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REPORT ON ACCELERATOR MARKET STUDY

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1. INTRODUCTION

1.1. BACKGROUND

Innovation is a central theme to recent European Commission funding initiatives and forms a major strand of the AMICI programme. There is agreement at all levels across the partnership, from the European Commission, through National Laboratories and Institutes, to Industry that there lies considerable untapped potential in particle accelerator technology to foster greater innovation and increase technological, societal and economic impact. The commonly expressed perception is that partnerships in locations such as the US and Asia are more effective in translating scientific innovation into technological, societal and economic impact than across Europe.

The AMICI project has the challenging task of co-coordinating the particle accelerator development, test and validation infrastructure of the National Laboratories in order to strengthen the capabilities of European Industry, enabling it to compete on the global market, not only as qualified suppliers of components for particle accelerators, but also in the development of innovative applications in advanced sectors such as healthcare and security.

To this end AMICI will develop a robust, industry-relevant innovation ecosystem centred on the effective coordination and exploitation of particle accelerator Technology Infrastructure.

Of note, the specialised National Laboratory – Industry partnerships required to facilitate industrialisation of components specifically for the needs of future European Research Infrastructures (RIs) are covered separately in AMICI Workpackage 5 – 'Industrialisation'.

1.2. TERMINOLOGY

A topic throughout the AMICI programme, and highlighted in the collection of data for this task, has been the significance of language and clear definitions. There is no ideal solution that will satisfy all parties across academia, industry and governments, but it is helpful to clearly define some of the language used in this report at the outset, rather than in a separate glossary.

Technical Platforms (TP) are installations which can be used to develop, fabricate, test and/or measure components for accelerators. A cluster of Technical Platforms at a location is termed a **Technological Facility** (TF). A network or conglomeration of complementary facilities forms the overall **Technology Infrastructure** (TI) that supports the development of Accelerator based research facilities, classed as **Research Infrastructures** (RI).

This report uses the term **National Laboratories** to describe large regional centres of expertise in particle accelerators that generally own or host one or several TFs, be they laboratories, institutes or research centres. It is not ideal, but alternative terms such as Regional Institutes cause confusion with Research Infrastructure and are therefore avoided. **AMICI Partners** is effectively a sub-set of this and is used to describe those National Laboratories and institutions directly signed as beneficiaries of the AMICI programme.

The term **Industry** is a broad brush term used to describe commercial interests. **Supply Chain** refers to companies that provide products, processes or services to the particle accelerator sector, and covers all sizes of businesses with widely differing dependence on the national-scale accelerator RIs. **Lateral Markets** is used to encapsulate commercial companies involved in accelerator-related societal application markets, for example radiotherapy devices, and these too vary in size and role from system integrators through to businesses with significant internal technology R&D programmes.

The term innovation means different things to different people. In particular it is often taken to mean the invention of something new, radical or disruptive. However, for this report we will adopt the term innovation to mean the broader development and translation of scientific knowledge or technology to a product, process or service that can be utilised by academia, industry and society. This may include steps which all parties consider inventive, but it is not a requirement. It also encompasses the development of ideas and technology that some collaborative parties may consider as routine, but that yield positive benefits when translated to new products, processes and services in a different application. For the purposes of this report, we have sub-divided innovation into four strands to differentiate the overall direction of technology or knowledge transfer:

- Co-innovation: This is taken to mean co-development of products, processes or services by the National Laboratories and Industry to meet shared technology development requirements.
- Outward Innovation: The translation of products/ processes/ services developed within the National Laboratories out to Industry for the purposes of industrialisation/ commercialisation.
- Inward Innovation: The opposite process, whereby products/ processes/services developed by Industry are adopted by National Laboratories to support the development of Research Infrastructures.
- Unrelated Innovation: The use of the Technology Infrastructure by Industry to develop products/ processes/ services for societal or economic benefit, which cannot be readily applied to the development of future Research Infrastructures (i.e. it covers the use of TIs by Industry for its own independent purposes).

Whilst this last strand of innovation may not be central to delivering key objectives for future Research Infrastructures, but it is nonetheless included in this report as it has the potential to play a role in some models of Technology Infrastructure sustainability.

1.3. INNOVATION AND THE SUPPLY CHAIN

At its most simplistic, there is a positive relationship between investment in large-scale science and the benefit to society through the translation and industrialisation of innovative technologies into applications, products and services, in addition to the progress of scientific understanding.

However, this over simplistic model does not adequately capture the complexities associated with national and international-scale Research Infrastructures such as particle accelerators. These machines are some of the largest, most complex and technologically advanced machines on Earth. They are at the cutting-edge of advanced technology development and require state of the art test and validation infrastructure to underpin their construction and operation. At face value, this is an environment ideally suited to innovation, where experience gained through development of such ‘flagship’ projects can be readily translated to more ‘practical’ applications.

In reality, the relationship between the RIs and its Supply Chain is many–tiered and complex. Development timescales can be extremely lengthy, encompassing very high levels of technical risk. The subsequent market potential for any technical solutions may be very limited or highly unpredictable, with many research projects undergoing years of preparatory development before failing to secure the large capital funding required for construction. As a commercial sales opportunity, the RI market can best be described as unpredictable and high risk. Similarly, the routes to societal markets for some of the innovation stimulated by the RIs are not necessarily straightforward. There are many examples of elegant and innovative high-end technology in search of true 'real world' applications. Nonetheless, the success of the current RIs is testament to the determination and capabilities of their Supply Chain, and many companies are clearly able to thrive in such a challenging market.

It is also evident that whilst both academia and Industry can envisage benefits from closer cooperation on shared technology challenges, there is rarely enough pull from either side for these activities to be self-starting or self-sustaining. There are a few notable exceptions where co-innovation has been the natural route to progress (e.g. European XFEL cryomodules) but the underlying theme is that such synergies have so far been underexploited.

European scientific research represents a very large investment of taxpayers' money. In addition to outstanding scientific outcomes, such investments are intended to generate significant economic outputs, enhance the skills base and enable European Industry to compete globally. The European Commission has supported a number of activities to assess and improve the translation of scientific investment (e.g. TIARA, EuCARD). For the Innovation workpackage of AMICI (WP4), the overarching driver is to assess and develop strategies and tools to enhance innovation with direct relevance to the technology development, test and validation Technology Infrastructure which underpin the accelerator developments enabled by the National Laboratories and Institutes.

2. METHODOLOGY

The decision was taken at the outset that the AMICI Workpackage 4 – 'Innovation' should be guided by Industry's needs where possible. This was achieved through a series of workshops, Industry engagements and conversations, but principally through a survey across Europe. The input of the Supply Chain and Lateral Market suppliers/integrators were canvassed. Based on previous experience and survey return metrics, the work was subcontracted to a specialist in survey collection across high-technology sectors. The process was initiated in late 2017, via a UK Government procurement exercise. An open tender was issued and Pan-European AMICI Partners invited to share the tender details with international suppliers. The contract was awarded to Qi3 Limited in March 2018. A kick-off meeting was held in April 2018 and data collection was taken through 2018. AMICI Partners and Industrial Liaison Officers were consulted regarding suitable contacts and to account for regional variations. Data was collected via three mechanisms:

- Desk Research – evaluation of current market conditions.
- 1-to-1 meetings (either face-to-face, or via pre-arranged telephone interviews) – qualitative deep dive to understand key market drivers / dynamics.
- Web survey – semi-quantitative broad survey to understand issues and variations across the market.

Following useful input from the technical teams at CERN regarding the National Laboratory perspective on the current state of innovation, the survey was expanded to cover input from the AMICI Partners. A total of eighteen 1-to-1 interviews were conducted.

A web survey of the Supply Chain was carried out to broaden the findings on Industry needs. The web survey profile was:

– Survey Population (no of companies mailed)	133
– Sample size (no of respondents)	37
– Confidence level	95%
– Margin of error	+/- 7%

The survey structure and questions were designed using the feedback from the 1-to-1 interviews in order to focus them on key issues. While quantitative in its own right, the survey information was designed to complement the findings of the telephone interviews, building a broader and deeper picture of Supply Chain companies' strengths, weaknesses and needs within the particle accelerator ecosystem.

All data was anonymised in order to preserve commercial sensitivities, and all collection methods and procedures were assessed to ensure full compliance with GPDR data collection policies.

3. EUROPEAN ACCELERATOR TECHNOLOGY ECOSYSTEM – CURRENT STATUS

3.1. AMICI PARTNERS

- CERN (Geneva)
- CEA (Paris)
- CNRS (Paris)
- DESY (Hamburg)
- IFJ (Krakow)
- INFN (L'Aquila)
- KIT (Karlsruhe)
- PSI (Villigen)
- STFC (Daresbury)
- Uppsala Universitet (Uppsala)

Figure 1: European Accelerator Technology Ecosystem, showing AMICI beneficiaries (diamonds) and other accelerator-related institutes (circles)[1]

3.2. LATERAL MARKETS

Lateral Markets covers companies that directly use accelerator-related systems as part of their products/processes/services. Examples include healthcare (e.g. radiotherapy, radioisotope

[1] http://www-elsa.physik.uni-bonn.de/accelerator_list.html

production), industrial processing (e.g. electron beam welding, EBM furnaces) and security (e.g. cargo scanning, threat detection).

Commercial markets using accelerator technologies tend to be global, niche and dominated by a small number of companies. The largest concentration of companies is in the USA, followed by Europe and East Asia.

3.3. EUROPEAN PARTICLE ACCELERATOR TECHNOLOGY SUPPLY COMPANIES

Figure 2: Number of identified Supply Chain suppliers per country

The European Supply Chain of companies providing systems and sub-systems to the particle accelerator Technology Infrastructure is highly fragmented, by technology, system complexity, location, company size, and other criteria.

At one end of the "market specialism" spectrum, there is a cohort of companies that supply systems and components especially developed for particle accelerators, while at the other end, there are companies supplying small quantities of their standard products for commoditised applications. Between these two ends of the Supply Chain spectrum, there are a range of companies supplying systems and components with various degrees of specialisation for the sector.

The analysis has focused on identifying companies which either focus on the Research Infrastructure sector, or which develop and customise their products to meet the sector's needs.

Companies for which the Research Infrastructure sector is a very small part of their business and which sell standard products for commoditised applications have not been included. The list of companies serving the particle accelerator market has been extensively researched but, due to the high levels of fragmentation, is not totally complete or comprehensive. However, the analysis gives a good overview of the sector structure.

4. MAPPING OF KEY TECHNOLOGY AREAS

Key Technology Areas (KTAs) are technical developments that are seen by the AMICI Partners as critical gaps in the technology development path for future RIs. Failure to substantively address the KTAs will lead to excessive costs, delays or failure to complete future RI developments, negatively impacting on the availability of advanced research facilities across Europe, and lessening their scientific, societal and economic impacts.

AMICI Workpackage 2 - 'Strategy' has developed a series of KTAs. Preliminary discussions have highlighted the following areas:

Table 1: AMICI Key Technology Areas

AMICI Key Technology Areas	AMICI Illustrative Examples
Particle Sources	Ions sources, ECR, EBIS, positron sources, polarized beams
Magnets and Vacuum Systems	Permanent & iron magnets for 4th generation synchrotron, FFAG, ion separators, small vacuum chambers
High Field SC Magnets	High Tc and Nb3Sn conductors, HFM technologies, cost reduction
Normal Conducting Radio Frequency (RF) Structures	RFQ & pill-box structures, high precision fabrication, RF breakdown conditioning
Superconducting RF Cavities and cryomodules	High Q_0, high gradient, HTC materials, fabrication methods, SRF guns, robotics, cost reduction
RF Power Sources	High efficiency Klystrons, continuous wave RF sources, solid state amplifiers
Cryogenics	High efficiency and , cryogen free cooling, cryo-safety
Beam Instrumentation	Non-invasive and RF diagnostics, beam control systems

Table 1 contains the requirement to develop both technology 'products' and also ways in which technology is achieved (i.e. processes), such as optimising RF cavity conditioning. Whilst these requirements can be viewed purely as technology development (R&D) type activities, it is clear that there are substantial opportunities for innovation as part of these development programmes.

By their nature, these KTAs are challenging and it is accepted that Industry can and should play a critical role in their development, offering opportunities for new thinking, co-innovation and industrialisation expertise. Industry also has technology challenges which it needs to urgently address in order to meet future customer demands, whether they are in accelerator-related sectors or elsewhere. Clearly, where the KTA demands of the RIs and Industry overlap, there is fertile ground for partnership, co-innovation and complementary funding to develop solutions for all parties. Linking the resource pools of the National Laboratories and Industry to common goals will help expedite KTA solutions, allow efficient R&D, test and validation programmes and help address wider societal and economic challenges.

4.1. KTA MAPPING – RESULTS FROM INTERVIEWS

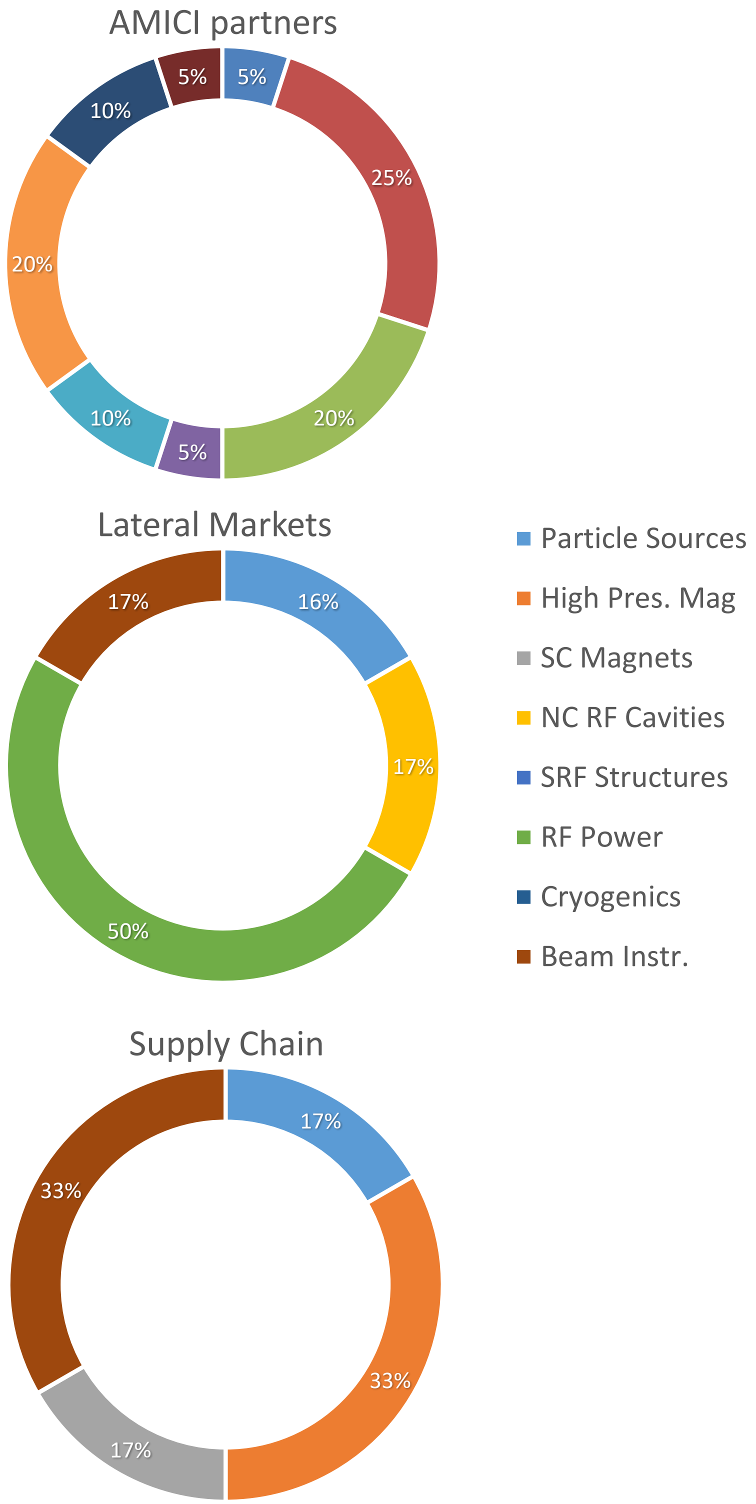

Figure 3: Distribution of positive responses received in Key Technology Areas

Figure 3 shows the breakdown of specific KTA responses received from the 1-to-1 interviews as a percentage of the total responses. The data from the National Laboratories shows registered interest in all KTA areas, with particularly strong interest in magnetic systems (both normal and superconducting) and RF power system development. This emphasis on certain KTAs will be influenced by the shorter-term requirements of the RIs currently in development, and is also naturally reflected in the make-up of Technical Platforms currently offered under the AMICI project.

The data from the Lateral Markets and Supply Chain 1-to-1s reflect the interests of those companies that responded to requests to participate in detailed interviews but immediately highlights some broad KTA areas that are of immediate development concern such as beam instrumentation, magnets and RF power requirements.

This feedback demonstrates that there is overlap in the technical requirements of both the AMICI Partners and Industry irrespective of the final specification and application. The TI is ideally placed to form the middle ground between Industry and the RIs, since development, test and validation of KTA products and processes is of critical value to both parties.

4.2. KTA MAPPING - RESULTS FROM WEB SURVEY

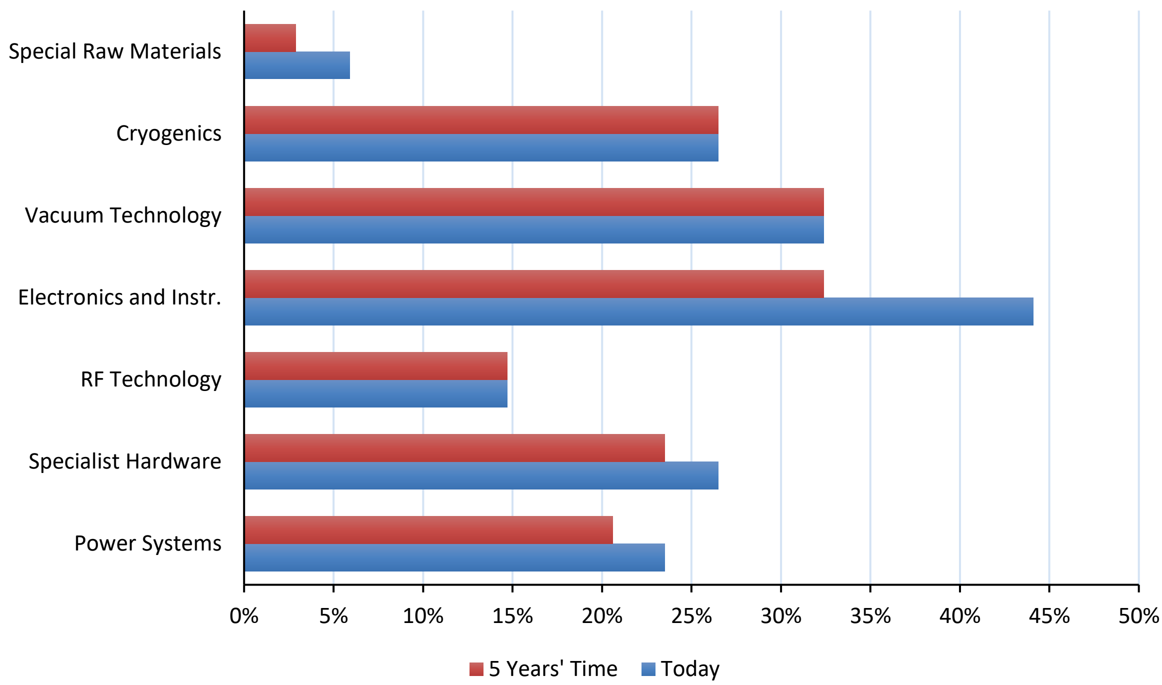

Figure 4: Supply Chain – “Which technologies do you supply to particle accelerator research institutes?”

Due to the timescales for data collection, the web-based survey made use of a list of Research Infrastructure KTAs as highlighted at the AMICI Industry meeting in Padova. It should be noted that these KTAs have subsequently been further refined by AMICI workpackage 2 – ‘Strategy’ (as shown in table 1). From figure 4 it is clear that the European

Supply Chain covers a very broad range of technology sectors and specialisms, showing considerable overlap with the AMICI KTA requirements. Some technology areas are covered by a comprehensive number of vendors, although several areas have a more restricted number, with critical restrictions in superconducting RF cavities and high precision permanent magnets.

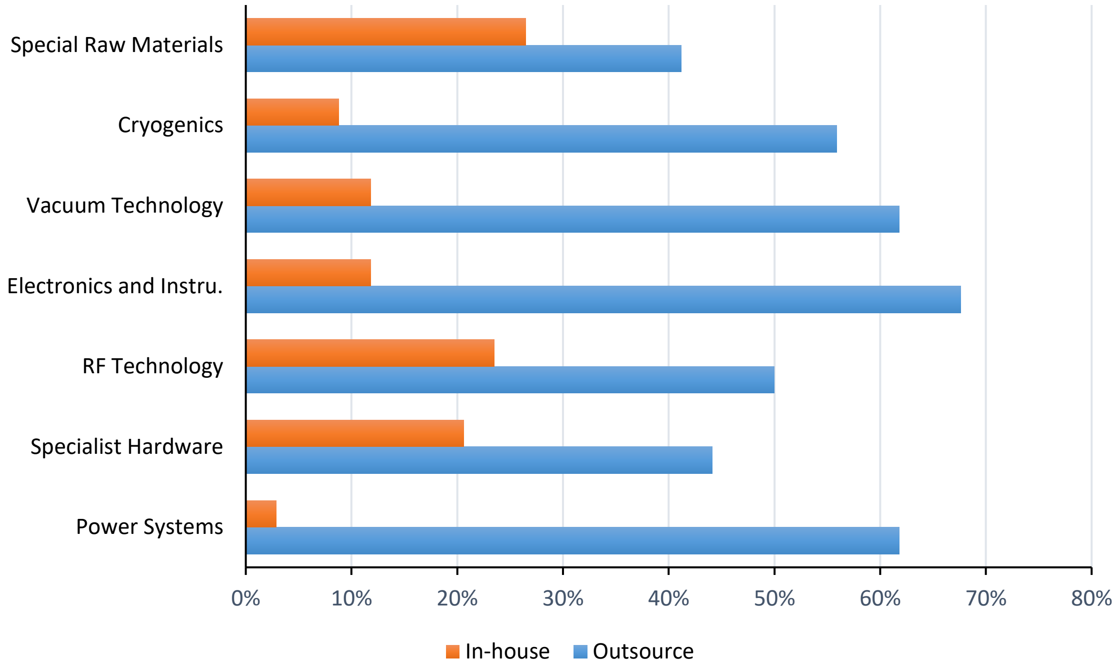

Figure 5: Supply Chain – "Which technologies should the particle accelerator research institutes outsource to Industry, and which should they keep in-house?"

The responses from the web survey illustrated in figure 5 support the prevalence of a generalised subcontract model whereby inventive steps and fundamental research are primarily undertaken by the National Laboratories, who may then work with Industry to prototype and develop the product or process, before transferring the project to Industry for production in volume.

The KTAs during the AMICI process were principally informed by the requirements of the National Laboratories. An initial step to developing a more effective European innovation ecosystem to support accelerator-related developments would be the integration of broader Industry-driven KTA requirements into the overarching development goals. Industry is primarily driven by economic considerations and will preferentially participate in collaborative R&D where it sees a viable, definable market, either with the RIs or application sectors.

5. SOCIETAL APPLICATIONS MAPPING

There is considerable interest in the broader societal applications of accelerators and related technologies. From the perspective of Industry, societal applications present a possibility to diversify markets, some of which will support considerable volumes and margins, helping to underpin a well-resourced and financially more stable Supply Chain. In particular, for those vendors with considerable exposure to the research accelerator market, additional applications will allow businesses to more readily deal with the cyclic and irregular nature of the scientific research market. For the National Laboratories broader application areas have sometimes been seen as a worthy endeavour but also a potential drain on resources from core tasks. More recently, funding concerns for some National Laboratories have seen an increase in interest, with regional and national funding initiatives and core funding increasingly being driven by a broader range of societal and economic metrics, in addition to scientific output.

In 2017, EuCARD-2 published a summary report 'Applications of Particle Accelerators in Europe'[2], a comprehensive overview of the current-state-of-play in accelerator usage across both fundamental research areas and societal applications. To avoid duplication, this workpackage review aligns itself with the topics and R&D development priorities within this EuCARD-2 review.

Here, we map the responses received from the 1-to-1 interviews and the web-based survey to understand the current level of engagement with the following market sectors:

- Health
- Industrial Accelerators
- Energy
- Security

It should be noted that there is anecdotal evidence that some parties are often more reticent to discuss applications surrounding either security or nuclear applications. The following analysis is sensitive to this caveat.

[2] https://edms.cern.ch/document/1325147/2

5.1. ACCELERATORS IN HEALTHCARE APPLICATIONS

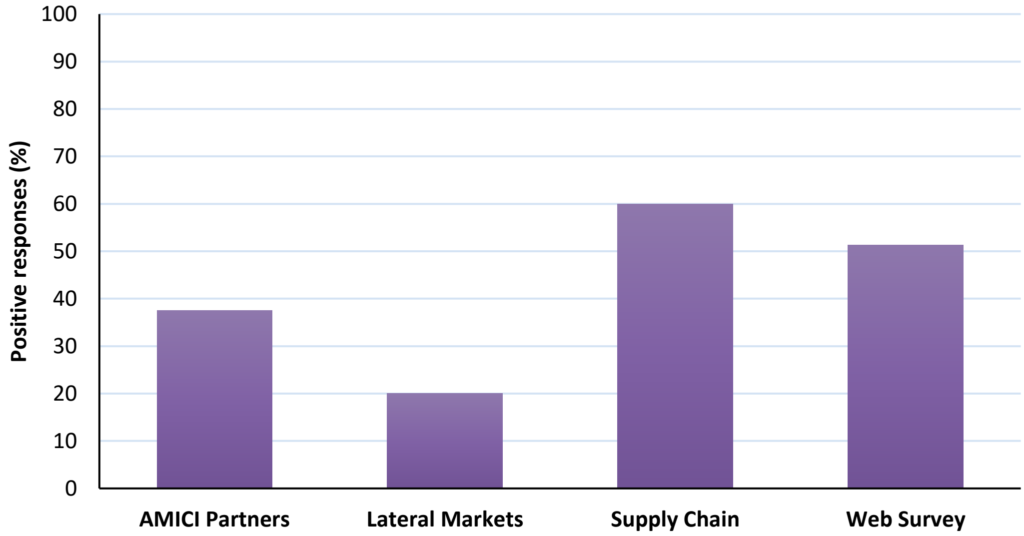

Figure 6: Current activity in healthcare applications, expressed as percentage of positive responses against total responses, for each ecosystem sub-category

5.1.1. Priority Areas for R&D in Radiotherapy and Radionuclide Production

- Cost-reduction methods for X-ray therapy machines.
- The development of new combined imaging methods and fast, lightly intercepting instrumentation for accurate delivery.
- The development of lower-cost particle sources from 250 to 350 MeV, including high-field cyclotrons, synchrocyclotrons, very compact synchrotrons, high gradient linacs and novel architectures such as laser-based acceleration with the appropriate beam properties.
- The development of solutions to allow depth-dose imaging, including improved diagnostic methods such as prompt-gamma imaging and proton tomography, and the development of particle sources supporting such imaging.
- The development of lower-cost, combined treatment machines capable of delivering the appropriate ion combinations resulting from radiobiological studies which could include both carbon ions and helium ions.
- The development of solutions for secondary-particle imaging for ions, particularly 11C/PET.
- The design and implementation of improved lighter gantry systems for proton and ion delivery, utilising superconducting magnets and/or FFAG designs.
- The demonstration of high-energy electron therapy and the design of a system to optimally use it.

- The demonstration of high-flux BNCT using improved production targets.
- Providing small, compact machines with low acquisition and operational costs is a challenge for the designers and producers of cyclotrons, FFAGs and linacs.
- Targetry and the target chemistry of novel medical radionuclides (like copper and scandium radionuclides) and/or alternative accelerator-based technology for the established medical radionuclides (99mTc and 68Ga).

The application of cutting edge technologies to healthcare is in the ascendency. Particle accelerators are playing a key role in this revolution, both from the use of light sources as a critical tool for life sciences, biomedical research and drug discovery, and their use in a broadening range of facilities in oncology treatment and radio-isotope production. In addition to enhancements to ‘conventional’ X-ray radiotherapy systems, accelerator solutions are now transitioning proton, ion and potentially very-high energy electron beams, from fundamental research to commercial-grade products. The potential scale of the addressable oncology market (e.g. 15,000+ installed X-ray radiotherapy systems worldwide) means the Supply Chain is highly active in supplying componentry and sub-systems in to the healthcare market.

Healthcare innovation is well supported, both politically and financially, with European, national and regional-level directives and funding initiatives. This is reflected in the survey results across the four sub-category areas which indicate high levels of engagement across the board.

One significant issue with innovating within the healthcare sector is the stringent requirements for appropriate testing and validation and certification of products, which requires both extensive use of test equipment over extended periods and knowledge of international testing protocols. This overlap with the expertise available within the TFs is already being exploited, with significant potential for future interactions. The priority areas for R&D highlighted by EuCARD include accelerator designs, imaging, beam diagnostics and beam transport, underlining the synergy with National Laboratory development aims.

5.2. ACCELERATORS IN INDUSTRIAL APPLICATIONS

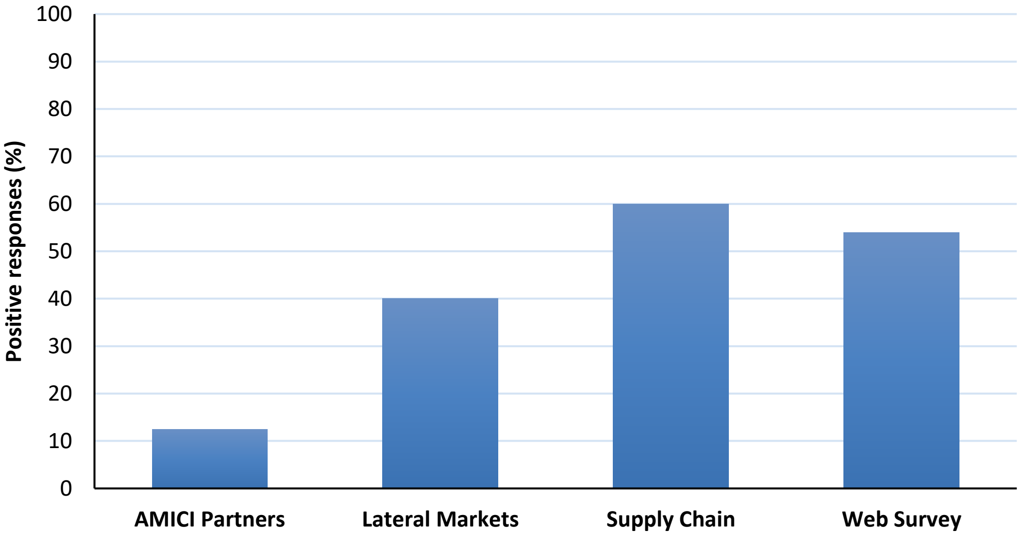

Figure 7: Current activity in industrial applications, expressed as percentage of positive responses against total responses, for each ecosystem sub-category

5.2.1. Priority Areas for R&D Low-energy e-beams, Ion Beams and Ion Implantation

- New or modernised accelerators.
- High-voltage generator concepts for compact modules.
- Insulation materials/technologies for compact accelerator design.
- Well-adapted e-beam sources for applications in 3D-shaped products.
- Concepts for electron exit windows in order to lower the usable energy below 80 keV.
- Enlarged sealed e-beam accelerators with a longer lifetime.
- New surfaces with lower X-ray-reflection to reduce shielding.
- New developments require the industrialisation of new solutions, like superconducting RF cavities and magnets, and other accelerator components such as cathodes, klystrons, advanced material windows, and so on.
- The design of small-footprint, or even portable, accelerators.
- The development of compact and highly efficient detection systems, and the implementation of appropriate data-analysis codes.
- A more 'open source' approach to accelerator design could help make new desktop units suitable for ion-beam applications, lowering overheads and improving reliability.

The application of accelerators to industrial processes is broad and highly prevalent. Accelerators are directly used in numerous manufacturing processes, from shrink wrapping of cable insulation and sterilisation of product packaging, to ion-beam implantation applications in the semiconductor industry. For both the Supply Chain interviews and the web-based survey, this proved the strongest positive response, and in general terms forms a significant element of their business models.

This contrasts with the National Laboratories, which did not respond positively to the potential of development in the industrial applications area, reflected in discussions at AMICI meetings and workshops. There may be some simple explanations for the apparent discrepancy in these responses:

- There are a number of off-the-shelf commercial systems available to address most current application needs in the sphere of industrial processing.
- Industrial application accelerators are generally very low beam energies, often below 1 MeV. The machines operate in different beam energy regimes to fundamental research facilities.
- The focus for industrial applications is often on serviceability, extended duty cycles and affordability.

However, in many cases, similar arguments could be made against machine development in the medical arena, but the National Laboratories appear to have clearer engagement in that application area. With medical applications of accelerators in a positive position within Europe, could a stronger emphasis on accelerator usage within the industrial sector net similar positive expansion?

What is evident is that a high proportion of the RI Supply Chain is also providing componentry and solutions for industrial applications. To establish an integrated ecosystem around accelerator technologies, it will be necessary to address the development, test and validation needs of this significant market sector. Test and validation of suppliers' products by the TIs could lead to more repeatable and better understood beam performance, and therefore higher yields of in-spec products. There are also significant opportunities for outward innovation (e.g. technology solutions, performance modelling) and inward innovation (e.g. industrialisation, fabrication).

Industrial processes are particularly price-sensitive as they often need to preserve margin on the final processed product and guarantee quick return on capital investment against alternative processing technologies. Reducing the risk for Industry to co-develop low cost, compact sources could have high ongoing economic impact.

5.3. ACCELERATORS IN ENERGY APPLICATIONS

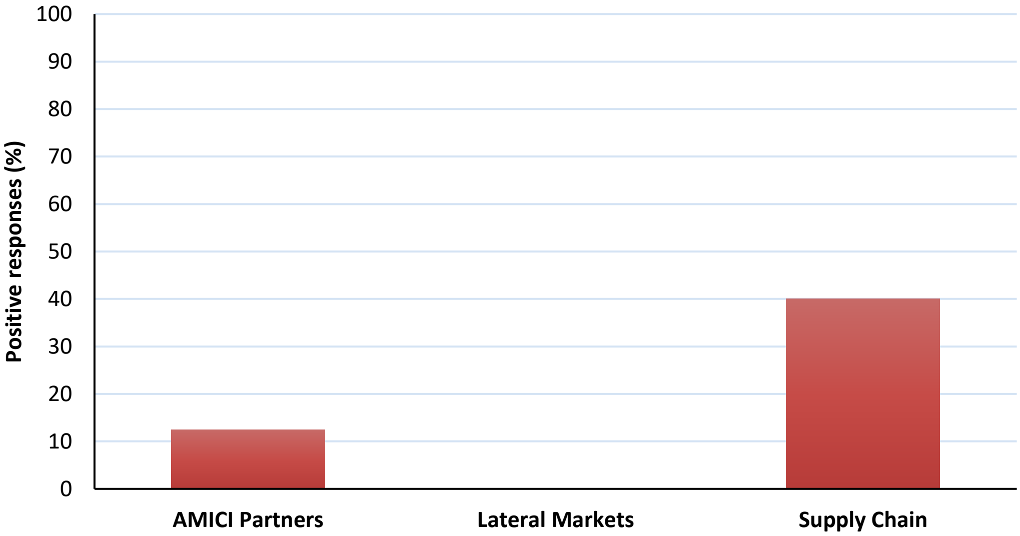

Figure 8: Current activity in energy applications, expressed as percentage of positive responses against total responses, for each ecosystem sub-category

5.3.1. Priority Areas for R&D in Energy

- Development of high-intensity high-reliability proton and deuteron beam injectors.
- Development of superconducting RF-cavity technology in a high-power, high-reliability context.
- Investigation of high-current beam dynamics and beam halos.
- Development of innovative beam instrumentation.
- Modelling of the reliability of particle accelerators.
- Safety studies of high-energy, high-current proton accelerators and their coupling to a spallation target.

It should be noted that ‘energy’ was not highlighted as a specific stand-alone market sector in the web-based questionnaire circulated, hence why that category is omitted from this section. Regarding AMICI Partners, both from the survey data and workshop discussions, energy has not featured as strongly as some other market sectors, although the existing TPs are used for some testing regarding advanced materials and detection capabilities for the nuclear energy market. There is clearly also an overlap with accelerator-driven sources research, but again, this was not highlighted as a priority focus area at this time.

Energy was not covered by any of the Lateral Market contributors. This potentially indicates that within those connected with accelerator systems, the commercial opportunities for system integrators within ADSR (Accelerator-Driven Subcritical Reactor), fusion and waste transmutation is significantly more limited than for material and component suppliers. This analysis is further strengthened by the stronger showing from the Supply Chain that indicates some commercial support for component development activity in this area.

Many of the nations covered within the AMICI partnership have additional national facilities dedicated to energy, fusion and fission research, plus a degree of testing infrastructure associated with these programmes either as separate entities within the country (e.g. Dalton institute, National Nuclear Laboratory) or within broader overarching organisation (e.g. CEA).

With accelerator-driven energy systems, there is significant test capability and innovation potential which could be further exploited.

5.4. ACCELERATORS IN SECURITY APPLICATIONS

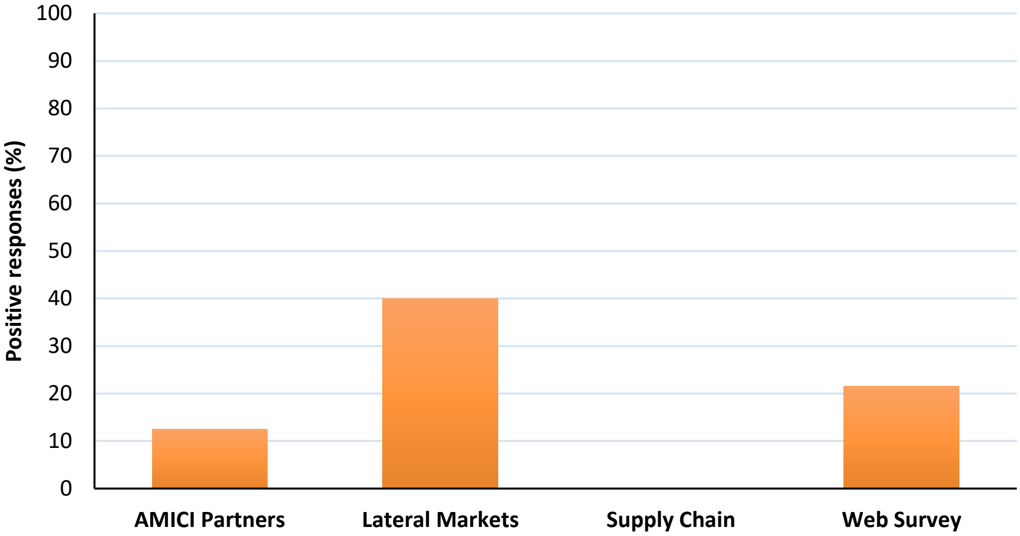

Figure 9: Current activity in security applications, expressed as percentage of positive responses against total responses, for each ecosystem sub-category

5.4.1. Priority Areas for R&D in Security

- Reducing cost and size across all security areas, the common beneficial thrust for all types of accelerator based systems is to drive down the cost, size and weight.
- The development of tuneable narrow-band (MeV) X-ray sources for nuclear resonance fluorescence and/or active fission techniques.
- The development of 3D imaging to allow better recognition of images for operators.
- The development of low-cost and robust short-pulse, high-repetition rate accelerators for time-of-flight backscattering could be useful without degrading image quality.
- Studies into the feasibility of developing muon accelerators to provide muon sources for muon-scattering tomography screening systems (muons are another elementary particle, like electrons, sometimes employed in analysis).

- The improvement of accelerator diagnostics and the innovation of more rugged, user-friendly, autonomous technologies for use in security applications by border staff, police and military end-users – including the development of automatic image recognition to identify high-risk items.
- The development of compact, multi-pulsed source technology to support stockpile stewardship.

This market sector covers a number of applications that require a broad range of technical solutions. The market is dominated by a comparatively small number of Lateral Market system integrators capable of delivering full solutions for personnel, baggage, cargo and threat detection. The market size is significant and Supply Chain networks are well established. The market is typified by a constant evolution of countermeasures to avoid detection, providing a significant drive for innovative technologies. The opportunities for co-innovation and outward innovation from the National Laboratories technology R&D programmes is considerable. Test and validation capabilities around diagnostics, imaging and dose delivery are also considerable, since security systems potentially need to consider unintended human exposure (i.e. stowaways).

The respondents from the AMICI Partners generally did not highlight security as a priority sector to promote innovation and commercial application. This may reflect the guarded nature of the marketplace. With comparatively limited players, intellectual property sensitivity plays a greater role in Industry's desire to develop solutions in house. Despite these IP concerns, the in-depth interview response for the security Lateral Market companies cited existing relationships with National Laboratories, and a desire to further extend these relationships.

6. CURRENT MARKET STATUS – FEEDBACK FROM THE 1-TO-1 INTERVIEWS

6.1. THE VIEW FROM THE AMICI PARTNERS

This section provides an overview of the feedback received during the survey process from the AMICI Partners on their existing interactions with Industry.

The research particle accelerator community can be relatively conservative and quite risk averse, particularly once the build phase of large-scale facilities has commenced. Unless specific R&D funding is made available during the preparation phase, tight budgets mean that there are limited resources to innovate and test new ideas, and it is difficult to manage the cost of failure that is inherent in innovation. Therefore, there is often a continued reliance on proven technologies with generally incremental improvements where necessary. The AMICI Partners have taken different approaches to working with Industry, which can be summarised into two general models:

6.1.1. Subcontract Model of Industry Engagement

- The general approach used under this model, for new and upgraded facilities, is to design and develop component technologies in-house, subcontract the prototype manufacture, assemble and validate in-house, and then licence the IP to Industry to manufacture in volume for the project. The licence may also cover sales to other customers by the manufacturer.

- The philosophy behind this approach is that many of the technologies and subsystems are specials or bespoke technologies for individual projects, thus requiring design and specification by the AMICI partner before engaging with Industry.
- The key to success of this approach is having an internal team who can build the whole machine, design innovative new solutions to achieve the next generation of performance parameters, and who liaise with Industry to undertake prototyping and manufacture. However, many AMICI Partners using this model report having problems maintaining viable teams.

6.1.2. Collaborative Model of Industry Engagement

- National Laboratories using this model buy in as much design, prototyping and manufacture as possible from Industry. The primary reason is that they do not have the internal resources (capability or capacity) in-house.
- The type of purchase varies, depending on the nature of the project:
  - Big and special projects have detailed performance specifications, and include technology / IP collaboration and transfer with technical support from the National Laboratory.
  - Standard components and accelerator systems are purchased on manufacturers' specification, or manufacturers are able to supply standard products to AMICI partner specification.

In general, working on collaborative projects with Industry could build a stronger ecosystem of suppliers, strong relationships with the individual companies, and enables the RIs to provide testing facilities and support to their Industry collaborators. Potential new vendors are regularly considered for "qualification" but they have to show the value they bring to the AMICI Partners alongside existing vendors.

However, in its current format, there is perceived to be little 'community' interaction and communication, even though there are many project-centric 1-to-1 relationships and conversations. The National Laboratories don't fully understand how Industry works, its needs and timescales, which makes it difficult for them to develop truly effective Industry support policies.

6.1.3. Outsourcing Supply

The main technologies outsourced are vacuum systems, magnets, RF, electronics and power supplies, with challenging areas including RF cavities, magnets and thermal cooling. The key problem from the National Laboratory perspective is a lack of internal skilled staff resource. Where the Supply Chain is weak or very limited, this drives the National Laboratories to develop the expertise in-house as they cannot afford to lose access to the capability.

- There are a range of technologies that can move towards standardisation across the full range of accelerator types:

  - Power supplies / High level RF / vacuum / cryogenic infrastructure / electronics / instrument components.

- These technologies will lend themselves to some system of 'type approval'. A combination of this and standardisation in design across most accelerators will strengthen the Supply Chain, reduce costs and increase reliability.
- Technologies that are likely to remain bespoke to individual systems include:
  - low level RF / magnets / cryo-systems / specialist engineering.
- Some current areas of technology innovation highlighted were the move to solid state amplifiers because of their high reliability / low maintenance, and the adoption of permanent magnets for lower lifetime costs.

6.1.4. Supply Chain Challenges

Overall, the core Supply Chain is viewed by the AMICI Partners as reasonably strong with positive relationships between National Laboratories and companies. However, this has often resulted in a very concentrated Supply Chain, with small numbers of companies supplying key technologies. This is the result of the customised, project based approach to many projects. This could become a strategic weakness, leading to a number of problems:

- Prices can be high as there are few or no alternative suppliers
- National Laboratories are vulnerable to companies obsoleting the technologies, leaving them without a Supply Chain (e.g. klystrons, where falling demand from the telecom and TV sectors may present a strategic threat)

A major challenge from the National Laboratories' perspective is encouraging and engaging with new entrants to the Supply Chain. There are several issues with this:

- The lack of understanding by new companies of the needs and terminology of the National Laboratories.
- Competition from exiting suppliers, making it difficult for new suppliers to enter the market.
- 'Valley of death' issues of bringing innovative new technologies to market.
- Lack of personal contacts and trust.

Obsolescence was also highlighted as a problem. RI facilities can have an operating life over several decades. This causes major problems in finding / making spares later in a facility's lifetime.

The National Laboratories are open to inward innovation from Industry, but it needs to be low risk (because of significant project risk and cost implications) and in areas where existing internal technical expertise is weak. Regarding outward innovation transfer, the National Laboratories supported by the AMICI Technical Platforms undertake considerable amounts of research and development, but the resulting knowledge and IP is typically transferred to Industry on a project basis. As a result, there is far more knowledge and IP available from the National Laboratories than the Supply Chain or Lateral Markets are aware of. Companies are also often reluctant to engage in co-innovation development with National Laboratories, especially for technologies where the market size may be uncertain and development risks are high.

6.2. THE VIEW FROM THE LATERAL MARKETS

This section provides an overview of the feedback received during the survey process from the Lateral Markets on their existing interactions with National Laboratories.

The Lateral Markets have two Supply Chain models for particle accelerators:

6.2.1. "Build In-house" Model

- Occurs primarily in the healthcare sector where technical requirements of the application require specialist design. The Supply Chain provides sub-systems and components.
- These companies will normally outsource the majority (85% +) of manufacturing unless there is a strong economic, intellectual property rights (IPR) or expertise reason. They focus on final assembly, quality assurance and commissioning.
- Certain very specialist manufacturing is often maintained in-house as external suppliers don't exist. Examples provided by survey respondents included Cu waveguides, ion chambers, and assembly of collimators.
- In some cases of technology adoption (e.g. solid state RF), there is general concern about the ability of suppliers to scale up as Lateral Market vendors migrate different product lines onto newer technologies.
- There is concern about the very tight Supply Chains for certain key technologies. This Supply Chain could be threatened if there is consolidation in this sector and the new organisation then decides to re-focus on other markets.
- Companies would benefit from some Supply Chain consolidation, enabling supplier companies to move up to the provision of higher level sub-systems. However, such consolidation is difficult to control and may have unforeseen consequences. It is unlikely that Lateral Market suppliers will go the final step and outsource the manufacture of full systems.

6.2.2. "System Purchase" Model

- Occurs primarily in the security and industrial manufacturing sectors where particle accelerators from companies meet application requirements.
- Companies using the "system purchase" model are primarily systems integrators who focus on applications development. They typically buy accelerating structures from external vendors, and develop the control / applications software, imaging systems and customer specials in-house. Any Supply Chain improvements will need to be through their approved suppliers.
- Some are companies considering bringing the manufacture of key technologies in-house in order to strengthen their technology brand, protect their Supply Chain and freedom to operate, and to manage customer expectations / concerns about supply security.

There is a need for the National Laboratories and Technical Platforms to make the value proposition to Industry much clearer. A key issue with relation to IP from the National Laboratories is easy availability and freedom to operate. A number of survey respondents commented that exclusivity is not typically an issue.

For a healthy Supply Chain to exist, Supply Chain companies need both RIs and Lateral Markets to service. Many companies supplying specialist systems to the RIs don't have the facilities or management capability to scale up for industrial demand. This may require consolidation in these parts of the Supply Chain in order to form organisations with the capabilities needed.

The respondents suggested three initiatives by the RIs which would help to maintain and strengthen a robust Supply Chain:

- A regular flow of small projects and upgrades to maintain a baseload of Industry capacity.
- Better coordination of major new projects and upgrades to smooth out the peaks and troughs.
- A programme of collaborative development projects, similar to the approach used in the Space sector for example, supporting companies to develop innovations, expertise, IP, and future capabilities.

Sharing knowledge and information within the particle accelerator community (academic & commercial) in Europe was judged as poor by the respondents, relying heavily on informal networks. To make a substantial difference to the Supply Chain strength, the particle accelerator community will need a more active / dynamic organisational approach.

6.3. THE VIEW FROM THE SUPPLY CHAIN

This section provides an overview of the feedback received during the survey process from the Supply Chain on their existing interactions with National Laboratories hosting TFs.

Demand is highly variable. From the Industry perspective, it is often best if the National Laboratories act as innovators, developing new technologies and then outsourcing system design manufacture, installation and support to Industry once they are proven. Technology developments tend to be incremental but continuous, which can lead to significant improvements over time. This suits the Supply Chain companies well as it is easier to manage than the introduction of disruptive technologies / changes.

Regardless of the technology, the main value Industry can bring to the TFs underpinning the building of RIs is expertise in the industrialisation of high technology products: serial manufacturing, cost reduction, optimisation of resources etc. Industry can highlight opportunities for adding flexibility and innovation to the industrialization processes without increasing cost.

The relationship between the National Laboratories and Industry goes through cycles depending on the level of budgets and the size / number of major accelerator projects being funded. These significant fluctuations impact on the amount of outsourcing undertaken by the National Laboratories dependent on internal capacity, with Industry required to rapidly scale up or down to meet the demand.

Major changes around standards and certification of people are also anticipated (an example of leak detection was cited). Increasingly challenging requirements from the RIs has led some companies to develop training, qualification and certification procedures for their own engineers, which the companies have developed into a service which they sell widely. This is a good case of how meeting the needs of the RIs can be developed into a wider business proposition based on the provision of services.

6.3.1. Outsourcing Supply

From the commercial perspective, it is desirable that all mature subsystems and components to be outsourced to Industry. Industry also believes that the National Laboratories should outsource the majority of their maintenance needs as this provides a commercial platform for companies to plan their business continuity. However, highly specialised technologies / capabilities not likely to be widely adopted, or that can be used across several departments within the Institute should be kept in-house.

By working closely with companies on new technologies and systems, the National Laboratories can help the companies to upskill their capabilities and people to meet future wider Industry needs. Most companies would like a balanced, cooperative relationship with the National Laboratories. They believe a more open approach will be more effective. It needs judgement and an "Open Innovation" approach.

6.3.2. Strengthening the Supply Chain

Figure 10 shows data from the web-based survey highlighting areas were the Supply Chain believes the National Laboratories can provide greatest assistance.

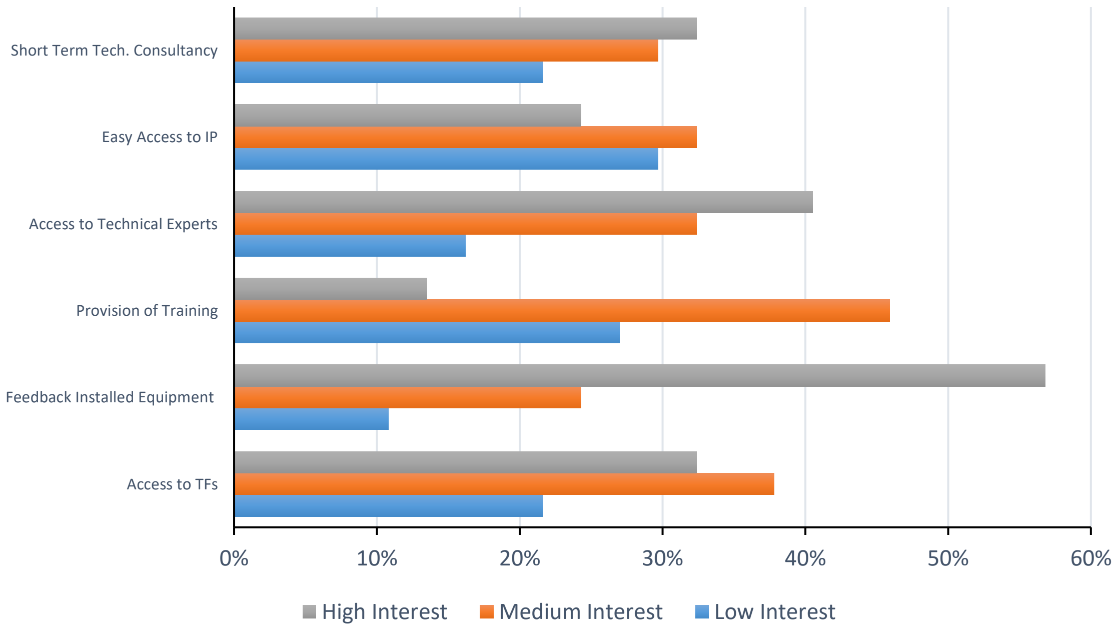

Figure 10: Supply Chain – "How can the particle accelerator research institutes best assist/ support your company?"

6.3.2.1. Working Relationships

A better framework for long-term supply relationships is needed. Companies with active collaborations will be well positioned to supply RIs requirements. RIs relying mainly on competitive tender for manufacture of systems already designed will be heavily dependent on the commercial interest and manufacturing capacity availability of suppliers. A more open, collaborative culture between the RIs and suppliers will lead to better forward planning, better improvement of technologies, and a stronger more reliable Supply Chain. In-house design and engineering teams can be seen as competitors to the suppliers. Closer co-operation and engagement with the suppliers will help to overcome this.

Earlier engagement with the designs and IP (under confidentiality agreements) will allow the Supply Chain to engage more constructively with the RIs. It will improve technology transfer (licencing, consultancy, collaborative development) and benefit the RIs through input to designs to improve performance, manufacturability (to reduce costs), and reliability / maintenance (to reduce operating costs).

6.3.2.2. Access to Facilities / Systems / Data

Better access to facilities and verification instruments is important. Testing and product validation is a major issue as not all companies can afford to have their own facilities. Access to TI facilities is often too expensive and restricted; a better approach would benefit both sides.

Sharing performance data with manufacturers will help improve design, manufacture, and support of future systems.

Industry needs more specialized staff to integrate new technologies. Training by the National Laboratories for Industry through training courses, personnel exchanges, research grants etc. should be considered.

6.3.2.3. Standardisation and Type Approval

Type approval of mature systems, components and operating procedures should be undertaken to enable different RIs to easily purchase “standard” approved products and services. This will enable Industry to standardise considerable proportions of its output improving productivity and commercial sustainability.

6.3.2.4. Collaboration and IP

Often companies will need a short piece of consultancy work to solve a particular issue or training to up-skill staff. If this is easily available as and when needed it will be very valuable. Longer term collaboration programmes may work for the National Laboratories but often don’t work well for Industry. Finding the right people to approach to help with consultancy work is a problem for Industry. Making it easier to understand what IP is available / relevant to Industry and easier to acquire would be helpful.

6.3.2.5. Broadening the Market Base

While the RIs are the main market for many companies, many are considering marketing their technologies to other sectors such as:

- Lateral Markets such as medical and security
- High tech markets such as space, ground astronomy and nanotech
- Major manufacturing sectors such as semiconductors, military and mining

The key requirements of these markets are similar to those of the RIs: price, capacity, and quality and on-time delivery. Transfer of IP, knowledge and expertise from the TFs and a stable demand would help the Supply Chain to become more successful in these Lateral Markets.

6.4. GAP ANALYSIS

6.4.1. Elements of Market Weakness

The weaknesses in the particle accelerator Supply Chain ecosystem stem from the different requirements of each of the three stakeholder groups for successful operations:

- *National Laboratories* require significant numbers of technically sophisticated companies in each technology areas with the ability to manufacture large / small volumes and one-offs to high quality.
- *Lateral Markets* require a small number of technically sophisticated companies capable of manufacturing large volumes consistently to quality and delivery requirements.
- *Supply Chain* companies require markets with a good customer spread, predictability, reasonable profit margins, and consistent demand.

This gap between stakeholder needs creates major weaknesses in the Supply Chain ecosystem. The different stakeholders have taken actions to mitigate these weaknesses, which in turn have exacerbated the weaknesses further:

- *National Laboratories* have taken more design, test, and even manufacture in-house, thus reducing demand.
- *Lateral Markets* have focused their purchasing on a small number of suppliers reducing the number of viable companies.
- *Supply Chain* companies have focused on niche technology areas where they can create and defend a viable business reducing the breadth of the Supply Chain.

6.4.2. Summary

The current ecosystem that supports European research accelerators, suppliers of accelerator systems for societal applications, and their supporting Supply Chain is adequate, but not optimal. Future market drivers and sizes are hard to quantify, the Supply Chain is technically proficient but relatively narrow, and communication and coordination at all levels is not efficient. The extensive pan-European test and validation infrastructure, which lies at the heart of this ecosystem and could be used to drive innovation, technology and skills transfer, is currently under-utilised by Industry. This challenges the long-term sustainability of the TIs and ultimately the supporting Supply Chain.

A better integrated ecosystem would significantly enhance the foundations for fundamental science discovery and maximise the societal and economic benefits from the expanding range of accelerator-based applications. The following section will investigate aspects of how this could be implemented in practice.

7. ROUTES TO INNOVATION

7.1. PURPOSE/ VALUE PROPOSITION

"There is a need for the Labs to make the value proposition to (Industry) much clearer."

To establish the AMICI ecosystem, it is essential that the role and benefits of AMICI are established in a clear and concise manner. This clarity and transparency in how AMICI works is essential to allow Industry to calculate its ROI and undertake effective cost/benefits analysis prior to approving collaborative projects.

7.1.1. The Offering

Technology development, test and validation is at the epicentre of both the delivery of inspiring new European Research Infrastructures for fundamental research, and also the development of innovative products, processes and services by leading European companies to generate measurable economic and societal impact.

The necessary building blocks of world class skills, test infrastructures and commercial expertise are already in place across Europe, both within the National Laboratories and Industry. The AMICI partnership is ideally placed to co-ordinate, promote and expand this concept, taking these building blocks and establishing a stable, integrated, innovation ecosystem that will assist in streamlining access processes, standardizing procedures, and maximizing innovation opportunities for both Academia and Industry.

7.1.2. The Benefits

For National laboratories, benefits include:

- Increased opportunities for co-innovation, providing solutions aligned with Key Technology Areas.
- Enhanced inward innovation from Industry through better knowledge of needs and strengths.
- Enhanced access to broader resource pool (facilities and staff) within Industry, augmenting capacity and capability.
- Prospect of alternative funding routes (e.g. share of national innovation programmes looking at societal applications thematic areas, often requiring commercial partners).
- Contribution to economic and societal impact metrics of Industry, which may be viewed favourably by regional and national funding bodies in justification of core funding.
- Demonstrable increase in demand for Technical Platforms – ability to retain/enhance dedicated resources and improve sustainability.
- Development of shared training programmes and skills base with Industry. Strengthens support for academic/ commercial strategic funding bids.
- Standardisation of some test and validation procedures – more efficient use of resources.

For the Lateral Markets and Supply Chain, benefits include:

- Access to advanced facilities for technology development, test and validation – opens new innovation opportunities and expedites product development.
- Increased opportunities for co-innovation and tech transfer into the Research Infrastructure market.
- Heightened knowledge of available IPR, capabilities and capacity located within National Laboratories.
- Coordinated (ideally, integrated) access, IPR, and technology transfer policies.
- Transparent costing and scheduling information, allowing accurate project evaluation.
- Exposure to larger Supply Chain, promoting opportunities for business-to-business partnerships. Increased opportunities to develop integrated sub-systems through brokering service.
- Opportunity to input into development of future platforms to better reflect Industry requirements.
- Underpins stronger, longer-term relationships with National Laboratories.
- Delivered through added value, not subsidy; allowing European Industry to continue to tender internationally.

For the European science base, the benefits include:

- Enhanced delivery in Key Technology Areas.
- Co-ordination of Technical Platforms, enhancing effective capacity, capability and expertise across existing infrastructure.
- Co-ordination of future Technical Platform developments – providing maximum scientific impact from capital investments.
- Enhanced sustainability of the TI through increased usage by a broadened user base.

7.2. COMMUNICATION AND MARKETING

“Sharing of knowledge and information within the particle accelerator community (academic and commercial) in Europe is poor. It relies on informal networks.”

Survey respondents were universally supportive of efforts to enhance coordination of the TI across Europe, but many commented that the overall picture for Industry regarding use of the TI was ‘opaque’. Forming clear communication channels between the National Laboratories and Industry will be a key ongoing activity within AMICI, and a central mechanism to realising genuine innovation.

7.2.1. Portal Optimisation

The AMICI website acts as a critical ‘shop window’ for the facilities and expertise available within AMICI. To best support innovation, suggestions for the website to be optimised include:

- Regularly updated information; needs dedicated resource (centralised) to co-ordinate and defined contacts at TFs with responsibility for keeping web information updated.
- Concise description of the AMICI Innovation ecosystem and its benefits.

- Standard information matrix for each platform including:
    - Detailed specification of facility and specialist expertise.
    - Industrial contact.
    - Access mechanism(s) for Industry: pay per day; collaborative research only; academic partner required etc.
    - % time available for industrial use (if restricted.)
    - Schedule of availability.
    - Indicative cost if possible – this could be in simplified terms (i.e. €, €€, €€€).
    - Publications.
    - Patents (those developed with help from TF) – to aid capture of industrial contacts through patent searches.
    - Case study material in common AMICI format.
- Search engine optimised.
- Use language which everyone understands, avoid the use of specialist terms where possible.
- To ensure effective co-ordination, time limits should be defined for responding to enquiries received through the portal. This will require assigned resource.

7.2.2. AMICI Back Office

For AMICI to act as a coordinated ecosystem for innovation, it is essential that all communication with Industry is conducted promptly. Whilst something of a generalisation, Industry project timescales are typically much shorter than those for National Laboratories, and Research infrastructures in particular. Industry also has considerable flexibility over suppliers and collaborators, and will move more readily to the next available option or develop internal capability if a response is not timely. Time limits should be defined for responding to enquiries received through the portal.

Optimally, all AMICI enquires will be routed through a centralised AMICI portal back office, with dedicated personnel resource to handle submissions. The expectation is that at least part of the resource to run this back office would be full-time, in order to ensure continuity of service. Enquires would then be relayed to the suitable Technical Platform(s) contacts for actioning. The centralised AMICI function would monitor the progress of enquiries through the various stages of the application process to ensure that any agreed services are provided on schedule, and to collect metrics against which the performance of the AMICI ecosystem can be evaluated. To close the monitoring and evaluation loop, the AMICI back office would also collect impact metrics from collaborating Industry partners and any feedback required for continuous improvement.

7.2.3. Promotion of AMICI

There are many examples of where National Laboratories and Industry work in effective partnership to deliver co-innovations. Many of these Industry representatives have attended AMICI workshop events and actively participated in previous European-level academic/Industry networking activities. These companies are well-informed, well-connected and have a high degree of awareness as to the facilities and expertise located within the National Laboratories. For AMICI to realise the full potential of the TI, drive innovation, underpin societal and economic benefits, and thereby expand the range of options for long-term sustainability, it needs to considerably broaden the range and number of companies it interacts with. Promotion should not be restricted to the accelerator community or known Supply Chain. The steps taken to improve innovation potential intrinsically strengthen the particle accelerator Supply Chain.

For the purposes of promoting AMICI, the main ‘customer’ focus should be considered as Industry. Central to the messaging for Industry are the previously highlighted outputs:

- Clear definition of AMICI.
- Clear articulation of benefits/ value to Industry.
- Clear information of capabilities, cost, availability, support.
- Clear contact route for access.

To realise the long-term project goals, it will be necessary to develop a full communication strategy to communicate the offering to European Industry. Elements of this strategy could include:

- Promotion of the technology development, test and validation infrastructures of the National Laboratories in terms which are meaningful to Industry
- Develop appropriate web and printed resources to promote AMICI activities, which could include a summary brochure and regular e-mailshots/newsletter
- Develop and maintain centralised AMICI contact list in conjunction with Industrial Liaison Officers (GDPR compliant)
- Develop suitable forums where Industry can learn of opportunities, and seek to develop appropriate partnerships. Promotion and workshops could be aligned to:
    - Technology themes.
    - Societal application themes/ market sectors.
    - Major science project announcements.
    - National/ international funding calls (particularly for co-innovation funding).

7.2.4. Communication Enhancement

The survey responses from Industry highlighted two further areas where improved communication could pay dividends for Industry. Firstly, Industry reported that the National Laboratories are generally poor at providing feedback on equipment performance once operational, which is in stark contrast to the detailed discussions around design and specification of the equipment prior to installation. It is self-evident that providing more detail about in-service performance, and feedback on possible improvements, would assist industrial R&D and may prompt additional opportunities for co-innovation or inward innovation from Industry. Such feedback would also further strengthen National Laboratory – Industry relationships, and may well provide the supplier with additional case study material to generate external sales, improve economic impact and help sustain the Supply Chain. This relatively minor change in approach could lead to significant benefits for all parties.

Secondly, Industry would benefit from a simplified roadmap of upcoming RI projects with an estimation about how likely they are to be funded and information about the likely sub-system/ component requirements. There are a number of sources for such European roadmaps (e.g. ESFRI) but Industry, particularly Small Medium Enterprises, report that it is often difficult to evaluate discrete technology requirements, size of potential markets, and likelihood of funding approval. AMICI could adopt the role of producing regularly-updated simplified technology development roadmaps for an Industrial audience, as a further mechanism for promoting the role of its coordinated technology development, test and validation infrastructure in the innovation landscape.

A further observation from the survey feedback is the increasing use of patent searching by Industry to solve R&D challenges. The proliferation of search tools, and of suppliers offering patent searches as a commercial service, means that some companies have now allocated dedicated resources to this activity. At least one of the AMICI Partners has undertaken commercially-funded work on a TF as a direct result of a routine patent search (material science for the space sector) undertaken by a company with which it had no previous relationship. Therefore, patent information should be added to the standard matrix of information provided by each TF, for patents either developed directly on/for the TF, or patents that have been secured by other users following usage of the TF.

7.3. ALTERNATIVE SUPPORT MODELS FOR TECHNICAL PLATFORMS

There is a conventional hierarchical structure to TI whereby hardware is designed specified to meet RI requirements, and located at National Laboratory sites. Access to such facilities is granted to Industry where opportunities exist for co-innovation beneficial to the RI, and project, regional, national and EU funding is used to supplement co-financing from Industry. IP rights are distributed on a project-by-project basis, following considerable negotiation and legal process. However, this model is now being supplemented by different TI- Industry interaction models.

Taking examples provided by STFC in the UK by way of illustration, they provided three examples of recent partnerships with Industry looking at how TI infrastructure is located and financed:

7.3.1. Industry Directly Supports TI Hardware at a National Laboratory Site.

Teledyne-e2v are supporting, through the provision of hardware, staff resource and finance, delivery of beamtime on the Compact Linac source, located at the STFC Daresbury Laboratory. In exchange for their direct support Teledyne-e2v receive a pre-agreed proportion of the available beam time for technology and application development, the duration of which has been fully costed and laid out in contract in order to comply with all state aid requirements. This part-industrial support allows the continued operation of a National Laboratory AMICI-registered Technical Platform which would have otherwise be decommissioned due to core funding limitations. The remaining facility beamtime access is controlled by STFC with no input from Teledyne-e2v, and is one of the facilities offered through the AMICI programme. A key added value for both parties comes from the day to day staff interactions enabled by the partnership.

7.3.2. Hosting of External Industry Test and Development Hardware at a National Laboratory Site.

Advance Oncotherapy (AVO) is continuing to develop proton therapy solutions incorporating innovative technology originally spun-out from CERN (i.e. ADAM). They have implemented a test and validation infrastructure at STFC Daresbury laboratory in a contractual partnership with STFC. AVO are making use of STFC TPs covered by AMICI (e.g. magnet test lab, surface science, the Engineering Technology Centre) and revenue from the commercial arrangements is funding further development, test and validation infrastructure development at a National Laboratory. This project also readily demonstrates the potential for innovation incorporating multiple AMICI Partners and Industry in the translation of accelerator-derived developments from fundamental research to societal application products.

7.3.3. Location of National Laboratory Hardware at an Industry Site

For the UK in-kind contribution to the US PIP-II project, STFC is locating technology development, test, validation and manufacture hardware at two Industry sites in the UK. Whilst a proportion of time on the hardware is reserved for PIP-II, the depreciated hardware will subsequently be made available for Industry for its own development purposes. The equipment provides an ideal platform for both co-innovation and outward innovation in the SRF sector for academic purposes and societal application development by Industry, crucially aided by its location off-site, will provide significant opportunities for unrelated innovation by Industry in non-accelerator market sectors.

The above examples will clearly not be suitable for accelerator-related TI deployment in the majority of cases, but demonstrate that alternatives to a straightforward National Laboratory TI model are in operation. In each case, a more conventional approach to the use of TI platforms by Industry would not have worked. It should be recognised that each of the examples provided required considerable political, financial and legal will and resource to establish, and very close links with the Industry partners.

The current list of AMICI Technical Platforms incorporates only platforms available at AMICI partner sites. Future developments should fully consider pre-existing platforms which are potentially available off-site within Industrial partners, and whether in the interests of maximally exploiting co-innovation potential, selected future platforms could be better located within Industry. The Compact Linac-Teledyne example given above illustrates that Industry is able, in certain circumstances, to allow no-exclusive use of facilities it supports. The view has been expressed by Industry representatives during the AMICI programme that it is willing, in the right circumstances, to work with other Industrials and indeed direct competitors on development project, recognising the capacity, resource and knowledge shortfalls of working in isolation, and the increasing size and technical challenge of some projects. This is particularly relevant to the TIs cross-sector and cross-TRL applicability, where AMICI could potentially provide a level of neutrality required to broker such arrangements.

8. FACILITY ACCESS CONSIDERATIONS

For an open innovation model to become established and sustainable, it is essential for it to deliver predictable and repeatable levels of service, such that Industry view positively further innovation activities. The following are desirable to deliver such a service:

- Lead facility contact.
- Published availability schedule.
- Defined pricing policy.
- Access policy, including selection criteria for oversubscription.
- Summary of facility health & safety requirements, including user risk assessment.

- IPR and Technology transfer policy.
- Standard legal & commercial documentation.
- Pre-assigned staff resource to undertake innovation work.

In an idealised scenario, these requirements should be harmonised across all AMICI Partners. Where legacy considerations make implementation difficult or delayed, policies should be aligned to AMICI best practice wherever practicable.

Timing is critical. In many cases, having clarity on scheduling and possible delays is as important to collaborators as having quick access. The effect of delays can often be countered, but there needs to be clarity at the start of engagement as to what those timescales are, so that Industry can draft project plans and accurately assess impact, since use of an AMICI Technical Platform may form just one part of a much larger development programme.

This requirement to efficiently process access extends to legal processes. If an AMICI overarching Legal framework is established to govern access, it may still be necessary for individual National Laboratory legal teams to issue documentation (e.g. quotations, IPR agreements, non-disclosure agreements) as part of the process. As with communications regarding initial enquiries, a prompt response is critical in keeping Industry engaged.

As with other elements of the AMICI coordination model, a valuable element of the formal creation would be to evaluate each facility's preparedness levels using test cases.

8.1. STANDARDISATION

Feedback from the survey on standardisation centred on two key areas: standardised testing and standardised components.

8.1.1. Standardised Testing

In general the technology development, test and validation infrastructure of the National Laboratories have been developed to meet the specific needs of the host laboratory and associated RIs, with minimal consideration of the requirements of Industry or the wider network of facilities. As facility designs become more multi-partner, international and larger in scale, some consideration should be given to how these individual platforms operate most efficiently within a wider TI network. The influence of testing requirements for Industry has been reserved for co-development opportunities, where testing is required for the National Laboratories qualification purposes. The impact of societal application technical development and the broader requirements of the Supply Chain have been minimal.

Going forward, Industry oversight incorporated in the AMICI Technical Platform provides a mechanism for participating Industry to input into the specification of testing protocols and hardware to enhance suitability for Industry, and a mechanism for reducing the likelihood of AMICI facilities encroaching on commercially available testing services (i.e. avoiding market distortion). The most straightforward mechanism to encourage active participation and inward investment from Industry into the AMICI ecosystem is to develop facilities and service which are directly relevant to Industry.

A higher degree of standardisation of appropriate tests at multiple AMICI Partners would allow cross-comparison and evaluation. This increases opportunities for both Industry and RIs to take advantage of additional capacity across the AMICI Partners, the efficient management of which would be one of the coordination roles of AMICI.

8.1.2. Standardised Components

The lack of standardisation of components was highlighted by a number of Supply Chain vendors as a barrier to cost effective engagement with the National Laboratories. Individual projects can often use large numbers of unique specification items. In some cases this is absolutely necessary to achieve the desired performance. But in a significant number of areas a higher degree of standardisation could benefit the Supply Chain's ability to supply components of sufficient quality and volume, improve the commercial sustainability of vendors, whilst reducing purchase costs for the RIs. With the use of defined performance specifications (as opposed to technology criteria), opportunities for new vendors to enter the market place are expanded, potentially leading to a broadened Supply Chain. Standardisation also promotes longer-term design stability, which makes it more attractive for new vendors to invest in production. This does not preclude the development of innovative solutions; new options can be evaluated (a potential further role for AMICI), resulting in an updated standard.

8.2. PRICING

"…access to Lab facilities is too expensive and restricted"

As parts of a stable innovation ecosystem, it is necessary to have both a sustainable TI and a robust, broad Supply Chain. The ecosystem must strongly underpin development of future RIs in order to continue to receive national and European-level core funding, secure contributions from international projects, and offer capabilities essential for Industry that will attract inward investment, either financially or the provision of resources. In order to achieve this, access pricing must be demonstrable as fair to all parties.

Some Industrial respondents to the survey commented directly that access to the TFs was too expensive. A more nuanced evaluation may be that Industry has previously found access poor value for money (i.e. the cost was too high for the level of service received). In the majority of existing cases, the TFs are certainly not optimised for external Industrial users and are not supported in the same way as, for example, industrial access to international-scale accelerator facilities (e.g. Industrial contract access to synchrotrons). User facilities such as these, and particularly those which routinely support paid-for access, require dedicated staff effort (e.g. ILOs, user support offices) and have personnel who directly support the experiments. The current arrangement for the majority of AMICI TFs is that support comes from the facility staff in addition to their 'business as usual' duties. This may be one factor in Industry's VFM assessment

Another factor to consider is the evaluation of technical risk and the impact on Industry's cost/benefits analysis when deciding to commit to innovation projects. Innovation activities are often high risk for commercial entities, particularly where future market sizes are hard to quantify, and the impact of project failure on a smaller SMEs will be markedly different to the impact on a TF supported by a National Laboratory. Feedback from Industry is that they would like to see a more thorough assessment of the contributions of Industry when assessing relative cost in co-innovation projects since co-innovation and collaboration are a good mechanism to reduce risk for both Industry and TFs.

Set against this feedback, TFs are supported by considerable taxpayer funding and are required to recoup Full Economic Cost or similar, as dictated by local funding policies. Organisations may choose to recover significant portions of the facility's capital funding through external income, or may work with amortised or depreciated costings. It is also necessary to avoid accusations of state funding or subsidy of European versus non-European Industry. This specific point was raised by one Industry respondent, who relayed that they would not be able to competitively tender for US government contracts if there was any suspicion of a product's development having been part-subsidised through EU-funded activities.

Industry needs to demonstrate a return on investment in a commercially-relevant timescale to encourage its internal finance /backers to invest in innovation programmes. Due to regional funding differences, and the complexity of access to some TFs in may not be practical to determine a unified pricing policy across all AMICI platforms. However, it should be possible in all cases to provide costing information that Industry can make effective use of in its evaluation of project viability.

Further points to consider:

- National Laboratories should fully consider the financial impact of delays when determining schedules and should be mindful of delivery to realistic agreed timescales.
- Full Delivery of TI facilities should also include exchange of any agreed measurements or other. The time and staff resources required to deliver these and any agreed reports should be fully defined, costed and communicated to Industry at outset of engagement.

8.2.1. Avoidance of Market distortion

Of note, there was specific concern that the desire to more broadly utilise taxpayer-funded TI platforms to perform more standardised testing could potentially, in some circumstances, affect those industries that offer such test measurements on a commercial basis, undermining their capital investments and business operation. The role of AMICI is not to compete or undercut commercial test and validation services offered by Industry. AMICI will not offer services where such services exist, to ensure there is no market distortion. The AMICI Industry advisory structure could have a role in identifying and bringing such conflicts to resolution.

8.3. SKILLS AND KNOWLEDGE EXCHANGE

In addition to the physical infrastructure coordinated under the AMICI banner, the value of the skills, knowledge, expertise and experience of the TF staff, and the Industries who collaborate with it, should not be underestimated. Indeed, in the responses to the web survey, 'access to technical staff' rated above 'access to TF facilities' when asked 'How can the National Laboratories assist your company?' In developing the optimum model for innovation, full consideration needs to be given to the inherent value and costs associated with providing staff resources, and TF pricing policies should incorporate expert consultation services where practicable.

The significant value of staff experience is, of course, equally true of Industry. As well as areas of significant shared technical expertise, the underlying driver for many co-innovation partnerships, Industry can bring additional areas of expertise not typically shared with TFs:

- Routes to application markets.
- Industrialisation and production scale-up.
- Reliability, maintainability, inspectability.
- Marketing and distribution.

In addition to facilities, AMICI could include a role in developing knowledge-based centres aligned with the TF specialisms. In the US, a strong framework of IP management / technology transfer enables scientist to readily transfer between academia and Industry. Improved knowledge transfer, in the form of strengthened communication channels or temporary personnel exchanges between different parties could instantly leverage pre-existing relationships for increased societal and economic impact.

8.4. IPR

Intellectual property rights are viewed as a significant challenge to optimising usage of the TI and other National Laboratory capabilities. This is being considered in detail elsewhere within AMICI (WP4.3) and other H2020 programmes and will not be assessed in detail as part of this report.

In support of these discussions, Industry reported the following as part of the survey process:

- Earlier engagement with the designs and IP (under confidentiality agreements) will allow the Supply Chain to engage more constructively with the National Laboratories.
- CERN's 'open' IP model was cited by Industry as a success, whereby CERN publishes IP that it has available for exploitation by Industrial partners. However, a fully open IP approach may not be suitable for all TI sustainability models
- IPR arrangements should be harmonised and streamlined across AMICI Partners where possible, in line with D3.2. Some flexibility will be required to match specific projects.

9. CONCLUSIONS

- Supporting innovation within the particle accelerator sector is essential for both the successful implementation of future European Research Infrastructures and in developing potential technology solutions for a broadening range of societal application areas.
- A number of existing co-innovation activities between AMICI Partners and Industry have resulted in products and services benefitting large-scale accelerator projects.
- The Supply Chain is highly skilled, often specialised, and with an average (mode) annual turnover of €1 – 5M in accelerator-related business. Industry views its involvement in the accelerator market as long term.

- Innovation activities between AMICI Partners and Lateral Markets, in order to develop accelerator-related societal applications, have favoured the healthcare sector, with some representation in the security sector. The industrial sector is a significant market for a high proportion of the Supply Chain, whilst opportunities for potential developments in the energy sector are comparatively unexplored.
- Industry sees the potential for increased interaction with the National Laboratories technology development, test and validation Technical Platforms, but investment of commercial resources must be able to be supported by a valid business case. The Technical Platforms should be able to supply clear specifications, costs and timescales to support such cases.
- Communications, cost of access, IP and transparency were highlighted by Industry as potential barriers to access. The outputs from AMICI WP4.3 will address barriers to access. Industry would like to see common, transparent systems and processes across the Technology Infrastructures where possible.
- The demand from Industry is not restricted to gaining access to uniquely specified Technical Platforms within the National Laboratories to address capability shortfalls; it also encompasses requirements for consultancy, training and for assisting in managing Industry's own fluctuating capacity requirements.
- The Research Infrastructure market for components and sub-systems is relatively hard to predict and can be viewed as high risk. Coordination of facilities and platforms under unifying Technology Infrastructure will significantly assist Industry in better assessing innovation opportunities and managing capacity.
- A detailed list of Key Technology Areas in support of RI development will be output from AMICI Workpackage 2 'Strategy'. The preliminary KTA mapping with Industry indicates considerable areas of overlap. An open, regular forum for discussion with Industry should be established to crystallise Industry's technology development needs, and then be routinely updated.
- A diverse, active and informed Supply Chain will be central to maximising the innovation potential of the Technology Infrastructure.
- AMICI Workpackage 3 'Cooperation' will output a structure to implement a coordinated ecosystem. In addition to the practical steps required, this coordination will oversee a transition from a primarily RI-driven model to a broader ecosystem supporting enhanced partnership with Industry. Such cultural changes need to be embedded and supported over extended periods of time, strengthening the case for AMICI to be a strategic activity, resourced and supported over the longer term.