RADICLE
Real-Time Dynamic Control System for Laser Welding

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2. Summary

The *Future Funding Requirements to Overcome "Valley of Death" Determined* is associated with the WP 7, Dissemination, Exploitation and Communication. This report for the RADICLE project has been prepared in accordance with the requirement of Grant Agreement 636932. The production of this document is the responsibility of the appointed Business Plan Manager. This document exposes the future funding requirements and course of action to ensure that RADICLE overcomes the *"Valley of Death"*.

This deliverable studies two connected topics: overcoming the *"valley of death"* while completing the activities currently preventing RADICLE's results from reaching TRL 9 and finding future funding programs and its requirements.

Overcoming the *"valley of death"* is a major concern in order to convert a prototype to a commercial product. It's a breaking point between a promising research investment and a successful commercial venture. The challenges and solutions presented were gathered from multiple sources who have studied this problem and are here presented in a brief and concise way. Moreover, an analysis is made on the outcomes of the RADICLE project, and on what is currently needed to assure the commercialization of the project results, namely future activities to further develop the RADICLE system and make it a commercial product.

Future funding program requirements are here displayed in preparation for an application to keep the project alive and reach its full potential. Amon the funding programs from Horizon 2020, only the ones that are more suited to this project were presented with the most important characteristics to take notice, especially concerning duration, funding and application requirements.

3. Background of the project

Laser welding is a high-energy density, non-contact, low heat input, high performance process which can be used for deep penetration, high aspect ratio and low distortion welding and is, nowadays, a fast-growing process.

The laser welding process has, however, strict requirements on the material preparation and fit-up of the abutting sheets / plates as a result of material vaporisation, fast welding speeds and subsequently fast molten fluid flows around the periphery of the laser induced keyhole. These fast fluid flows can generate instability in the melt pool, leading to potential keyhole collapse and ultimately, weld integrity issues, such as porosity. Concerns over defects and the cost of rework or scrap have slowed the uptake of laser welding for high value, safety critical manufacturing, particularly in the automotive sector.

Even where laser welding is used, significant time and cost is invested in Non-Destructive Testing (NDT) as a part of the Quality Assurance (QA) process. This testing can only detect defects, post-process, resulting in significant additional time and cost penalties in addition to the quality issues. To date, in-process monitoring systems are only capable of detecting surface defects and not the critical defects formed within the material, inside the laser keyhole.

If a solution could be found that eliminated the in-process defects and therefore the associated cost of rework then the uptake of laser welding systems would increase significantly, benefitting laser welding system suppliers and the European high value manufacturing industries.

The RADICLE project addressed the development of a real-time adaptive control system for laser welding using a range of sensors in combination with intelligent and adaptive control technologies for in-process monitoring and control to eliminate defects. The project focused on key high value materials and geometries for safety critical components from the aerospace, automotive and power sectors. The RADICLE system also targeted pre- and post-welding measurement to give a completely integrated quality system.

The RADICLE project was coordinated by the Manufacturing Technology Centre (UK) who operate a state-of-the-art industrial scale laser welding cell totally dedicated to research and

development. A group of world-leading industrial companies partnered with MTC: General Electric (Switzerland), Rolls-Royce (UK), GKN Aerospace (Sweden) and CRF (Italy).

These companies have significant market share in the critical markets of automotive, aerospace and power generation. Providing the process and sensor knowledge, the consortium also included Laser Optical Engineering (UK), Permanova (Sweden), BitAddict (Sweden) TWI (UK) and VTT (Finland). LOE are experts in laser processing and have a novel sensor technology to analyse the weld plume. Permanova is one of the world's leading suppliers of fibre laser welding systems. BitAddict is a technology innovation partner with expertise in software applications, IT systems, embedded electronics and machine solutions. TWI is widely recognised as the world's leading research institute in the field of welding and joining and brings a breadth of expertise in sample preparation and characterisation. VTT - Technical Research Centre of Finland is the biggest multi-technological applied research organisation in Northern Europe with leading expertise in ICT including algorithm development, software and control. The European Welding Federation led the project's dissemination and business planning activities.

This pan-European partnership contained some of the world's leading technical experts in the field of laser welding, some of whom are also world leaders in their industry. This gives an indication of the strength of the laser welding sector in Europe and the RADICLE project has enabled these world-leading organisations to work together and create a solution that can strengthen and reinforce the EU's position in both laser welding and high value manufacturing.

4. Overcoming the "Valley of Death"

The "*valley of death"* (Figure 1) describes the point where a business has a working prototype for a product or service that has not yet been developed enough to earn money through commercial sales. So, the company needs to find sufficient funding to develop the prototype until it can generate sufficient cashflow, through sales to customers, that would allow it to be self-sufficient and to grow.

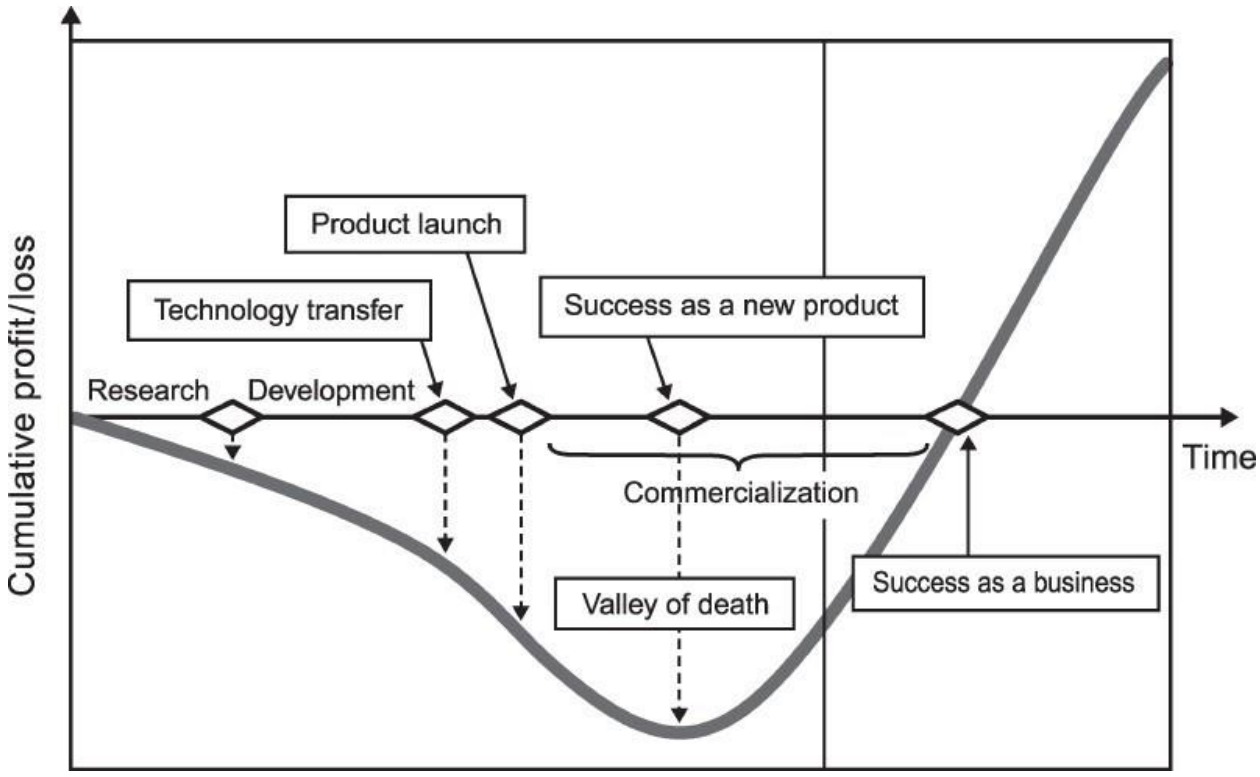

Figure 1 – Valley of death

To correctly analyse the valley of death and its connection to research, it is important to discuss the concept of Technology Readiness Level (TRL). The TRL of a device or system is a measure of estimation of its technical maturity against an increasing numeric scale. In the case of EU projects, there are nine TRL levels (aligned closely with the nine levels developed by NASA, considered to be the creators of the TRL scale).

The Technology Readiness Levels, as defined by the EU are:

1. Basic Principles observed.
2. Technology concept formulated.
3. Experimental proof of concept.
4. Technology validated in lab.
5. Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies).
6. Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).
7. System prototype demonstration in operational environment.
8. System complete and qualified.
9. Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).

For many in the research and development community a technology is generally “proven” when it reaches Technology Readiness Level 6 but there is a difference between being technically proven and having a successful implementation.

After TRL 6, there is a significant cost to mature the abilities of products and systems so that those seeking to use them can be confident that they will work as advertised. This cost and risk is the first part of the *"Valley of Death"* that makes it hard to transition a new technology or approach to real life. Even if the risk is low that a new invention will work as intended, there is still an enormous amount of cost and risk before successful implementation on or as a product.

Many of the difficulties found to cross the "*valley of death*" lie in the hand-off between public and private sector financing, but other problems occur, like the divergence of public versus private sector vision and goals. It's difficult to satisfy the public sector with high-risk research while simultaneously satisfying the private sector with specific product development sought to penetrate markets.

The main challenges to overcome the *"valley of death"* and reach a commercial solution (i.e. TRL 9) concern:

- **Collaboration difficulties** – communication problems, especially between groups of distinctly different set of skills, such as researchers and businesspeople, who can have different opinions on how to tackle a certain problem.
- **Rigid organizational processes** – slow decision processing and adaptation to the environment.
- **Lack of autonomy –** lack of flexibility to manage fast paced research and development projects.
- **Lack of resources** – embracing both financial, structural and human capital**.**
- **Lack of or deficient business model** – innovative technologies from research often lack a clear path towards the market.
- **Risk aversion** – if the risk of failure is considered too high to continue the project will never reach maturity.
- **Managerial scepticism** – innovative ideas face resistance, especially if the receiver's knowledge of the subject is outdated.
- **Undefined or diffuse goal** – lack of a clear and common goal.
- **Market introduction challenges** – companies are often impatient, dismissing the time needed for a new venture to become successful. Also, although the product may be ready, the market may not be.
- **Legal or regulatory restraints** – sometimes it's necessary to first establish precautions and security measures in form of regulations before releasing a product or service.

A way to tackle this problems regard:

- **Supplying sufficient financial resources** – most projects reach a point where they will be forced to face a high cash demand in a situation with very limited possibilities of raising it. The problem lies in the fact that there is a gap between the stages that the public sector focuses their investments on and the earliest point where the private sector wants to invest, since it can turn out to be a high-risk investment for venture capitalists and private sector. The cash demand for commercialization can be greater than the cash demand for the technology development or basic research.
- **More interaction among stakeholders** – strive towards interaction that creates normative interests between academia, state, and industry to facilitate university spin-offs and provides an innovative environment.
- **Adequate information about funding programs** – there is a lack of procedures to allow the private sector into the public-sector programmes. Allowing the private sector earlier access, not to the funding, but to the information about the programmes could help narrow this valley.
- **Incremental approach to innovation** – incremental approach to R&D implies that investors would provide funding based in incremental progress, over for instance predetermined milestones.
- **Co-investing and partnerships** – a co-investment partnership could provide several advantages, additional capabilities, resources or network.
- **Secure entrepreneurial abilities** – look for individuals with entrepreneurial abilities and attitudes
- **Involve costumers early** – engaging the customer into the development process could encourage the project on developing a product with a better focus on customer needs, which improves the project's credibility in a way that can increase investments.

5. European Funding Programs

In order for RADICLE to overcome the *"Valley of Death"* is essential to ensure proper funding to vanquish the technical limitations and create a wide dissemination program.

Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020) and employs different forms of funding: grants, prizes, procurement and financial instruments. There are different types of actions, some of them targeted for researchers, research organisations, public sector or funding bodies, etc.

In this report only three European funding programmes will be presented, since only those apply to the RADICLE project. As a rule, under Horizon 2020, there is only one funding rate per project whatever the type of activities and participants.

5.1. Fast Track to Innovation

5.1.1. Summary

The Fast Track to Innovation (FTI) is an innovation support programme endorsing close-to-the-market innovation activities open to industry-driven consortia and all type of participants. It was launched on 27th October 2017 as part of the Horizon 2020 Work Programme 2018-2020 and will accept calls until 27th October 2020.

This programme aims to reduce time from the conception of an idea to final commercial solution, attract inexperienced applicants to EU research and innovation funding and attract private sector investment in R&I.

More information on this programme is available at https://ec.europa.eu/easme/en/eic-fast-track-innovation-fti-0.

5.1.2. Proposition & Funding

This program is aimed at relatively mature new technologies, concepts, processes and business models which lack final incentive to create a new market and reach a wider audience. So, actions are encouraged to be interdisciplinary, cutting across different sectors and technologies. Also, impacts on sustainability or climate change must be highlighted.

The consortium should ensure that the technology is at least Technology Readiness Level (TRL) 6. As the timeline to initial market take-up should be no more than 3 years from the start of the action, although it can be prolonged depending on the innovation field or industry sector.

When submitting the proposal, it should be explicit:

- The desired result as well as key performance pointers and success criteria;
- Draw and present a business plan describing the market potential, business opportunities for participants, measures to enhance the probability of eventual commercial take-up, and a credible commercialisation strategy outlining future work
- Ensure IP protection and ownership and consider a possible commercial exploitation
- Specify the expected impact in quantitative and qualitative terms, with factors such as time sensitivity and international competitiveness according to the technology field, innovation area and industry sectors concerned

It should be ensured:

- the participation of 3 to a maximum of 5 different legal entities, independent of each other, in a consortium.
- Allocation of 60% of the overall budget to the industry consortium partners' (or a minimum of 2 out of 3 or 4, or 3 out of 5 industry partners of the consortium)
- All members must be established in an EU Member State or countries associated to Horizon 2020

The maximum EU contribution per action is €3 million (funding rate: 70% for profit entities, 100% for non-profit entities).

5.1.3. Evaluation Criteria

Proposal evaluation is made by independent experts who score 3 different criteria, from 0 to 5:

- Impact (50% Weighting – threshold 4)
- Excellence (25% Weighting – threshold 4)
- Quality and efficiency of implementation (25% Weighting – threshold 3)

Total threshold criteria sum must be 13.

Fast development, commercial take-up and/or wide deployment of innovative solutions, time to initial market take-up, leveraging of private investment in research and/or innovation, bring important progress to or revolutionise an existing industrial sector, business practice and/or societal challenge and work plan is coherent and effective, are some points which are appraised.

5.2. SME Instrument

The SME Instrument is another program managed by the EASME – Executive Agency for SMEs, which aims to support small and medium-sized EU-based enterprises to develop innovation projects through EU funding. The SME Instrument desires to boost fast company growth and marketing-creating innovation through staged funding and ramped up business acceleration services.

More information on this programme is available at https://ec.europa.eu/easme/en/section/sme-instrument/eic-sme-instrument-funding.

5.2.1. Summary

SME Instrument offers Europe's entrepreneurs the chance to step forward and request funding for breakthrough ideas with the potential to create entirely new markets or revolutionise existing ones. It was launched on 27th October 2017 as part of the Horizon 2020 Work Programme 2018-2020 and will accept calls until 4th November 2020 (for Phase 1).

This programme supports close-to-market activities, with the aim to give a strong boost to breakthrough innovation with a market-creating potential. The SME Instrument is for businesses that come under the definition of "small and medium-sized enterprises" (SMEs). To count as an SME, the organisation must be engaged in an economic activity, have fewer than 250 employees and an annual turnover of no more than € 50 million and/or a balance sheet of no more than € 43 million. Other partners, such as research providers or larger companies, can be involved as associates ("third parties"), but are not eligible for funding.

5.2.2. Proposition & Funding

The SME Instrument provides full-cycle business innovation support. It has three phases, including a coaching and mentoring service. There are no set topics - innovative companies across the board are welcome to submit their bright ideas. Companies are recommended to apply for Phase 1 first, but may also apply directly for Phase 2 depending on the maturity of their project:

- Feasibility study – Phase I
- From concept to market – Phase II
- Business acceleration services and coaching – Phase III

In **Phase I** it's explored and assessed the technical feasibility and commercial potential of an idea that a company wants to exploit and commercialize. Activities like risk assessment, design or market studies as well as intellectual property exploration are funded. Phase I it's funded with a lumpsum of €50,000 and should usually last 6 months. By the end, there should be a feasibility study (technical and commercial), along with a business plan. If the conclusion of the study states that the project has potential to be developed to the level of investment readiness/market maturity, the SME can apply for Phase II.

Phase II supports the development of the business concept into a market-ready product, service or process aligned with the company's growth strategy. Activities such as trials, prototyping, validation, demonstration and testing in real-world conditions, and market replication are done through this phase. Grant funding is provided (funding rate 70%) between €0.5 million and €2.5 million. A higher or lower amount can be requested if properly justified when applying. This phase should last between 1 and 2 years but can be longer in exceptional and well-justified cases.

Finally, **Phase III** takes advantage of EU support via a range of business support services offered on the EIC Community Platform. This support takes the form of training, links to investors, partnering and networking with other EIC SME clients and larger firms and services to help you access international markets. It desires to provide access to new markets or costumers and link with investors. Phase III does not provide direct funding. By the end of phase 3, one or several innovations (product, process, service etc.) should have been placed on the market, thus boosting the business competitiveness and growth.

5.2.3. Evaluation Criteria

Proposal evaluation is made by independent experts who score 3 different criteria, from 0 to 5:

- Impact (50% Weighting – threshold 4 (Phase II))
- Excellence (25% Weighting – threshold 3 (Phase II))
- Quality and efficiency of implementation (25% Weighting – threshold 3 (Phase II)))

During **Phase I** the threshold for individual criteria is 4 and for the sum is 13. Regarding **Phase II**, the threshold for the total sum of criteria is 12.

Convincing specification of substantial demand (including willingness to pay) for the innovation, good understanding of need for a realistic and relevant analysis of market conditions (**Phase I** only), realistic and relevant analysis of market conditions and growth-rate, highly innovative solution that goes beyond the state of the art in comparison with existing or competing solutions, including on the basis of costs, ease of use and other relevant features, technical/business experience of the team, are some points which are appraised.

5.3. Eurostars (EUREKA Association)

The Eurostars Programme is a European Joint Programme dedicated to the R&D performing SMEs. Eurostars' programme between EUREKA and the European Commission is co-funded from the national budgets of 36 Eurostars Participating States and Partner Countries and by the European Union through Horizon 2020. It aims to stimulate SMEs to lead international collaborative research and innovation projects by easing access to support and funding.

5.3.1. Summary

Eurostars is a funding programme supporting SMEs and partners which subsidies innovative projects that will be rapidly commercialised. Every project should have the market and commercialisation in mind.

The development of these new products, processes or services is made through support and access to national funding. Eurostars is backed by €861 million of national funding from its countries and it's further supported by €287 million of EU funds, for a total of €1.14 billion.

SMEs must be the main project partner in Eurostars, while the other partners can be Universities, Research centres or other organisations. In a project consortium there must be at least 2 different partners (independent legal entities) from 2 different Eurostars countries.

5.3.2. Proposition & Funding

To apply to Eurostars funding programme, the project must comply with the following rules:

- The project leader must be a R&D-performing SME.
- The project leader is from a Eurostars country.
- The project must contain at least two legal entities that are independent from one another.
- The consortium is a partnership of two different Eurostars countries, in which one of the countries is a EUREKA member country.
- The budget (excluding subcontracting) of the R&D-performing SME(s) located in Eurostars Partner Country(ies) is equal to at least 50% of the total project budget.
- No single participant is responsible for more than 75% of the project budget.
- The participant(s) from a given country may not be responsible for more than 75% of the total project budget.
- The project duration must be below 36 months.
- Market introduction is within 24 months of the project's deadline.
- The project meets the EUREKA criteria and must have a civilian purpose.
- Each of the participating organisations in the consortium is a legal entity in the host country.

- None of the participating organisations have convictions for fraudulent behaviour, other financial irregularities or illegal business practices.
- None of the participating organisations have been declared bankrupt or are in the process of being declared bankrupt.

5.3.3. Evaluation Criteria

Eurostars uses a two-step expert evaluation process: Evaluation by three remote experts and assessment by an independent evaluation panel.

Experts are looking for a project with the most promising application of technology to produce marketable products, processes and services. Although the degree of innovation and technical merits are valued, the applied marketing strategy of the project is also taken into high account.
The three main criteria and sub criteria assessed are:

- **Quality and efficiency of the implementation** – Quality of the consortium, Realistic and clearly defined project management & planning and the added value of the co-operation.
- **Impact** - Market and Commercialisation – Market size, Market access and risk, Competitive advantage, Clear and realistic commercialization plans.
- **Excellence** - Innovation and R&D – Degree of innovation, Level of technical challenge, Techincal achievability & risk and if the project will lead to the creation of new knowledge.

5.4. Other Funding Programmes

Besides the most relevant funding programmes managed at the European level presented previously, other public funding initiative exist, directed at SMEs that are looking to ramp up innovation and deliver new products or services to market.

Next are listed other examples of other types of available funding mechanisms:

- COSME Programme
    - Guarantees to small and medium-sized enterprises for loans mainly up to EUR 150 000.
    - Equity (growth and expansion stage).
- InnovFin Programme (Horizon 2020)
    - Loans and guarantees to innovative businesses.
    - Financing of research & development projects.
    - Equity (early and start-up phase).
- Creative Europe
    - Loans to small and medium-sized enterprises in the cultural and creative sectors.
- Programme for Employment and Social Innovation (EaSI)
    - Microloans up to EUR 25 000 to micro-enterprises and to vulnerable persons who wish to set up or develop a micro-company.
    - Investments up to EUR 500 000 to social enterprises.
- European Structural and Investment Funds (ESI funds)
    - Loans, guarantees, equity financing or business grants.
    - Support is provided from multi-annual programmes co-financed by the EU.
- European Investment Bank and European Investment Fund
    - Business loans, microfinance, guarantees and venture capital.

Adding to the above, there are also available a number of funding mechanisms both at the Regional and National levels. However, these frameworks are not presented in this report, since they are usually not so much targeted at establishing such a wider cooperation or specifically to foster SMEs development.

A summary of the three funding mechanisms considered relevant for RADICLE to overcome the valley of death are included in Table 1.

Table 1 – Funding programs parameters

Type	Code	Conditions for Participation	Financial rate	Duration	EC Contribution	Objective
Fast Track to Innovation	FTI	From 3 to a maximum of 5 independent legal entities	70% - profit entities 100% - non-profit entities	≤ 3 years	≤ €3 million	Accelerate the market uptake of ground-breaking innovations by providing funding in an open, accessible scheme that nurtures ideas from consortia of innovators of all types and sizes from across Europe
SME Instrument	SME	≥ 1 for-profit SME from EU Member State or Horizon 2020 associated country	Phase I – lump sum of €50 K/project (6 months) Phase II – from €500,000 to €2,5 million / project (1 to 2 years) Phase III – No funding			Support small and medium-sized enterprises to develop and bring to market new products, services and business models that could drive economic growth
Eurostars (EUREKA Association)	-	≥2 entities (project leader R&D SME from Eurostar country)	Managed by funding body & according to national funding rules and procedures	≤ 3 years (market introduction ≤ 2 years)	Managed by funding body & according to national funding rules and procedures	Eurostars is a funding programme supporting SMEs and partners which subsidies innovative projects that will be rapidly commercialised

6. Future funding requirements for RADICLE

The RADICLE project addressed the development of a welding control system, designed for the laser welding process where solid-state (1µm wavelength) laser sources are applied. RADICLE consists of four core building blocks: a process tool, a sensor array (integrated into the process tool), a sensor control box, and a system control box (containing proprietary control algorithms). Secondly, RADICLE relies on the understanding of the relationship between input parameters, process emissions and weld 'attributes' (which may or may not be considered defects depending on occurrence frequency, scale, etc.).

The RADICLE concept was developed to create an adaptive process control system to link and integrate a range of pre-process, in-process and post-process sensors using a high-speed algorithm. Using a database of welding parameters, RADICLE addresses the selection of recommended parameters for welding of a material (and thickness). By monitoring the welding process (via the sensor arrays embedded in the process tool), the RADICLE system monitors key welding parameters to allow for a stable welding process and a finished part of appropriate integrity.

Although RADICLE was originally conceived to assist the laser welding of high-value, safety-critical fabrications such as those typically associated with aerospace, space and power generation sectors (sectors where laser welding has seen limited deployment), it has evolved and includes valuation/development appropriate to automotive and general engineering sectors - opening up the RADICLE system to more diverse and larger potential markets.

Looking at its integration: RADICLE was developed as a stand-alone control system and can be integrated into new or existing laser processing facilities (subject to hardware requirements, communication protocols, etc.). The algorithms within the system necessitate the use of a specific process tool and sensor array.

The RADICLE project was trans-disciplinary, as it combined expertise in welding, materials, optical measurement, lasers and software/ICT. It was also cross-sectorial since it worked to deliver solutions to the power, automotive and aerospace sectors. Finally, as the project brought

together academic and industrial partners from across Europe together, this benefits the project as a whole.

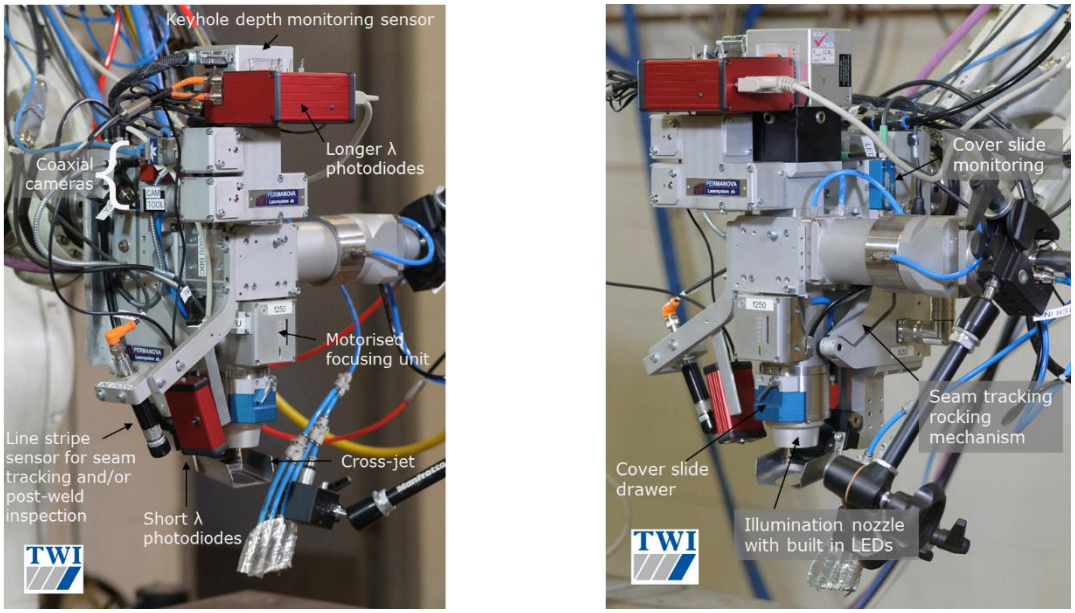

Figure 2 - Overview of the RADICLE system

The overall performance of the RADICLE system is described thoroughly in Deliverable 6.5. In this report is explained that the RADICLE process monitoring systems, in line with other highly capable process monitoring systems, also employs a multi-sensor approach. Like other multisensory process monitoring systems, RADICLE is a combination of separate modules that enable the end-user to build a process monitoring system of tailored functionality. In the case of RADICLE however, there is not yet one common software system that ties the individual modules together. This has been identified as the main shortcoming of the developed results and the one that will require funding to allow for its further development. However, the RADICLE system is capable of process monitoring and alerting the operator to welds that may potentially contain defects (by being made using inappropriate parameters).

RADICLE cannot yet control parameters beyond the adaption of the seam path to compensate for minor variations in desired seam path. Key weld defects, such as porosity requires measurement and analysis within timeframes that are currently beyond the latency experienced in existing data acquisition and processing machines. Furthermore, hardware latency further extends any potential system response time. In conclusion, the RADICLE system will indeed require further R&D to be put into place to allow for the current project results to be brought to TRL 9.