Scientific Outcomes

Analysis of the Measurements Performed by Industrial Companies for the Science Link Project

EU flagship Project “Science Link“

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1. Statistics of Science Link's calls

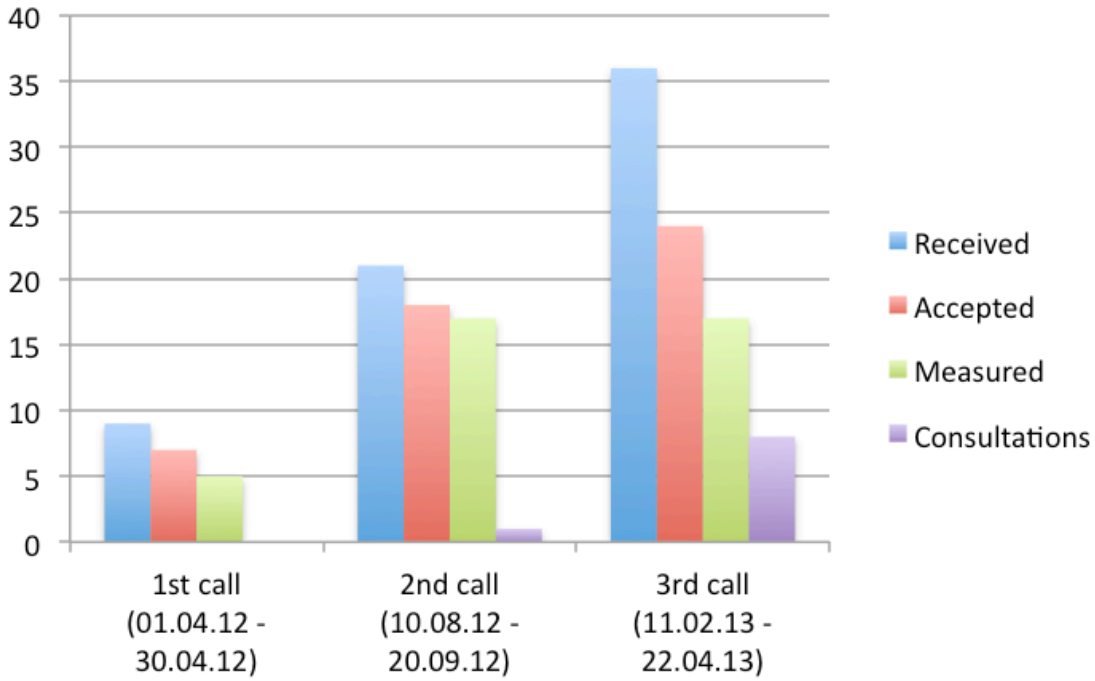

Figure 1: Applications received during each of Science Link's calls

During Science Link's project period, three open calls were organised which attracted a total of 66 applications. The progress of the success rate for each call is shown in Figure 1.
Of 66 received applications from companies in the Baltic Sea region, 49 were finally accepted for a measurement using x-ray or neutron radiation at one of the research infrastructures (RIs) within the Science Link network. This exceeds the defined goal of Science Link to attract 40 new industrial users to the RIs.
The primary reason for declining an application was that the problems that needed to be solved could be solved using a conventional laboratory technique, that is that synchrotron or neutron radiation was not required. For these applications, the companies involved were given consultation as to how they could solve their problems using a local academic partner. This is an indication that despite a lot of effort to explain the offers provided by Science Link, many industrial companies did not recognise that the offer consisted only of measurements at a synchrotron or neutron source. It also gives the conclusion that many industrial scientists employed at the participating companies do not actually understand the kind of measurement techniques and analysis possible at a synchrotron or neutron source.
This bottleneck indicates a need for education and training for industrial scientists to learn about scientific analysis techniques available at local RIs. During the Science Link's third call, a "Road Show" was organised in Estonia and Finland where ILOs and other staff from German RIs presented "Industrial Applications of Synchrotron Radiation" to industrial scientists from local companies. Participation was free, however the turnout was rather low and many registered participants didn't actually attend the events. It is doubtful that even one application for the third call was attracted from these work-shops, and it underlines the

Country	Received	Accepted	Measured	Lost
DE	5	5	3	2

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DK	3	3	3	0
EE	4	3	3	0
FN	6	4	4	0
LT	6	5	5	0
LV	5	2	1	1
NO	1	1	0	1
PL	14	8	6	2
SE	22	18	14	4
Total	**66**	**49**	**39**	**10**

Table 1: Applications received per country, and those which were accepted, measured and lost.

need for a long-term marketing strategy to educate industrial scientists in the application of synchrotron and neutron radiation facilities.

Table 1 shows the statistics of all projects received from each country, as well as how many were accepted, measured and with which contact was lost. It can be seen that 22 of the 66 applications came from Sweden and 14 from Poland, while the other participating countries each generated 3 – 6 applications each. Sweden's success can be partially explained as Science Link's Communication group was centred at Invest in Skåne and there was already a well-established extensive network with local companies. Another factor contributing to Sweden's success was the employment of a physicist who acted as a local contact point and was very active in communicating the possibilities of Science Link with local businesses. On the other hand Germany, which is the location of three of the participating RIs as well as a number of project partners, only managed to attract five applications, and of these only three resulted in a successful measurement. In Germany, no extra local contact point was employed as there were already too many project partners within Germany and Germany would require too much of the project budget to employ a local contact point. It was considered to be the jobs of the local Industrial Liaison Officers (ILOs) as well as the Technology Transfer (TT) departments of the German RIs to attract companies – however the duties of the ILOs also included organising and sometimes even participating in industrial measurements, attending exhibitions and conferences, writing the content for the website and case studies, while the TT departments were relatively inactive during the calls due to their other duties. The high number of applications from Poland is encouraging, however the fact that only eight of the 14 received applications were accepted indicates that the quality of the applications was not as high. This is likely to be due to the fact that their local contact points were not well educated in synchrotron science. The other participating nations in general didn't have synchrotron experts as contact points or academic partners which has hindered their performance. In future instances of the Science Link project, participating nations can learn from the Swedish example of employing a local scientist with experience in synchrotron radiation as contact point who can dedicate their complete working time to attracting companies.

As seen in Table 1, of the 49 accepted companies, 39 of them successfully completed a measurement at one of the RIs and submitted a project report. Of the 10 "lost" companies who had their application accepted but were unable to complete a measurement, a variety of reasons were responsible. In one case the company was unable to deliver samples on time, even two years after their application was accepted, and in another case it was found that the experimental conditions required for the measurement were not available at any of the RIs. One of the companies reported that their research direction changed and that such x-ray analysis was no longer necessary and one company reported that a departure of one staff member resulted in cancellation of the project.

Such problems were also influenced by the shutdowns of many of the radiation sources during the project period, such as DORIS III and PETRA III at DESY and BER II at HZB. It was known in advance that the such shutdowns would occur during the project period, and steps were taken by the Scientific Review Committee to distribute those applications unevenly to DESY and HZG during the first and second calls while DORIS III and PETRA III were still in operation, and to distribute more of the applications to MAX-Lab and HZB in the third call when DESY and HZG would have much less beamtime available. Finally, the shutdown of PETRA III was postponed from September 2013 until February 2014, so more beamtime became available at DESY and HZG, while HZB struggled to complete all of their allocated measurements in the last year of the project period.

In some cases, contact between Science Link partners and other companies were simply lost due to the failure of the companies to reply to emails or phone calls, resulting in cancellation of their project. A method to improve this in the future would be to establish deadlines at the beginning of correspondence, so that if the customer has not replied to the last email from the ILO within 10 days or two weeks for example, the project will be cancelled.

A final contributing factor to the "loss" of several companies can also have been the requirement that any obtained results must be published. Industrial companies are very protective of their intellectual property and in some cases it required a lot of negotiation before they would agree to Science Link's Terms and Condition.

2. Experiences of Industrial Users

From the reports submitted by 39 companies summarising their experiences with the Science Link project, it can be seen that in general the companies had a variety of opinions and outcomes relating to the project. 19 of the companies expressed that the performed measurements produced useful results which will help their product development while 14 companies expressed that they obtained useful results but require future measurements. Five of the companies obtained results that didn't help their development and one company was unable to produce any results at all.

32 of the 39 companies expressed that they were satisfied with the help and support they received and with the Science Link project in general. Two of the companies were not satisfied, due to long delays, due to lack of communication or because synchrotron access became unavailable due to a shut-down. The remaining five companies did not provide any opinion about the project.

31 of the 39 companies indicated that the access to RIs was useful to them but only four of them specifically expressed a desire to return for future measurements. This is of concern as a defined goal of the Science Link project was to attract 40 new commercial users for all of the participating RIs. A reason for the lack of interest for regular "paid" measurements is that roughly two thirds of the participating companies were small/medium enterprises (SMEs) with less than 200 employees. Regular industrial measurements at an advanced light source such as PETRA III can cost up to 750€ per hour, depending on the agreement between DESY and the user regarding confidentiality of results. Even for a short measurement time of one shift (eight hours) this can cost more than 10,000€ when extra time for sample preparation and analysis of results is accounted for. A follow-up measurement for Volkswagen at HZG in August 2012 cost 50,000€ for three days of

measurements and analysis. It can be much too expensive for an SME and therefore new ways to support the use of RIs by SMEs need to be considered. The large companies which participated in the Science Link project should be pursued by the Technology Transfer departments of the relevant RI, to discuss future possibilities.

3. Industrial Categories

Category	Received	Accepted	Measured	Lost
Agriculture and Food Science	3	3	2	1
Chemicals	6	4	4	0
Construction and Engineering	19	13	11	2
Environment and Energy	7	5	5	0
Home and Personal Care	2	2	2	0
Life Science and Biotechnology	13	10	7	3
Material Science and Nanotech.	16	12	8	4
Total	**66**	**49**	**39**	**10**

Table 2: Applications received per industrial category, and those which were accepted, measured and lost.

Table 2 shows the distribution of the received and accepted applications over the defined industrial categories. It can be seen that companies within the categories of "Construction and Engineering", "Material Science and Nanotechnology" and "Life Science and Biotechnology" where most successful, with 26 of the total 39 completed measurements falling in these three categories. Of the remaining categories, "Agriculture and Food Science" and "Energy and Environment" are industries which can have a significant impact on important global problems. It can be of great interest to RIs to improve their visibility in these areas, to show that they can really contribute to solving the world's problems such as limited food supplies, green energy and climate change rather than simply focussing on investigating nano-structures and other fundamental science.

Table 3 shows the different synchrotron techniques required by each of the 49 accepted applications. It can be seen that 28 out of the 49 accepted applications required either x-ray diffraction (XRD) or x-ray absorption spectroscopy (XAS). XRD is particularly useful for Construction and Engineering, to test stress and strain in mechanical components. XAS is most useful for Life Science and Biotechnology applications, however XRD and XAS are both widely

	XRD	XAS	SAXS	Tom.	PEEM	IRS	UV/VIS	XPS	Lab	n^0
Agriculture and Food Science	2	1	-	-	-	-	-	-	-	-
Chemicals	1	1	-	1	-	-	-	-	1	-
Construction and Engineering	7	1	4	1	-	-	-	-	-	2
Environment and Energy	1	2	-	-	1	1	-	-	-	-
Home and Personal Care	1	-	1	-	-	-	-	-	-	-
Life Science and Biotechnology	-	5	-	3	-	1	1	-	-	-
Material Science and Nanotech.	4	2	-	-	2	-	1	2	1	-
Total	**16**	**12**	**5**	**5**	**3**	**2**	**2**	**2**	**2**	**2**

Table 3: The x-ray techniques required for the accepted applications (also neutrons overall)

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used for all industrial categories. For the remaining applications, only one or two techniques were useful for each industrial category. It can be seen for example that Small angle x-ray scattering (SAXS) is most useful in Construction and Engineering and Material Science and Nanotechnology, while Infrared Spectroscopy (IRS) was only useful for companies within Environment and Energy and Life Science and Biotechnology. While two companies were originally given the possibility to use neutron (n^0) analysis, it should be noted that no neutron measurements were made. One of these companies was "lost" and the other used x-ray tomography instead due to the shutdown of BERII.

Twelve of the most successful completed measurements have already been processed into industrial "case-studies" to be used as publicity material for both Science Link as well as the participating RIs. Three case-studies each from "Material Science and Nanotechnology" and "Life Science and Nanotechnology" were created, two from "Construction and Engineering" and one each from the remaining categories. Case-studies from 13 other completed measurements will be also prepared in the future.

The following sections provides a summary and conclusions from the submitted project reports from companies who are grouped into Science Link's defined industrial categories, with the aim to determine what the RIs can learn from the attracted industrial users from each category. The performed measurements will be compared about which examples were suggested by synchrotron experts and offered for each category on Science Link's website to determine which kind of company was missed.

3.1 Agriculture and Food Science

The two companies classified as "Agriculture and Food Science" both used x-ray diffraction (XRD) to make structural analysis on materials used as fertilisers. One company (NanoGeo Finland Oy) could use the obtained results to drastically reduce the high temperatures required to synthesise their product. This leads to a significant saving in production time and energy for NanoGeo.
According to the described examples on the Science Link website, analysis of plant structures, contaminants, germs and roots and soil have been missing, as well as any measurement on actual food. It would be of benefit to RIs in the future to focus on advertising their possibilities to companies in these categories.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Agriculture and Food Science (http://www.science-link.eu/the-offer/agriculture-and-food-science/index_eng.html)

3.2 Chemicals

Four companies of the 39 who performed measurements were categorised as being in the Chemical industry. Two of these were Polish chemical companies who use x-ray absorption spectroscopy (XAS) to study co-ordination chemistry of their chemical catalysts and XRD to characterise the

crystal structure of their catalysts. A third company used x-ray microtomography to visualise cracking in iron-ore pellets during a reaction which is fundamental to the iron industry. Finally, a Polish electronic cigarette company performed an analysis on the liquids used in their products, to compare the concentrations of metals such as arsenic to those found in regular tobacco. During consultation with synchrotron scientists at DESY, it was concluded that the best technique for this problem was actually mass-spectrometry (a non-synchrotron technique) which was then performed by another research branch within HZG. This is an example of successful consultation and collaboration within Science Link's different RIs to find the best solution for a company's needs.
These results demonstrate the use of XAS for chemical catalyst companies, but the use of time resolved measurements for *in situ* measurements should be emphasised.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Chemicals (http://www.science-link.eu/the-offer/chemicals/index_eng.html)

3.3 Construction and Engineering

From 39 received reports, eleven were categorised as "Construction and Engineering" and six of these required the use of XRD techniques while the other three made use of small angle x-ray scattering (SAXS). Four companies who performed XRD were primarily interested in analysis of residual stresses in various metallic components following the manufacturing process and made use of regular XRD as well as energy dispersive diffraction (EDDI). The other two companies who used XRD were interested in investigating fatigue in metal tools which arises during use.
Two of the companies using SAXS have investigated the structural properties in paint formulations to optimise paint compositions and to characterise the processes occurring as paint dries. The final company, JJ X-ray, produces components for x-ray sources and is the only example of an x-ray optics company who participated in the Science Link project. RIs would benefit from providing industrial beamtime to x-ray optics companies to allow them to demonstrate the performance of their devices.
Of the remaining companies, one used x-ray tomography to analyse the spatial distribution of impregnated oil solutions used to strengthen wooden surfaces and the other used XAS to analyse discoloration in PVC furniture exposed to sunlight.
These results show important examples that RIs can use as case studies to demonstrate their value in measurement of stress and strain in mechanical components, analysis for the industries of colours, dyes and pigments, and resistance to corrosion for outdoor materials. According to the described examples on the Science Link website, studies of dynamics of microstructural transformations are absent, as well as analysis of materials used by the oil industry and in automobile tyres, and the use of elemental analysis.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Construction and Engineering (http://www.science-link.eu/the-offer/construction-and-engineering/index_eng.html)

3.4 Environment and Energy

Five of the completed measurements were from companies which can be classified as "Environment and Energy". Sydvatten AB used XAS to study the sludge produced during water purification at a water-treatment plant and ST Ritvanen Oy used XAS to study the water and sediments produced with their own water purification method. Furthermore, Orbital Systems AB used XAS as well as x-ray fluorescence (XRF) to understand the functionality of a novel water filter device for more efficient showers. In this case, the original XAS measurement at MAX-Lab was unable to supply adequate results to the customer, so a further XRF measurement was arranged at DESY to continue the study. It is an example of the cooperation between the RIs in the network to ensure the best results for the customer. Solvoltaics AB from Sweden used photo-electron emission microscopy (PEEM) to obtain high-resolution chemical information about nano-wires used in solar-cell elements, and finally Lutora used synchrotron infrared spectroscopy to analyse materials formed as high-value products from bio-waste.
These diverse studies are an effective advertisement for the RIs ability to assist in development of water treatment technology, solar technology and recycling of waste, however it remains a challenge to RIs to offer more support for companies who specialise in lighting, cooling and heating devices, batteries and thermal insulation.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Environment and Energy (http://www.science-link.eu/the-offer/environment-and-energy/index_eng.html)

3.5 Home and Personal Care

Two companies successfully performed measurements within the category of "Home and Personal Care". One company used SAXS to study the effects of different treatments of starch-encapsulated emulsions used in cosmetics and skin-care products. The other company was a good example of collaboration between industry, university and the RI. The Latvian cosmetics company SIA Dzintars applied for a project, but didn't have a definite proposal for a possible measurement. Following consultation between the industrial customer and the local academic partner in Riga, samples were sent to the University of Riga for test measurements using conventional XRD. These results were used as a starting point for a proposed measurement which was agreed between the company and DESY. Finally high-resolution XRD was used at DESY to investigate structural changes occurring and stability in Dzintars' lipstick samples between -50 – 50°C.
With these results, RIs can effectively advertise their importance to these industries, but further effort can be made to attract customers who are interested in the effects cosmetics on human hair and skin, as well as the aging of cosmetic products.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Home and Personal Care (http://www.science-link.eu/the-offer/home-and-personal-care/index_eng.html)

3.6 Life Science and Biotechnology

Seven of the successful companies are considered to be within the category of "Life Science and Biotechnology". Four of the companies used XAS, one to analyse the chemical structures of pastes used for dental implants while another analysed the coordination chemistry of atoms within nanoparticles designed to be used as contrast enhances for magnetic resonance imaging of cancer tumours. The third attempted to analyse the nature of technicium ions in a system designed for the early detection of cancer, while the fourth combined XAS and SAXS to study metal ions in a polymer matrix within a medical device which will function as a portable kidney. One study involved the analysis of urinary sediments and kidney stones with synchrotron infrared spectroscopy (IRS) to determine a chemical correlation, and found that the synchrotron source allowed analysis of much smaller sediments than can be used with conventional light sources. Another used microtomography to image microstructures in pharmaceutical tablets, and finally one company investigated the operation of their CCD detector with UV synchrotron radiation to test its suitability for device which detects disease from a patient's exhaled air.
It should be noticed that three of the companies which were accepted for a Science Link measurement, but did not succeed in completing a measurement were also from the "Life Science and Biotechnology" category. The projects were concerned with studies of corrosion on bone-graft materials, interactions between bone and implant surfaces and the method of degradation of a nano-particle based wound dressing. These project were cancelled due to factors such as unacceptably long response times by the user so that the relevant RI ran out of time, or the user setting a Terms of Agreement contract that could not be accepted by the RI.
Nonetheless, it is encouraging to see such a broad range of diverse applications of "Life Science and Biotechnology" companies who were a part of the Science Link project. The examples of possible measurements defined on the Science Link website are well represented and even exceeded by the attracted companies, however there was not one company interested in structural biology (protein crystallography or bio-SAXS) for new drug development which is an issue that the RIs should address.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Life Science and Biotechnology (http://www.science-link.eu/the-offer/life-science-and-biotechnology/index_eng.html)

3.7 Material Science and Nanotechnology

Eight companies who submitted a report are categorised in the "Material Science and Nanotechnology" category. These studies consist of a wide variety of measurement techniques and application. Three of the companies used XRD techniques, to characterise the effect of a surface treatment on iron, to analyse stress and strain in a physical vapour deposition coating, and to investigate structural changes in brazen stainless steel components during heating. Two of the companies were interested in analysis of defects and impurities in optical surfaces used for laser technologies, in one case x-ray photo-emission spectroscopy (XPS) was used and in the other

case IRS. A second company used XPS to test for aging in commercial semiconductors. One company used PEEM to tests surfaces of graphene for formation of surface adsorbates during storage and one used synchrotron UV spectroscopy to characterise the electron transitions within new dosimetry materials.
In general this is a satisfactory range of projects for this category, as "Material Science and Nanotechnology" is a very broad term and many other examples from other categories could also have been placed in this category.

User reports, as well as case studies prepared from successful measurements in this industrial category can be found under:
Material Science and Nanotechnology (http://www.science-link.eu/the-offer/materials-science-and-nanotechnology/index_eng.html)

4. Summary and Conclusions

The 66 applications received during the Science Link project has exceeded the results expected from the project directors and managers, and the 49 accepted projects has adequately fulfilled the initial requirement of a total of 40 new industrial users distributed amongst the four participating RIs. The fact that only 39 of these accepted companies actually completed a measurement at one of the RIs is slightly disappointing, but reflects the dynamic nature of industrial research in which changes in staff members and shifting research interests can significantly influence collaboration with RIs. On the other hand, the coincidence of the Science Link project's project period with the permanent shutdown of DORIS III and the long-term shutdowns of PETRA III and BER II also influenced the ability of Science Link to fulfil the customer needs. In the future, similar projects should take such issues into even better consideration.

Applications were received from every country in the Baltic Sea region, with 22 out of 66 applications coming from Swedish companies. The success of Swedish companies can be attributed to the extensive already-existing Swedish networks, as well as the employment of a physicist as a local contact point for companies, who could effectively describe the benefits of the Science Link project to potential customers. The other participating nations should learn from this example in future similar projects.

The majority of received applications (48/66) as well as the completed measurements (26/39) came from the defined industrial categories of "Construction and Engineering", "Material Science and Nanotechnology" and "Life Science and Biotechnology". These statistics demonstrate the importance of RIs to these types of industrial company and have generated a wealth of case studies which can be used as publicity materials for the RIs to advertise their necessity to the general public as well as to future industrial users. The accepted applications demonstrate a variety of diverse range of industrial applications of synchrotron radiation, many of which were not even previously considered by the synchrotron scientists who contributed to the content material on the Science Link website.
The remaining industrial categories of "Agriculture and Food Science", "Chemicals" and "Environment and Energy" were relatively underrepresented and this shows that RIs should make a bigger effort to attract companies from these categories. The measured projects from these

categories include themes such as improvement of fertiliser materials, reduction of pollution and water-wastage, development of solar energy technology and new catalysts for green chemistry. These are issues that have great importance in current global problems such as food shortages, climate change and the need for renewable energy sources and the RIs would do well to contribute more to overcoming these challenges.

28 of the 49 accepted companies required the use of x-ray diffraction or x-ray absorption spectroscopy. This imbalance was already well known to the industrial service groups of the participating RIs and it is not a surprise that most of Science Link's companies also required these techniques, however the completed measurements demonstrate that there are indeed useful industrial application of other techniques such as SAXS, PEEM and tomography and such examples should be developed to promote their use further in the future.

19 of the 49 accepted companies reported that the scientific analysis performed provided useful results which will help their product development while 14 companies reported that they obtained useful results although future measurements would be required. 32 of the 39 companies were satisfied with the help and support they received and with the Science Link project in general. 31 of the 39 companies indicated that the access to RIs was useful to them but only four of them specifically expressed a desire to return for future measurements. It would be of interest to understand why from 14 companies who specified that they require further measurements; only four of them expressed a desire to return for future measurements. One reason is the extremely high costs for regular industrial measurements at a synchrotron source like PETRA III, for an SME of 10 – 50 employees, it can be much too expensive. It is in any case a challenge for the RIs to maintain communication with the attracted larger companies and to keep them interested in future measurements, and to offer some sort of continued support to SMEs.