPL division**, the University of Oxford and Imperial College London. The results signified a major breakthrough in fusion energy, as **the Lawson Criterion for ignition had been exceeded**, meaning the experiment produced more energy than it consumed. Fusion energy could potentially mitigate climate change by providing clean energy with an abundant supply.

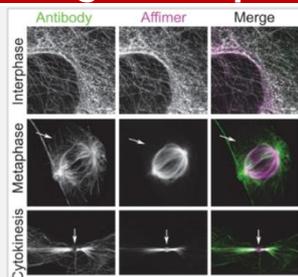
Measuring environmental Impacts³



This experiment outlined how aerosol pollution released when cooking, such as unsaturated fatty acids, can degrade the atmosphere and **contribute to climate change**. These findings help us to better understand the source and scale of challenges from aerosol emissions, and **predict the impact of cooking emissions on the environment**. The research featured CLF staff and the Universities of Bath, Birmingham and Reading.

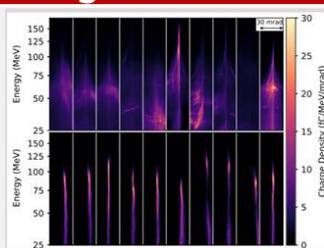
Other research at the CLF has shaped the frontier with **cutting-edge techniques**:

Using Affimer proteins to better understand molecular processes



A 2017 paper⁴ outlined a collaboration between the University of Leeds, Avacta Life Sciences (a spin-out company), CLF staff, and Dstl. The experiment at Octopus investigated the use of **affimer proteins as affinity reagents**, to replace the need for antibodies in studying molecular processes. This has led to better tools for scientists to study the processes of life, and was referenced in two patents for Avacta Life Sciences, relating to cancer treatment and COVID-19 diagnosis.

Using AI to enhance experiments in plasma accelerators



A 2020 experiment⁵ led by Imperial College London at Gemini proved, for the first time, that artificial intelligence (AI) could be used to improve the control of powerful plasma accelerators across multiple parameters. This breakthrough has been applied to further experiments in studying antimatter and quantum physics, providing future lessons for optimising the CLF's EPAC facility, through AI/Machine Learning.

² Abu-Shawareb, H et al. 2022. Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment. *Physical Review Letters*, 129, 075001

³ Milsom, A. et al. 2022. The impact of molecular self-organisation on the atmospheric fate of a cooking aerosol proxy. *Atmospheric Chemistry and Physics*, 22(7), pp.4895-4907

⁴ Tiede, C. et al. 2017. Affimer proteins are versatile and renewable affinity reagents. *eLife*. 24903(6)

⁵ Shaloo, R. J. et al. 2020 Automation and control of laser wakefield accelerators using Bayesian optimization. *Nature Communications*. 6355(11)

3 UK Competitiveness & Reputation

In this section we explore the international standing of the CLF, and its impact in terms of the UK's global reputation, competitiveness, and influence.



"In terms of leadership in the field, nothing has changed. The CLF are the leaders and an ideal entity to partner with"

"There are not many other places around the world like the CLF. Other facilities don't have the same breadth of capabilities."

"The CLF is globally leading, talk to anyone in the high-power laser community. Also, UK groups have become globally leading through it, as the facilities have underpinned the research for these groups."

"They are absolutely world leading in high-power lasers, which will only be helped by the upcoming developments at the CLF."



3.1 Partnerships and collaborations

By tracking the key users of the CLF, as well as the key collaborators and strategic partnerships, we illustrate the CLF's participation and influence within the international laser community. These findings can also broadly be assumed to correspond to the organisations who may have gained benefits from the CLF's capabilities and support.

The CLF supports a broad range of UK research organisations...



- The CLF supports research organisations from **every region and devolved administration in the UK**
- Stakeholders regard the CLF as a **hub for the UK laser research community**, noting there are "not many avenues to progress the science" without it
- This map highlights the distribution of **UK grants awarded** to use the CLF, so does not capture all user organisations
- **94% of grant-funded users are academic institutions**, while the remaining **6% consist of other research organisations**

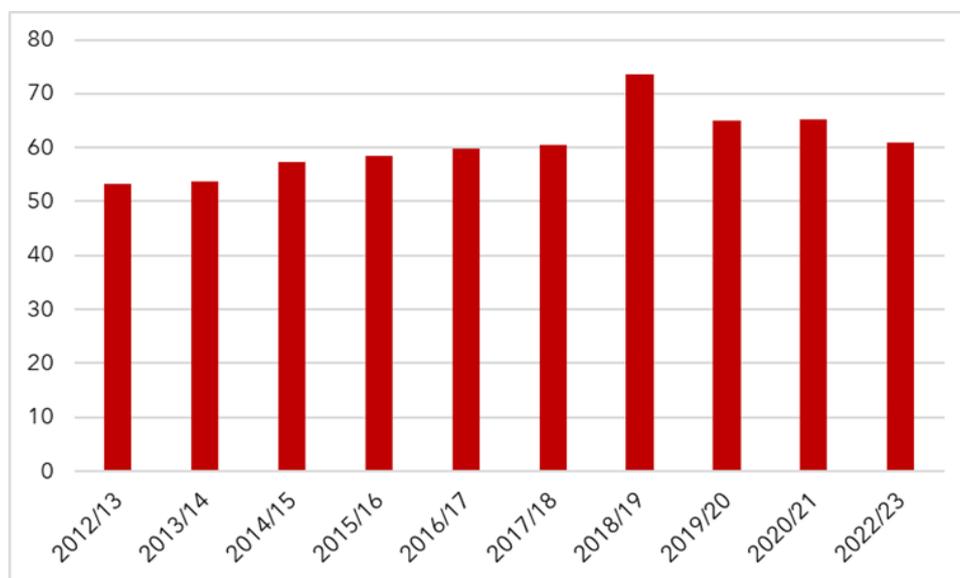
The CLF has enhanced the global competitiveness of the UK laser community, and also supports a **high level of international collaboration**. As stressed by one

stakeholder, "it is very rare for impactful science to be done without cooperation and collaboration".

Of course, **we should not assume that collaborations have to be international to be impactful**, as domestic research is also important. However, consistent high levels of international collaboration can provide an indication that the facilities, and the research undertaken at them, are **globally competitive**.

In analysing publication co-authorship, we found that **CLF-related publications have generally become more internationally collaborative in both absolute and relative terms over the last decade**.

Figure 2 % of CLF publications which are internationally collaborative



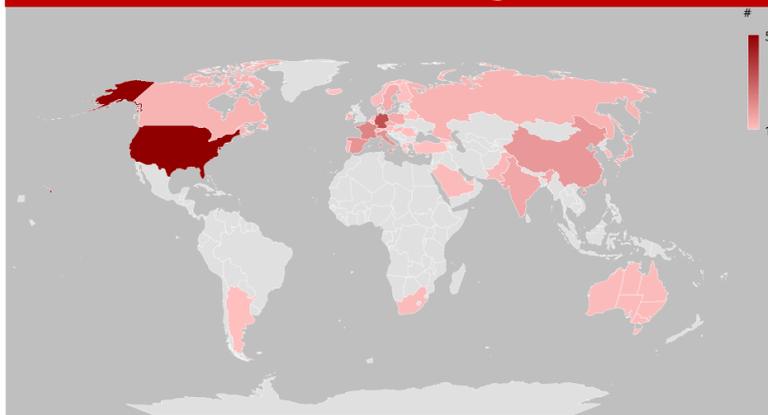
Source: know.consulting analysis of CLF publication data

The CLF has a **strong international collaborator base**, which is encouraged through the CLF's memberships across a variety of groups, organisations, and projects. The varied network of collaborators suggests that the CLF's expertise is sought out by experts from across the world, and also provides evidence of the CLF's continued efforts to extend its influence internationally.

Since 2019, the CLF has collaborated with over 220 international organisations across the world. Among these collaborations are other prestigious facilities such as the National Ignition Facility (USA) and Laboratoire pour l'Utilisation des Lasers Intenses (France). Approximately **80% of CLF's collaborations are with academic institutions**, but they also work with **research organisations, industry, and government bodies**.



The CLF collaborates with organisations from across the world....



- The CLF collaborates with organisations in **every continent except Antarctica** *
- **124** organisations are from **Europe**
- The USA are the **leading collaborating country**
- Other key collaborators include **Germany, France, and Italy**

*The CLF has also collaborated with the British Antarctic Survey (BAS). As the BAS is headquartered in the UK we do not count it as an "Antarctic" collaboration though note that it could be interpreted as such

The CLF is part of several collaborative projects and/or partnerships which provide mutual strategic alignment between the CLF and international organisations. These partnerships provide evidence of the CLF's global reputation in laser science:

Laserlab-Europe



Laserlab-Europe is an integrated initiative of European Laser Research Infrastructures. This EU-funded project has 35 leading interdisciplinary laser-focused institutions across 18 countries. Laserlab-Europe brings together the capabilities of 24 laboratories which research teams can access, supported by the European Commission. **The CLF is a founding member of Laserlab-Europe**, taking part in joint research, and providing training weeks for international PhD students. Professor John Collier (Director of the CLF) is the current Executive Director of Laserlab-Europe AISBL.

HiLASE Centre of Excellence



HiLASE, based in the Czech Republic, develops and operates high-power diode pumped lasers. Its facilities support research in various physics fields. The CLF was contracted to design and build a DiPOLE100 laser system for HiLASE in 2013. Additionally, the CLF has continued to collaborate with HiLASE as part of a €50m venture funded through the H2020 Widespread Teaming programme and the "Czech Ministry of Education, Youth and Sports", delivering a 100 Hz DiPOLE laser system and other innovative technological solutions. **The DiPOLE laser system exemplifies the CLF's world-leading laser development capabilities.**

The Extreme Photonics Innovation Centre (EPIC)



EPIC is a partnership between the CLF and the Tata Institute of Fundamental Research (TIFR), funded by UKRI's Fund for International Collaboration. EPIC aims to revolutionize areas such as industrial non-destructive testing and bio-medical imaging. It also serves as a hub for advancements in engineering, diagnostics, and target fabrication. This project builds on a **long-standing collaboration** between the CLF and TIFR.



The European X-Ray Free-Electron Laser Facility (XFEL)



European XFEL is a 3.4 km long underground X-ray laser research facility. The CLF constructed a DiPOLE laser system, DiPOLE100-X, for the facility in 2018, and CLF staff participate on the scientific advisory panel. The **XFEL Physical Science Hub** is operated by the CLF, and supports UK academics by providing guidance on accessing XFEL. From 2020 to 2023, the Hub jointly funded 21 PhDs, academic travel, and workshops at the European XFEL.

Helmholtz International Beamline for Extreme Fields (HiBEF)



HiBEF is a European XFEL consortium coordinated by the German Electron Synchrotron (DESY), the Helmholtz-Institute Jena, and Helmholtz-Zentrum-Dresden-Rossendorf (HZDR). The CLF is a consortium partner, and is delivering a long pulse laser system through the DiPOLE100-X.

The European Plasma Research Accelerator with eXcellence In Applications (EuPRAXIA)



EuPRAXIA is a Europe-wide project for developing a Free Electron Laser facility based on plasma accelerator technology, with applications in medical imaging and material testing. It is the first European project to develop a dedicated particle accelerator research infrastructure, based on novel plasma acceleration concepts driven by innovative laser and linac technologies. EuPRAXIA is one of the projects on the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap of 2021. The initial £2.5 (€3m) Design Study, funded under EU Horizon 2020, involved 16 European institutions, including the CLF. The second phase of the project, the preparatory phase for the construction, is currently ongoing. CLF's EPAC is one of the potential sites for the laser-driven arm of EuPRAXIA.

The Integrated Management and reliable oPerations for User-based Laser Scientific Excellence (IMPULSE)



The **IMPULSE** project involved 14 partners from 9 European countries to find cost-efficient, reliable solutions for user-based high-power laser systems, focusing on the Extreme Light Infrastructure (ELI) facilities. The CLF played a key role in optimising performance and efficiency, implementing operational procedures, developing advanced optical components, and enabling user and industry access.

3.2 Reputation and influence

There was a strong consensus from stakeholders that **the CLF has played an instrumental role in establishing the UK as a nation with world-leading laser-based capabilities, as well as world-leading scientific outputs, and scientific support.** Stakeholders noted that the CLF has been influential in developing laser technology and associated technology and techniques worldwide, and providing a best-practice operational model which other facilities have tried to explicitly

replicate. Examples mentioned were the NIF (USA), TIFR (India), Lund Laser Laboratory (Sweden), and facilities across Europe.



100% of CLF users* interviewed report improvements in the **UK's international reputation** in science due to the CLF



100% of international stakeholders** report the CLF is **world-leading for its facilities**



100% of international stakeholders report the CLF has **world-leading research support**



95% of CLF users interviewed regard the capabilities at the CLF as **sufficient for undertaking their intended research**

*21 CLF users were interviewed for this study

**5 international stakeholders were interviewed for this study

CLF staff are internationally recognised for their contributions to laser technology and associated technology and techniques, and **the CLF's global reputation is also driven at the individual level**. Stakeholders interviewed stated that the depth of expertise held by staff members is key in underpinning UK competitiveness in laser-based research. Some notable examples of awards and prizes given to staff include:

- The **Meggors Award** for contributions to spectroscopy and metrology.
- The **Richard Glazebrook Medal and Prize** for leadership in the field of physics.
- **Institute of Physics' Cecilia Payne-Gaposchkin Medal and Prize** for contributions to physics and relativistic laser-plasma interactions.
- The **Edward Teller Award** for groundbreaking work using lasers to generate particles and for advancing scientific applications.
- The **IOP Technician Award** for accomplishments in micro-engineering.
- The **TechWoman100 Award** for work in laser-driven biological research.
- The **Hannes Alfvén Prize** for contributions to plasma physics.

CLF staff also occupy a range of high-influence positions, **sitting on at least 15 international scientific advisory boards, as well as at least 6 editorial boards for high-impact journals**.

To remain world leading, the CLF must continue to advance state-of-the-art technologies. This is also key in attracting and retaining staff. Recently, the CLF has secured funding for facility upgrades which will deliver new capabilities:

- ☑ **£103m** to fund the Extreme Photonics Applications Centre (**EPAC**)
- ☑ **£85m** for **Vulcan 20-20**, building the world's most powerful laser
- ☑ **£17.2m** for **HiLUX**, upgrading the Artemis and Ultra facilities
- ☑ **£470k** for the **Octopus imaging cluster**, introducing a fast-freezing system



Collaborations between the CLF and UK government agencies

The **Ministry of Defence (MOD)** and its executive agency, the **Defence Science and Technology Laboratory (Dstl)**, have maintained a long-standing and impactful partnership with the CLF, which has been integral to advancing defence and security capabilities. This collaboration has spanned over a decade, driven by the use of the CLF's **HPL** facilities, and has resulted in **new R&D to support national security interests, training and workforce development, and reputational benefits.**

The joint R&D with Dstl started over a decade ago and is centred around the use of high power lasers and the secondary sources generated by them for developing disruptive capabilities for defence and security. The CLF and the MOD's long-standing relationship has resulted in the **MOD contributing £22m** to the construction of EPAC, to exploit some of the applications. According to consultees, this investment will be essential for the MOD and Dstl, enabling them to conduct classified, cutting-edge experiments in areas crucial for national security.

Through its association with the CLF and its cutting-edge laser capabilities, we also heard how the MOD secures benefits to its international reputation. For example, the **US Department of Defense was particularly impressed** with EPAC after visiting the facility, helping to solidify the MOD's position as a leader in defence technologies.

The CLF has also developed a strong relationship with the Atomic Weapons Establishment (AWE). We heard how CLF staff' knowledge has been essential in developing the AWE's laser, Orion, and its portfolio of laser capabilities which support nuclear science and technology development for national security purposes.

The Orion laser was approved for funding once key enabling technology was demonstrated at the CLF. A former CLF staff member led the £183m business case and delivery team for Orion. Supporting the business case for Vulcan 20-20, Prof. Andrew Randewich, Director S & T at AWE said: *"A broadly based UK community of theoretical and experimental specialists in high energy density physics is an essential requirement for MOD's deterrent programme. The CLF's contribution is critical, saving MOD tens of millions of pounds [per annum] compared with alternative ways of meeting this requirement."*

While much of the R&D undertaken by AWE is not publicised for security reasons, **close collaboration with the CLF has helped to validate AWE's capabilities by association.** An AWE interviewee was of the view that the technical expertise held across the CLF and AWE **makes the UK a sought-after collaborator internationally**, and helps to signify AWE's corresponding international leadership in defence. AWE intends to collaborate closely with the CLF to support future laser development and applications.

4 Skills, Knowledge & Inspiration

The CLF **supports the domestic and international skills pipeline** in laser research and related industry applications. This section captures the CLF's impact on **enhancing human capital** in the UK. Skills development is essential in improving the **technical expertise and capabilities** of the UK research base, as well as for generating significant benefits in other areas of the economy through **knowledge spillovers**.



"The staff are incredible... they are incredibly friendly and approachable, and have incredible expertise."

"The CLF is good at engaging young audiences, they have a visitor centre set up with videos and displays to teach young people about lasers. You don't see that at other high-power laser facilities."

"The CLF definitely supports personal development of soft skills as well, such as public speaking, negotiations, and networking skills."

"Training programmes are key - all of my students have benefited from them."



4.1 Developing skills

The CLF supports a breadth of users at **different levels of seniority**. Taking academia as an example, users range from department leads and research fellows to undergraduate students, as well as every position in between.

PhD students have been the most frequent users of CLF facilities over the last decade, making up around **40%** of the total. The CLF has maintained a consistent rate of PhD student users, at an **average of over 150 a year**, who will access the facilities several times during their PhD. Over the last decade, the experiments they have undertaken have supported **188 PhD theses**.

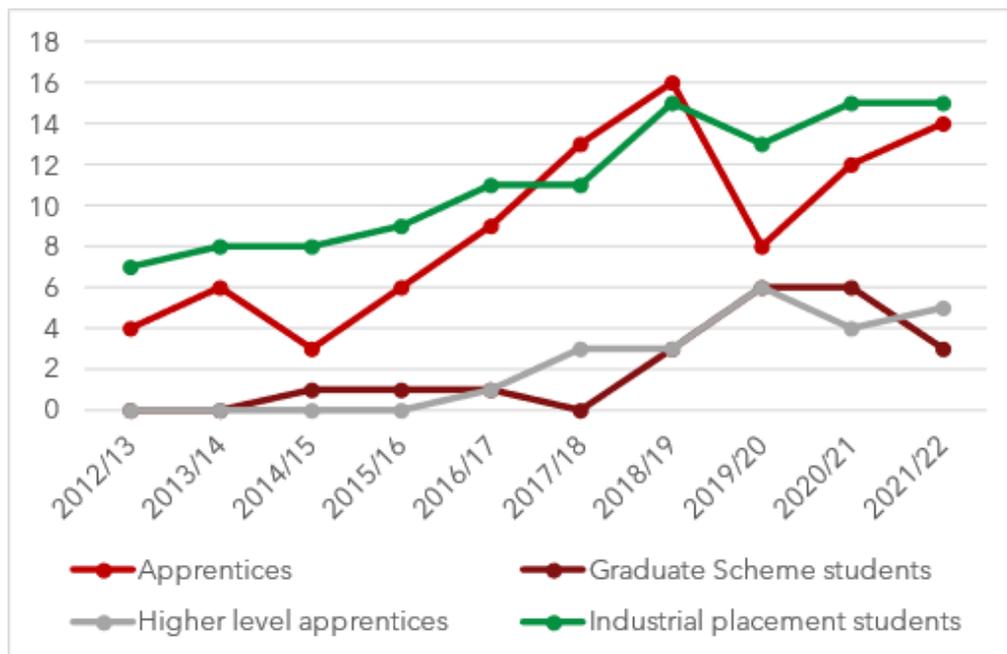
Several stakeholders noted that they use the CLF because of the **technical and scientific expertise offered by support staff**. Staff are seen as experts in their own right, and are adaptable, resourceful and keen to provide innovative solutions. This has helped to keep the CLF **accessible to a range of users**, and supports consistent knowledge exchange between the scientists at the CLF and the users, fostering the upskilling of both groups.

The CLF was also noted as a key enabler for gaining experience on state-of-the-art laser technologies, which the CLF continually invests in improving and de-risking.

This has led to new expertise being developed by users, improving the quality of academic and industry R&D alike.

The CLF has also increased its intake of apprentices, graduate scheme students, higher level apprentices, and industrial placement students over the last decade. This allows individuals taking part in these programmes to develop **technical and research expertise** at the facilities, as well as **soft skills** such as project management, public speaking, and networking.

Figure 3 CLF placements, schemes and apprenticeships per year



Source: know.consulting analysis of the CLF Review 2023

These schemes provide vital early-career skills development opportunities for students, ensuring young people from diverse backgrounds can acquire hands-on learning opportunities. The CLF has supported **112 summer student placements** across the facilities in the last decade, and **currently supports 14 apprentices**. Apprenticeships and graduate schemes are also typically multi-year in duration.

Case Study: From summer student to CLF staff member and beyond ...



During her degree in Physics at the University of Oxford, a student participated in the **CLF's Summer Student Scheme**, focusing her studies in the high power laser division.



She later began a **PhD focusing in laser-driven ion acceleration** and she returned to the CLF as a PhD user. Eventually, she transitioned into a role at the CLF as a laser specialist. Since then, she has taken up a senior position at an international nuclear science and technology research organisation.

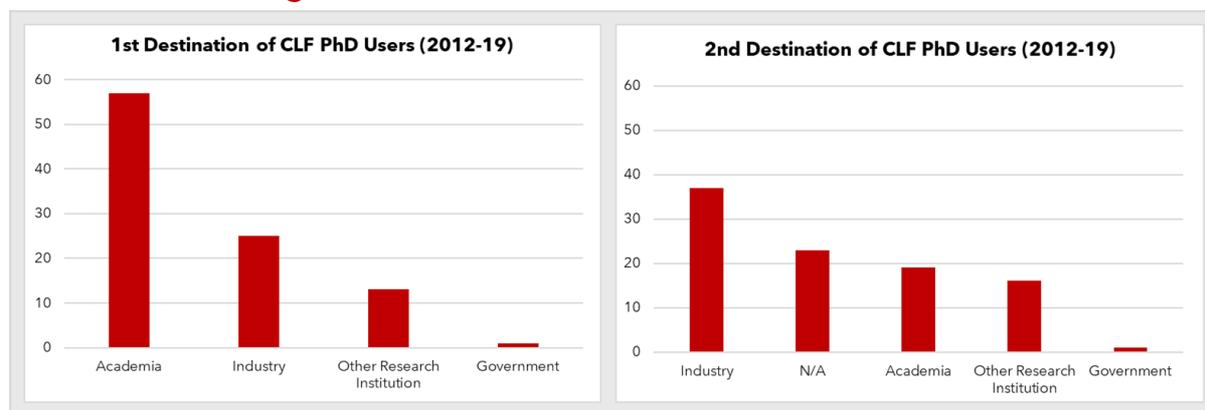


This individual's career trajectory is indicative of someone who **benefited from early engagement with the CLF** during her early studies and in the early stages of her professional career. She is one of the many CLF PhD users who have continued to contribute to the UK's laser science community.

4.2 Building the pipeline

Through **developing technical and soft skills at the CLF**, users and staff have equipped themselves with in-demand expertise. These capabilities support the future pipeline of research, but also flow into other sectors through knowledge spillovers. As the most prominent user group at the CLF, we have mapped the career trajectory (using publicly available data such as from LinkedIn scraping) of **162 PhD researchers** who have used the CLF to produce their theses over the previous decade. They transition into a variety of careers, leveraging their expertise in **laser technologies, R&D management, and computing**.

Figure 4 Destinations of former PhD users at the CLF



Source: know.consulting analysis of CLF PhD user data

The majority of former PhD users take up **academic** positions after finishing their PhD (referred to as their 1st destination above), including professorships and fellowships. The most common subsequent destination for employment (or 2nd destination) is **industry**.

Beyond academia, knowledge spillover to industries and companies include...



Optics Applications: ASE Optics Europe, Thales, Andor Technology, Element Six



Data Science: BAE Systems Digital Intelligence, Edif ERA, MUFG Securities



Renewable Energy: First Light Fusion, P3 Group



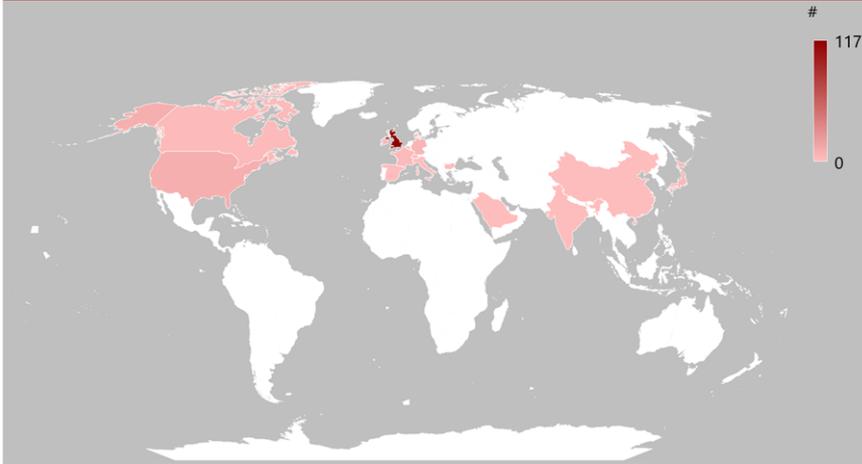
Industrial Laser Manufacturing: UNIK Lasers, Coherent Inc.



Patent Law: Forresters LLP, Mewburn LLP

It is important that the **UK retains its talent pipeline domestically**, though exporting talent internationally can also provide ‘soft power’ and reputational benefits to the UK. While **over 70% of former PhD users stay in the UK** following their study, a smaller subset have moved to international positions. Some of these individuals may also be returning to their home nation following their study in the UK.

Most former PhD students stay in the UK, but a subset relocate...



- **117** PhD students have stayed in the UK
- The most common international destinations are the **USA (10)**, **Germany (6)**, **Ireland (5)** and **Japan (4)**
- Many work at other international facilities, research institutes, and centres (e.g. Max Planck, CERN, NIF)

The CLF makes significant efforts **to engage with the public and with young people**, by running regular events, especially through the CLF Visitor Centre which opened in 2012. Through various mechanisms, both offline and online, we saw evidence of how **the CLF has engaged with the next generation of scientists to foster their interests in laser technologies and laser science research**. This includes the CLF participating in open days/weeks which invite students to engage with STEM subjects.

The CLF also **engages with industry through targeted workshops**, focusing on potential applications of laser systems in high value sectors, such as aerospace, new materials, and nuclear energy.

In person outreach...



The CLF records **over 1000** in-person visitors a year at the visitor centre



The CLF hosts industry workshops, career days, and school open days

Online outreach...



The CLF has posted **346 news articles**, which are linked to social media pages



The CLF's X following has grown between **25%** and **47%** a year since 2018

5 Innovation & Commercialisation

This section outlines the CLF’s track record of supporting new innovation and invention, and how these are translated into commercially viable solutions. The CLF’s in-house capabilities enable users to pursue innovative R&D applications, and plays a key role in de-risking technologies for the user community. This in turn supports industry users’ competitiveness and profitability.



“As a consequence of my research at the CLF, we secured further funding for a commercialisation study. We worked closely with the CLF here, scouting for viability. What is positive is that the CLF are very alert to opportunities, and they pointed us in the direction of industry.”

“Cobalt Light Systems was a really impressive spin out of technological developments at CLF. They applied Offset Raman Spectroscopy methods in a range of industries”

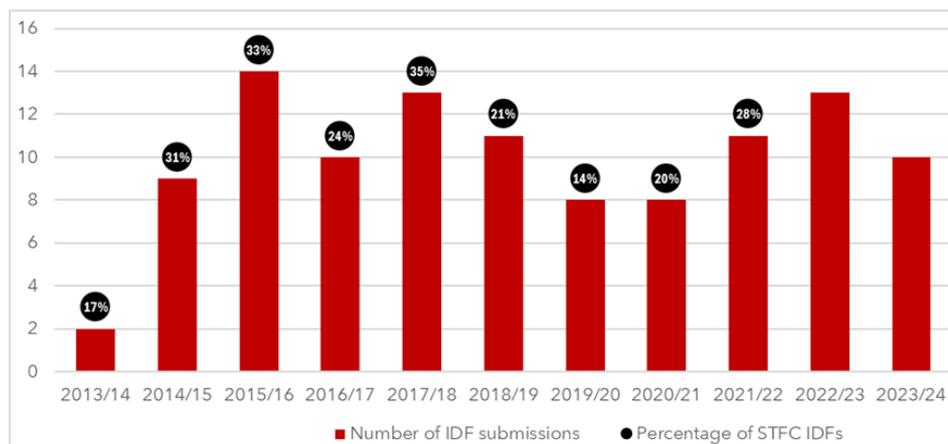
“They’re internationally leading at the Scitech spin-out.”



5.1 Intellectual Property

While not all new inventions will result in a commercially viable product, the number of invention disclosure forms (IDFs) arising from CLF-enabled research indicates high innovative potential. While only accounting for around 8% of STFC’s total staff (i.e. scientists, technicians and engineering roles as well as administrative and non-STEM), in some years the CLF produces **over one third** of all IDFs at STFC.⁶

Figure 5 Total IDF submissions from the CLF, and the proportion of the STFC total

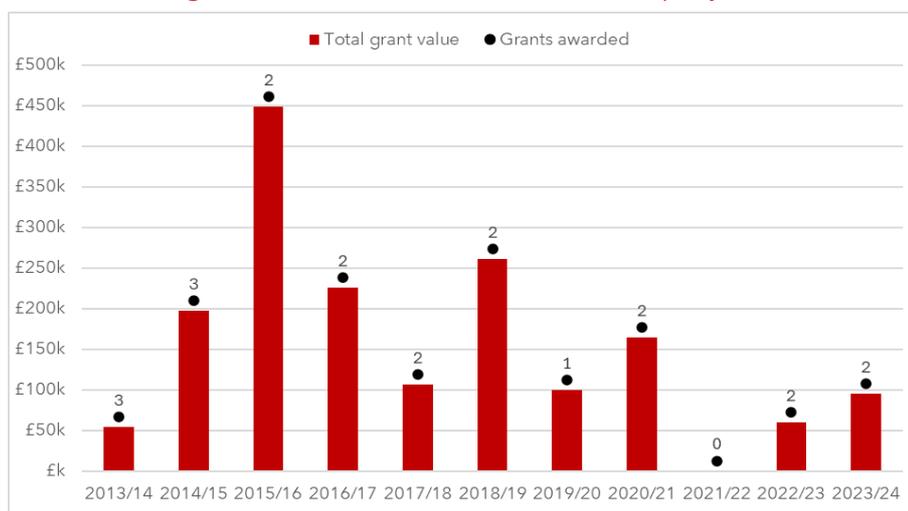


Source: know.consulting analysis of CLF IDF data

⁶ Based on 192 staff at the CLF (source: internal data for 2023/24), and 2,500 total STFC (STEM and non-STEM) employees (source: Science and Technologies Facilities Council, 2023. STFC - Written Evidence (PSU0061). Available at: <https://committees.parliament.uk/writtenevidence/111225/pdf/#:~:text=2%2C500%20people%20are%20employed%20to,are%20engineers%2C%20technicians%20and%20scientists.>)

Producing workable proofs of concept (PoC) is an essential interim step in bringing products or services to market, helping stakeholders to understand whether the proposed idea is feasible, practical, and worth putting resources into. Over the last decade, the CLF has directly received funding to develop **21 PoCs** relating to laser technologies and ancillary services. This represents funding for **two POCs a year** over the decade, totalling **£1.7m in funding**.

Figure 6 Number and value of CLF PoCs per year



Source: know.consulting analysis of CLF data

Patents are legal protections which give owners exclusive rights to make, use, and sell their inventions for a fixed period. High patent activity often demonstrates that an organisation has a **competitive edge**, as the holder maintains ownership and a related market edge with respect to that specific technology.

There are several reasons why organisations do not patent specific technologies (e.g. to promote open-access science, reach market more quickly, or to avoid disclosure requirements). However, we investigate patent trends at the CLF as one lens through which to view innovation impacts, while recognising these limitations.

The CLF itself has a portfolio of **23 active patent families**, spanning a range of industries. Examples include: 3D biomaterials printing, non-invasive cancer diagnosis, nuclear waste management, cell imaging techniques, and optical tweezers, as well as patents from spin out companies (discussed below) and the DiPOLE laser. **The CLF has generated over £15m** in income from these patents, including from external funding, licensing revenues and sales of products, demonstrating the CLF's capabilities in **spectroscopy and target fabrication**.

Of course, these figures only represent patents associated with CLF staff themselves, and hence the true commercial impacts - i.e. including industry users - may be **significantly higher than these figures**.

5.2 Spin-outs

The CLF has directly spun out two companies, **Scitech Precision Limited** and **Cobalt Light Systems**, that have leveraged their leading in-house technical capabilities to bring a range of products to market. In doing so, these companies have led to **direct commercial impacts**, such as income generation, investment, and jobs supported. Moreover, there are **indirect societal benefits** associated with the products and services of these companies.

Scitech Precision Limited...	Cobalt Light Systems..
 Established in 2009 to provide targets for high-power laser experiments using precision engineering	 Established in 2008 to exploit commercial use of Spatially Offset Raman Spectroscopy (SORS), which was developed by CLF staff
 Products and services have medical, environmental and nuclear applications, supporting UK-based R&D	 Products had security, pharmaceutical, medical and rescue service applications, using non-invasive analytical techniques
 Regarded as an internationally leading component manufacturer, exporting products to the USA, Germany and India	 Cobalt developed airport security scanners which were used globally, and worked in pharmaceuticals across Europe
 Turnover has remained between £250k-£300k , reaching £400k in 2023/24, and is projected to remain stable in the future	 Cobalt generated £44.4m in revenue from 2012/13 to 2017/18, before being acquired by Agilent Technologies for £40m
 Supports 5-6 employees annually, amounting to 39 job years since 2017/18	 Supported 88 job years in 2016 and 2017
 Maintains strong connections to the target fabrication group at the CLF, being based in Harwell with common staff	 Cobalt won multiple innovation awards for societal benefit , proven commercial success and ground-breaking innovation

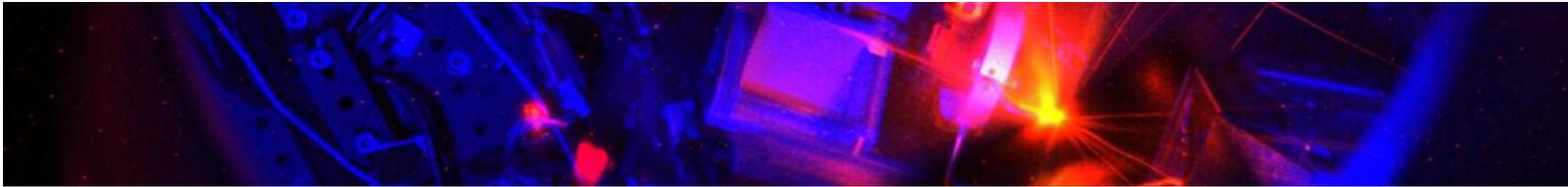
5.3 Commercial outcomes

Industry users leverage the expertise and technologies of the CLF to support their internal research and development and improve their commercial innovative potential, in turn leading to improved production techniques and products. Notable examples we heard in interviews included:

- **Johnson Matthey (JM)** has undertaken spectroscopy and imaging experiments, focused on catalysis and materials science applications for recycling. As a result of this long-standing relationship, JM has also funded research fellows at the CLF.
- **Rolls Royce** has worked collaboratively at CLF in X-ray imaging, laser peening (an advanced surface modification technique), fluid inspections in complex engine systems, and non-destructive evaluation of laser-driven sources.

Other industry users span sectors such as biotechnology, manufacturing, nuclear, defence, aerospace, automotive, and medicine. Industry access has brought **£200k-£300k in income to the CLF a year** between 2017/18-2021/22.

The majority of CLF access is allocated to **grant-funded projects**. Recipients have received **over £360m** between 2012-2022 from diverse sources, including UKRI Research Councils and charities (e.g. Wellcome Trust, Cancer Research UK).



6 Conclusions

The Central Laser Facility (CLF) has generated **significant socio-economic impacts**, benefiting the UK research community, industry, and society. Its international leadership and influence in laser technology, built over decades, have helped to **position the UK at the forefront of global research**.

The CLF's world-class laser capabilities have supported a wide range of academic disciplines and industrial applications, with "free at the point of access" use for academic researchers. The CLF supports fundamental and applied research across disciplines such as Physics, Chemistry, Biology, and Biomedical Sciences. Through research at its facilities, the CLF has advanced fields including nuclear and plasma physics, material science, and fusion energy. **Research involving the CLF and its staff contributes to a strong pipeline of high-impact publications, with its research being cited far more than the global average.**

International collaboration is a cornerstone of the CLF's success, with a large fraction of its publications involving global partners. This collaboration emphasises the CLF's international competitiveness and influence, with its staff playing a key role in establishing and upgrading laser facilities worldwide.

To maintain its global leadership, the CLF is pursuing **significant facility upgrades**, including Vulcan 20-20, EPAC, and HiLUX. These developments are expected to enhance the CLF's capabilities and secure its status as a leading global facility.

The CLF is also committed to **developing the skills and knowledge base** within the laser research community. It supports PhD students, apprentices, and young professionals through various training programmes, helping to build the UK's future research pipeline.

The innovative research conducted at the CLF has led to **numerous commercial opportunities**, resulting in societal, commercial, and employment impacts. The CLF has contributed significantly to innovation within STFC, leading to patents, external funding, and over £15m in income. The CLF has also **spun out two companies**, Scitech Precision and Cobalt Light Systems, which have driven revenue, exports, and job creation in the Oxfordshire area.

In summary, **the CLF is a "key enabler" of the UK's laser science research capabilities**, ensuring that the country remains a world leader in the field. These capabilities **underpin the UK's international competitiveness, and enable broader socio-economic benefits for the UK**. They also support advancements in knowledge, and underpin the generation of better products, services, and techniques.

... now you **know.**