NMP2-CT-2003-505504

ELFNET

European Lead-Free Soldering Network

Coordination Action

Priority 3 – Nanotechnology and Nanosciences, Knowledge-Based Multifunctional Materials, New Production Processes and Devices

Publishable Final Activity Report

Due date of deliverable: 15th May 2007
Actual submission date: 25th May 2007

Period covered: from 1st April 2006 to 31st March 2007

Date of preparation: 10th May 2007

Start date of project: 1st April 2004

Duration: 36 months

Project coordinator: Dr. Jeremy Pearce
Project coordinator organisation: ITRI Ltd, UK

Revision: 0

1. Project Execution

1.1 Project Overview

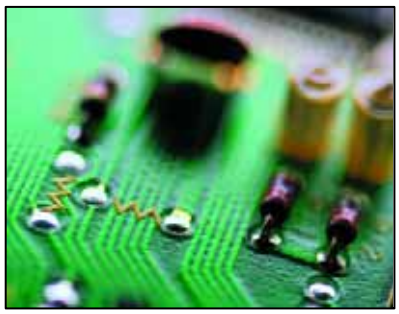
1.1.1 Project Description

Project coordinator
Dr. Jeremy Pearce, ITRI, UK
Technology Information & Forecasting, ITRI, Unit 3 Curo Park, Frogmore, St Albans, Hertfordshire, AL2 2DD, UK. Telephone: +44 (0)1727 871311, Fax: +44 (0)1727 871345, Email: jeremy.pearce@tintechnology.com

Budget
ELFNET had a budget of €2.5 million of which €2.3 million was contributed by the EU.

Term
3 Years (April 2004 – April 2007)

Outline
The EU RoHS Directive requiring removal of lead hazard from electronics production processes in Europe by 2006 is now in force and is in line with similar initiatives in Japan, in the US, and in China, seeking greater sustainability. The necessary lead-free soldering technology exists and had been in development for a number of years but required urgent research and industry coordination on a pan-European scale in order to support the transformation of European industry and improve its competitiveness.



Major EU, Regional and National projects had been initiated with parallel industrial implementation. However, the technology was seriously lacking integration and synergy, particularly with regard to candidate countries, and there is no coherent knowledge base.

ELFNET was a Coordination Action that addressed these problems by using a new organizational model to create a network of research institutions and industry bodies from across Europe. It had a 3-dimensional structure with National Networks in 19 countries, recognized Technical Experts from each field and Industry Networks from each sector. It aimed to mobilize and optimize the necessary critical mass of research and development in an industry-led initiative and to provide technical information to each Member State.

1.1.2 Project Objectives

The overall strategic objective of the project was:

"To urgently coordinate, integrate and optimise the critical mass of European research in lead-free soldering; providing pan-European support for implementation of the RoHS Directive"

By the time ELFNET was granted EU funding, the group has been informally assembled over 2 years and already included coordinators of all major EU research projects and representatives from major National projects, EUREKA, IMS and COST projects. Thus ELFNET was in a unique position to achieve this objective.

Specific objectives were:

- *To focus research activity within key technical field and industry sectors*

This was to be achieved using Technical Expert Groups (TEG) and Industry Networks (IN) to review state-of-the-art, collate data, identify research gaps and nurture new projects. Outputs were to be sets of Technical Review and Industry Review reports, accessible to the public. This benchmarking was to be enhanced in a specific workpackage dedicated to status research, gathering and publishing pan-European information on industry implementation as 3 Annual Status reports. By the end of the project ELFNET aimed to have nurtured at least 5 new collaborative projects in the focus areas identified, collectively worth at least €10 million.

- *To refine R&D strategies of both research and industry organisations.*

ELFNET recognised the importance of being strongly industry-led through both Technical Expert Groups and, in particular, 4 sector-specific Industry Networks. Bridging the gap that existed at the time between industry and research was a key to optimising effort. Industry guidance was to be provided directly to the European research community, whilst at the same time RTD/University research will be brought into intimate contact with the market. The end result was an initiative that would refine direction, accelerate exploitation and reduce time-to-market. In its Core Member Group, ELFNET brought together 19 key research organisations with 17 of Europe's top electronics companies in around 36 meetings. Data generated was to be directly disseminated to additional Affiliate Member organisations, numbering at least 200 by the end of the project, and made available to at least 100,000 visitors to the website.

- *To link existing Regional and Technical networks*

Coordinators and participants from all of the identified networks were represented in ELFNET, creating a strong mechanism for synergy. Achievement was to be measured by successful exchange of signposting information between ELFNET and all other networks and at least 1 exchange meeting with all existing networks. A representative from each network should be an Affiliate member of ELFNET.

- *To harmonise and signpost the European knowledge base, adding value to technology dissemination projects*

The ELFNET infrastructure was to be capable of adding unique and important value to EU and National dissemination projects, including dissemination of data from research projects. The European scope was to be widened and the information harmonised. A budget was allocated within ELFNET for translation of information into local language, without which information would be useless to non-English speaking technologists, possibly the majority of end-users. ELFNET aimed to identify and signpost every trans-national collaborative lead-free soldering project, all major National projects and every significant knowledge source in Europe. An additional objective was to have used the ELFNET infrastructure to relay disseminated information from at least 30 such projects in line with their Exploitation Plans. This project information was to be disseminated to the 37 Core Members and at least 200 Affiliate Members and made available to at least 100,000 visitors to the website.

- *To provide a focal interface point for European lead-free soldering technology*

ELFNET represented a pan-Europe network of RTD's as National Representatives reaching at least 19 member states. Its organisational model also had both technical and industry dimensions. Thus it provided an opportunity to make a significant contribution towards the European Research Area, creating a new technology organisation capable of interfacing nationally and internationally with trade associations, environmental associations, media, National and EC policymakers and standards organisations. This improved integration was to be visible through the project website with contacts databases, weblinks and organisational details for all Core Group and Affiliate members. It is expected that the Affiliate membership, representing key research and industry players, would grow to at least 200 by the end of the project.

1.1.3 Project Consortium

The project was coordinated by ITRI and included the following 19 research organisations and 15 industry organisations.

1. ITRI Ltd (UK) – Jeremy Pearce, project coordinator
2. DELTA - Danish Electronics, Light & Acoustics (Denmark) – Kim Zacchariassen
3. EMPA - Swiss Federal Laboratories for Materials Testing and Research - Guenter Grossmann
4. Helsinki University of Technology (Finland) - Jorma Kivilhati
5. IMEC - Interuniversitair Micro-Elektronica Centrum (Belgium) - Bjorn Vandecasteele
6. Fundacion INASMET (Spain) - Cristina Jimenez
7. Institute of Mechanics of Materials & Geostructures S.A. (Greece) – Paul Michelis
8. Institute of Physics of Materials, Academy of Sciences (Czech Republic) – Ales Kroupa
9. ISQ - Instituto de Soldadura e Qualidade (Portugal) - Maria Margarida Pinto
10. IVF Industrial Research & Development Corporation (Sweden) – Dag Andersson
11. Ecole Nationale Supérieure Electronique Informatique Télécom Bordeaux (France) – Christian Zardini
12. NMRC - University College Cork (Ireland) – Finbarr Waldron
13. Politecnico di Milano (Italy) – Pietro Cavallotti
14. TNO Institute of Industrial Technology (The Netherlands) – Jan Eite Bullema
15. Institut für Anorganische Chemie, Universität Wien (Austria) – Herbert Ipser
16. Technische Universität Berlin (Germany) – Karl Heinz Zuber
17. SINTEF Electronics & Cybernetics (Norway) – Dag Ausen
18. Institute of Metallurgy and Materials Science, Polish Academy of Sciences (Poland) – Zbigniew Moser
19. Institute of Physics of the Slovak Academy of Sciences (Slovakia) – Petr Svec
20. ABELIA (Norway) – Knut Aune
21. BAE Systems – Avionics Systems Division (UK) – Clive Simmonds
22. Marketing & Technologies Avancees (France) – Jorge Viera da Silva
23. Celestica Ltd (UK) – Brian Smith
24. Solectron (Germany) – Siegmund Zweigart
25. FCI France (France) – Laurent Tristani
26. Schneider Electric (France) – Xavier Lambert
27. Heraeus GmbH (Germany) - Matthias Scheikowski
28. Henkel Loctite Adhesives Ltd (UK) – Hector Steen
29. P and A Europe (UK) – Andy Longford
30. Philips Electronics Nederland B.V (The Netherlands) – Jacob Klerk
31. Hewlett Packard (France) – Patrick Rouband
32. Robert Bosch GmbH (Germany) – Wolfgang Nuchter
33. Siemens AG (Germany) – Bernd Schwarz
34. AMI Semiconductor Belgium BVBA (Belgium) – Eddy Blansaer
35. Avantec s.a. (France) – Fabrice Pires

1.2 Work Performed and End Results

1.2.1 Work Programme Structure

The work programme for the project was loosely based on experience of successful growth of networks. With the ultimate aim of creating self-governing and sustainable sub-networks, the planned growth cycle was described thus:

Year 1 - Initiate, publicise, recruit, identify – issues, projects, information providers
Year 2 - Engage, grow, find solutions
Year 3 - Deliver, measure, forecast

1.2.2 Initiation

The initial focus was on the creation of a strong brand and good communication tools. ELFNET was to be an ambitious initiative in a strongly topical field with a legislation-driven industry deadline for technology implementation. To achieve success it was vital that the project had high visibility and a strong identity to command attention, as well as to be able to communicate efficiently with a highly fragmented and heterogeneous audience.

This was achieved in facilitated branding meetings, linked with production of high quality graphics, template materials, business cards and a set of descriptive summaries. The project logo was developed from a creative combination of the concept of linked communities with the image of electronics interconnection on a circuit board. This identity was projected onto the project website, project fliers and an exhibition stand.

The chosen website technology was based on a leading-edge virtual community platform, amongst the first of its kind. The technology included membership management, newsletter preparation, discussion forums and other features specifically for network building. It was database driven, enabling easy desktop operation. A key feature was the ability for members of the network anywhere in the world to be able to post data including profiles, news, events or documents.

The website also included 30 linked sub-sites, supporting the individual national, technical and industry sub-communities, as well as special Administration and Nursery areas for project operations.

The website can be found at: http://www.europeanleadfree.net. The site was fully built and live within 5 months, in August 2004, ahead of schedule.

The project was formally initiated at a kick-off meeting in May 2004 at ITRI, UK, bringing together 40 partner representatives from 19 countries for the first time. The

project identity and tools were presented to the partners and planning of the workpackages was detailed. Planning documents were subsequently circulated.

Figure 1 - ELFNET Kick-Off Meeting, April 2004

Thus ELFNET's unique 3-dimensional infrastructure was created, based on National Networks in 19 countries, Technical Expert Groups (TEG's) in Soldering, Components, Assembly, Reliability and Recycling plus Industry Networks (IN's) in Consumer, Automotive & Industrial, IT & Telecoms, Aerospace & Defence industry sectors. These are described below:

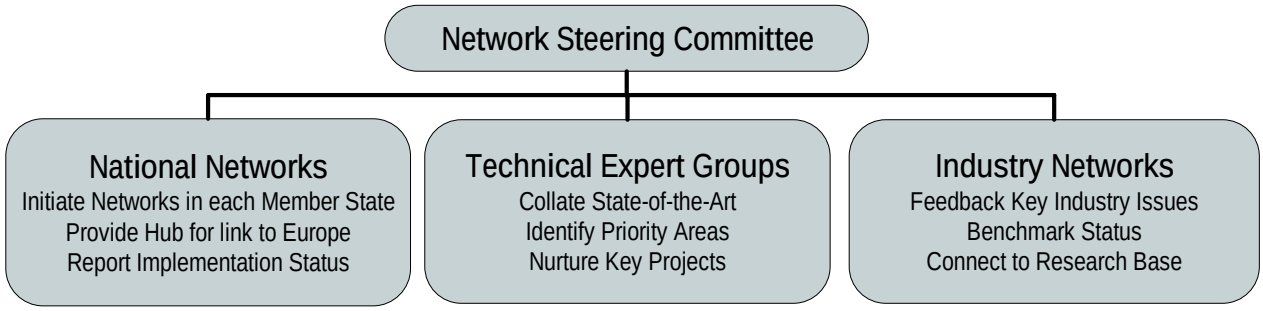


Figure 2 - ELFNET 3D Network Structure

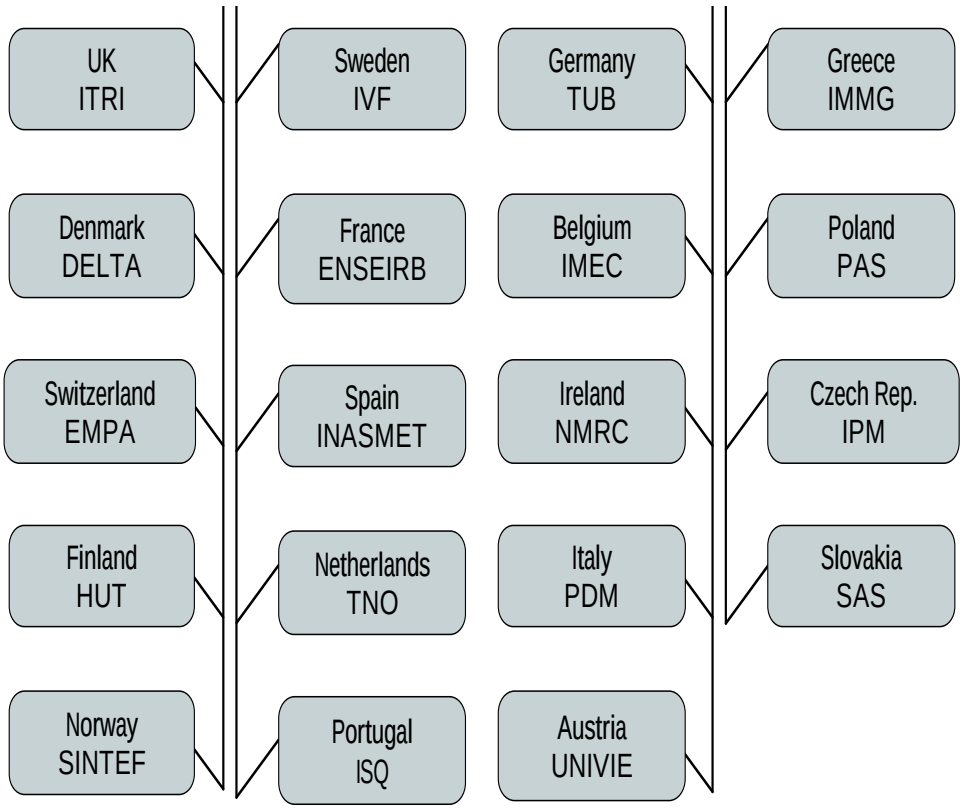


Figure 3 - ELFNET National Networks

The 19 National Representatives replicated the ELFNET activities on a national basis, recruiting new members, holding lead-free meetings and seminars, publicising the project and disseminating technical information. New members were joined to the national networks either as Affiliate experts, or as Subscribers. This pan-European structure was unique in scale within the electronics industry.

The Technical Expert Groups and Industry Networks were created. Membership grew over the 3-year project term to include around 300 Affiliates, 50% more than the target of 200. Each was joined, free of charge, via the website, on the basis that they were resident in Europe, had research experience and would be prepared to contribute knowledge to the project. Each was classified as an expert in their field, with individual and company profiles available on the website, and joined one or more networks of their choice. Group Leaders took responsibility for managing and communicating with their membership.

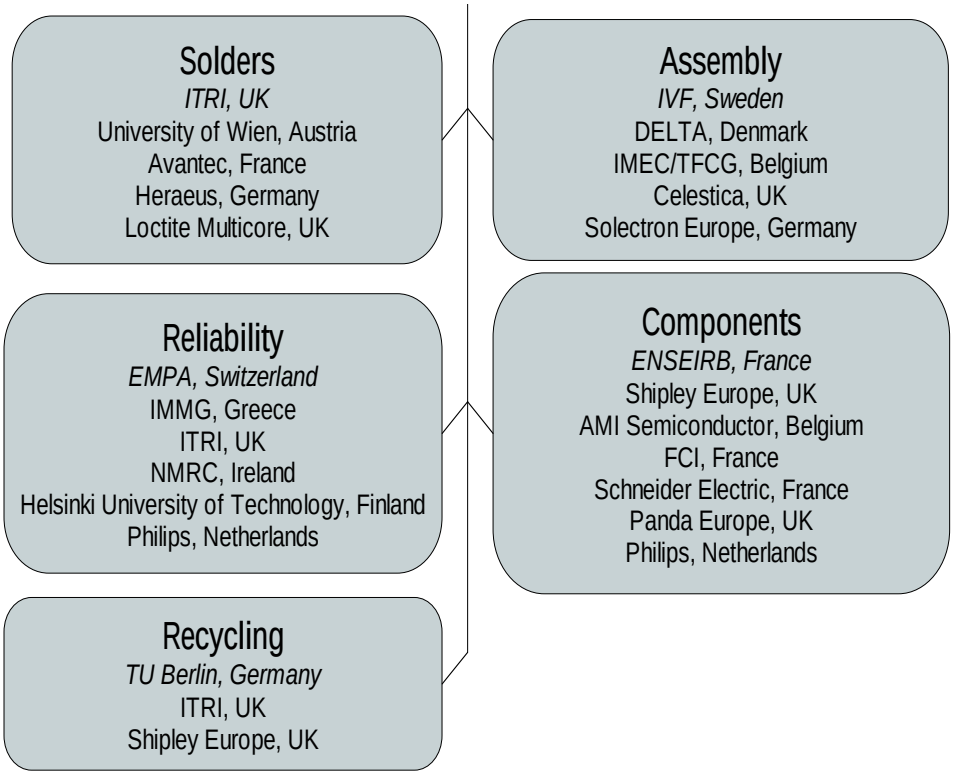


Figure 4 - ELFNET Technical Expert Groups

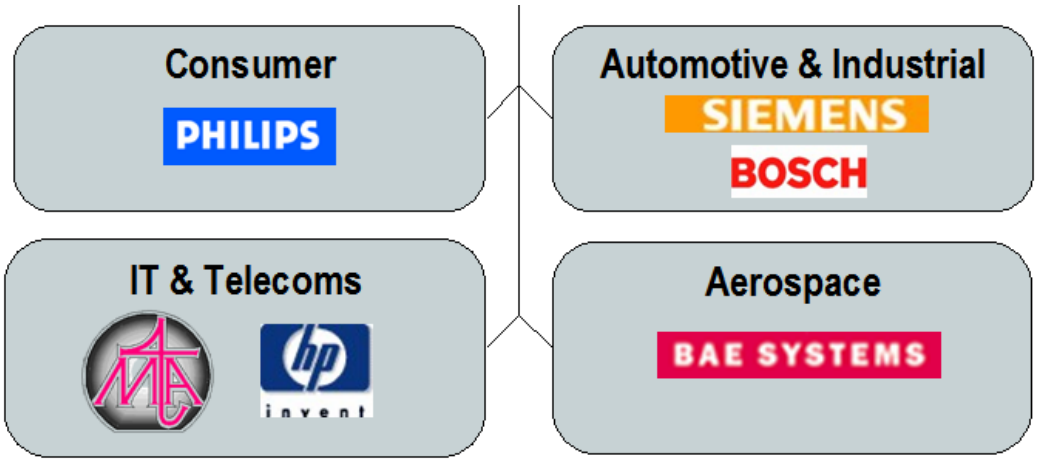


Figure 5 - ELFNET Industry Networks

At the same time a unique lead-free soldering project database began to be created on the ELFNET website, with coordinator contact details and disseminated information, eventually totalling 120 global lead-free research projects. Some projects purposely used ELFNET as a dissemination route. The database was a unique source of information on state-of-the-art and important in meeting the objective of refining research strategies. Previously there had been a serious lack of information about what had already been done in the field.

Other networking data on the site includes links to other key industry and research consortia and agencies.

1.2.3 Communication

The ELFNET website grew to become a primary source of information on rapidly changing developments in key areas of lead-free soldering technology relating to the business logistics of lead-free technology as well as the broader issues of RoHS compliance, including, for example, materials declaration, marking & labelling and standards. It contains detailed and searchable technical information, as dedicated topic webpages, technical forum posts and uploaded reports and presentations.

Website ‘push’ technologies were also fully exploited. This included electronic newsletter preparation and distribution and dissemination of key information and news as email bulletins to the whole membership or to relevant sub-networks. The site newsfeed became a powerful and authoritative source on latest developments in the field. This was syndicated to at least two other website newsfeeds through RSS and items were quickly replicated by other news websites. New posts resulted in website visits, sometimes within minutes, from key players globally.

Site traffic was monitored closely and grew steadily through the project term. Such statistics are always confused by search engine robots and duplicate logging effects, but a figure equivalent to 250,000 visitors per year towards the end of the project is not unreasonable, exceeding the target of 100,000.

Seven formal Press Releases were issued during the course of the project, receiving good coverage from European and national journals and in particular from news websites. Towards the end of the project a WebTV interview about the project was broadcast by the Evertiq website.

As mentioned above, publicity was replicated across the 19 national networks. Slovakia and Poland produced their own mirror websites in local language. Some Press Releases were translated and issues nationally. During the project information about ELFNET was presented at more than 60 European and national meetings and conferences and articles authored or facilitated by partners were published in national trade publications across Europe.

The exhibition stand was used for at least 2 European events each year, to publicise the project, as well as to increase awareness of the lead-free soldering technology

issues and disseminate project knowledge. ELFNET also provided sets of exhibition seminars at the SEMICON Europa event in Munich, Germany, April 2006 and the Electronix Fair in Gothenburg, Sweden, September 2006.

Figure 6- ELFNET Seminars at SEMICON Europa 2006

At the SEMICON Europa event, ELFNET also brought together poster presentations from all ten key European research projects in lead-free soldering in the ‘Lead-Free Village’.

Figure 7 - ELFNET 'Lead-Free Village' at SEMICON Europa, April 2006

1.2.4 'Issues to Solutions'

In the first year, the Technical Expert and Industry networks began to meet, setting a pattern of two large pan-European meetings per year. New technical data was presented and industry began to exchange valuable information on their own company progress in implementation of lead-free technology – all of which was further disseminated on the project website. The first sets of technical and industry review reports were published.

Each network was tasked with producing and prioritising a list of key implementation issues related to their particular market or technology perspective. Work from these groups was collated in December 2004 to produce a harmonised list of 54 key Issues remaining for lead-free soldering implementation, published in the ELFNET Issues to Solutions Matrix.

An 'Issues to Solutions' initiative then prioritised 18 issues for allocation of ownership, identification of project champions and formation of working groups. The initiative was launched at a project meeting in Eindhoven in March 2005 and several project champions came forward to lead the Solutions initiatives.

These Solutions were developed over the next year, reported via the ELFNET website and presented at a major industry event - SEMICON Europa in April 2006

Issue	Definition	Project Champion	Solution
Materials Declaration	Reporting required for RoHS compliance but lack of harmonisation	Jeremy Pearce, ITRI	- Webpage to track developments - Newsfeed - ZVEI identified as Europe actor - ZVEI info at meeting September 2005 - ZVEI meeting January 2006 - ZVEI presentation April 2006 - Tracking of IPC 1752 & IEC standards developments
Component Numbering	Some suppliers will not change PN's – affects logistics, compliance etc	Jeremy Pearce, ITRI	- Webpage to track developments - Newsfeed including industry survey results - Real-world pragmatic solutions, in-house renumbering, distributor relabelling etc
Marking & Labelling	Some new standards but not fully harmonised or used in practice	Andy Longford, Panda Europe	- Webpage to track developments - Newsfeed - New Japanese standards highlighted January 2006 - Contact made with IEC TC91 WG3 - IEC will not pursue global standard *(this now under review)* - IEC presentation April 2006 - Tracking of IPC/JEDEC US standards

Patents & IPR	Effects on use restriction and price unknown	Andy Longford, Panda Europe	- Webpage - Not possible to discuss openly, info limited - Market impact possibly not as great as initially feared
Component Availability	Supply restriction for lead-free components	N/A	- Monitor status and relay information - Presentation from leading distributor April 2006 - In practice did not measurably affect implementation ultimately
Obsolescence	RoHS-exempt sectors (aerospace, defence, automotive) may not be able to source SnPb components	Clive Simmonds, BAE Systems	- Webpage to track developments - Work with Components Obsolescence Group (COG) - Sponsor GOG RoHS Guidance booklet, joint press release - COG presentation April 2006 - Link with IEC standard WG - Real world pragmatic solutions, inventory stocking etc.
Standards	Need to be updated for lead-free technology	Andy Longford, Panda Europe	- Webpage to track developments - Status presentations at several ELFNET events - US making most progress, IEC, EU processes still lagging
RoHS Support to SME's	Major projects not cooperating	Geert Willems, IMEC	- GREENROSE, LEADOUT, LFS-for-SME's, LEADFREE brought together in a meeting October 2004 - Posters from all at ELFNET Village April 2006 - LEADFREE presentation April 2006 - Joint Dissemination Event March 2007
Laminate Stability	Laminates for large boards degrading, warping under lead-free processing temperatures	Dag Andersson, IVF	- Webpage to track developments - iNEMI, US work highlighted - IVF in-house round-robin project - Presentation by Philips April 2006 - Presentation by leading producer Isola April 2006
Repair & Rework	Effect on reliability unknown, poor wetting, component damage	Anders Ekeloff, Ericsson	- Ericsson presentations at ELFNET events - LFS-for-SMES presentation on hand soldering - Equipment improving, better operator training should solve
Tin Whiskers	Phenomenon related to lead-free surface finishes – danger of failure due to shorting	Antonello Vicenzo, Politecnico de Milano (PDM)	- Detailed technical webpages on Test Standards and Mechanism - Newsfeed - PDM presentations at several ELFNET meetings - ELFNET Web/Email Forum for members discussion

			- Links to iNEMI, US and other groups - Technical work largely in closed industry groups
Intermetallics	Solder/finish compatibility issues due to complex intermetallics formation	Tomi Laurila, Helsinki University + Per-Erik Tegenhall, IVF	- Detailed latest technical data presented at ELFNET meetings - IVF Literature review - IVF Swedish national project
Solder Alloy Properties	Basic property data needs collation and publication	Clemens Schmetterer, University of Vienna	- Joint initiative with COST 531 project - Database for industry standard SAC alloy family launched as pdf on website, Press Release April 2006 - Updated version with binary alloy data to be released May 2007
High Temperature Solders	No economically viable replacement for high lead solders used in component packaging	Jacob Klerk, Philips	- Topic important but no new ideas - Some new Japanese work reported - New COST MP0602 project will explore new alloys
Heterogeneous Assembly	New advanced process technologies needed to assemble large and very small components on the same board	Jacob Klerk, Philips	- Project consortium assembled - Several meetings held - Future interconnection specifications roadmapped - Proposal targeted for F7 December 2007 Call
Reliability Data Exchange	Exchange of reliability data is needed to resolve trends and harmonise interpretation	Bart Vandevelde, IMEC	- Website created for database - 6 partners contributed datasets - Insufficient momentum, willingness to contribute - Abandoned
Reliability Test Methods	Test methods lack harmonisation, still in development	Dag Andersson, IVF	- 11 meetings of Europe experts to discuss and develop concepts - ELFNET Web/Email Forum for members discussion - All known lead-free quality defects and failure mechanisms listed - Delegated to individual experts to produce state-of-the-art report and test recommendations - Launched, published as ELFNET Quality & Reliability Colour Books, pdf file web downloads, distributed to 500 members March 2007 - Book publications in discussion with Springer, IPC

Harsh Environments	Lead-free technology issues under extreme conditions not fully understood	Bernd Schwarz, Siemens	- ELFNET Web/Email Forum for members discussion - Presentations by experts on various environments October 2005 - Links made with CAVE, Auburn University, US
WEEE, RoHS National Regulations	Situation in different member states not well-known	Karl-Heinz Zuber, Technical University Berlin	- ELFNET discovered and circulated Perchards Report and other similar data

1.2.5 Roadmapping

During the final year of the project, Year 3, the RoHS Directive implementation deadline passed and it was time to build on the previous work to look forward towards the next 10 years. As the majority of solder in use was moving towards lead-free, the topic was at the same time broadened to include the whole of electronics interconnection, including nanotechnologies and component packaging.

The ELFNET knowledge base was integrated with existing industry roadmaps, including the major IPC, iNEMI and ITRS documents, to produce an initial draft text, with tables of topics, with R&D directions for each highlighted.

A series of meetings was held, including all ELFNET partners, to refine the tables, prioritising the topics and setting timescales. The first meeting was at the Electronix Fair, Gothenburg, Sweden in September 2006. Other meetings were hosted by BAE Systems, Rochester, UK in December 2006 and by BOSCH, Stuttgart, Germany January 2007.

The final version of the ELFNET Roadmap – 'The Future of Electronics Interconnection', presented 50 high priority challenges and highlighted associated R&D needs over the next decade. This was launched, along with other key data at a major dissemination event in San Sebastian in March 2007.

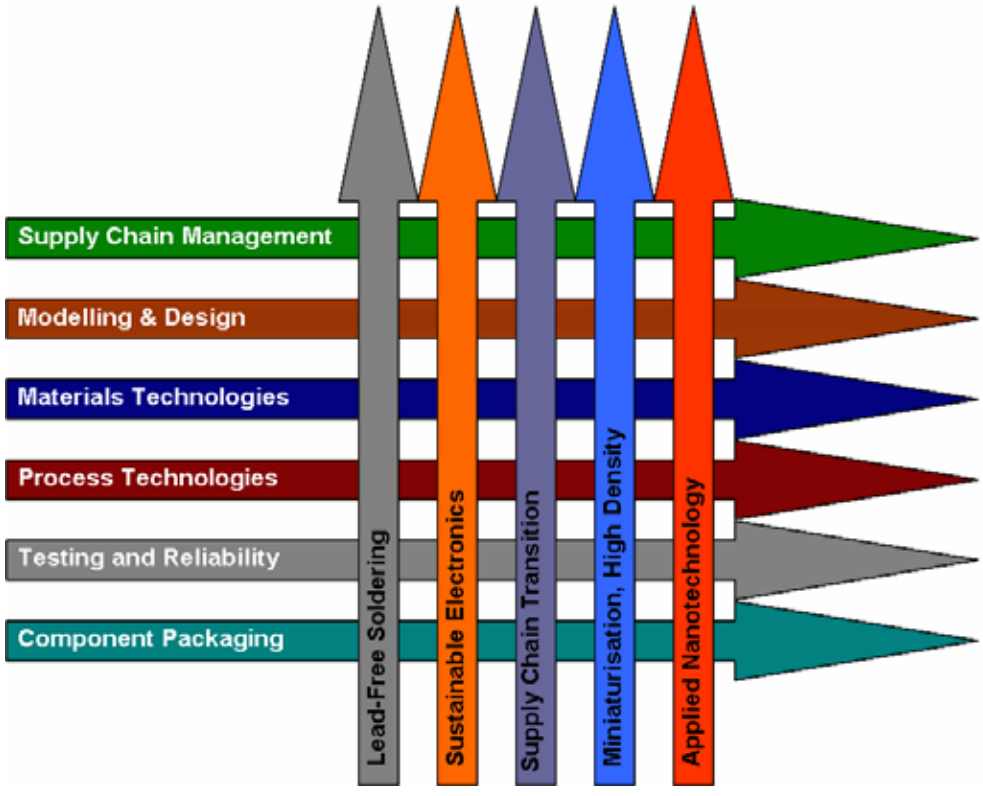


Figure 8 - ELFNET Roadmap Structure

High Priority				
Issue	Challenges	R&D Needed	Notes	Target
Lead-Free Solders	High reliability solders	Evaluation of the contribution of solder joint properties within holistic model of product reliability	Include mission profiles	2015
		Modification of SnAgCu alloys e.g. additions of ternary elements, nanoparticles to improve ductility, strength, improved sintering via nanoscience	Needs meaningful data and specifications	2015
Lead-Free Finishes	Low cost, high quality finishes	Development of Sn, OSP finishes to match flatness, barrier properties, durability of NiAu, Ag, Pd-containing solutions	Needs measurement values, quantified effects. Number of OSP reflow cycles e.g.	2010
		Development of combined immersion Ag/organic finish suitable for both soldering and wire bonding		2010
	Intermetallics control	IMC growth reduction technologies for drop test resistance, increased shelf life	Needs fundamental knowledge of IMC process	2015
Substrates	Thermally resistant laminates	Minimisation of warping during processing	Needs mechanism measurement methodologies	2015
Halogen-Free Materials	Non-Phosphorus fire retardant systems	New halogen-free fire retardant technologies for substrates, component packaging, cables e.g. ZnSn, Mo, nanoclays		2010
CTE Matching	Thermally compatible vias	New ductile polymer, metal materials for vias		2015

Figure 9 - Example of ELFNET Roadmap Topic Table

1.2.6 Implementation Status Surveys

A specific workpackage was dedicated to monitoring implementation status of lead-free soldering technology across Europe. This built on earlier work by Soldertec.

Methodology was based on distribution of questionnaires through ELFNET and other industry networks. In the last year a prize draw was used at two European exhibitions to increase responses. These were analysed, and results reported annually. The exercise started from a baseline in 2004 and bridged the RoHS Directive implementation deadline of July 2006.

The focus of the studies was on materials used; tracking changes in the variety of alloys and finishes for example. Other elements included equipment changes, remaining problems and information aspects. The 2005 survey included questions over marking and labelling, since this had been highlighted as an issue by ELFNET.

Results were announced and distributed on the ELFNET website and reached a wide audience.

Some interesting conclusions from the 2006-7 survey were:

- Although 50% of respondents were not mandated to comply with the RoHS Directive, 75% were using lead-free solder
- The number of alloys and finishes appeared to have increased in diversity rather than harmonised
- The SnAgCu (SAC) alloy has grown in favour to around 70% of lead-free solder used in hand, reflow and wave soldering.

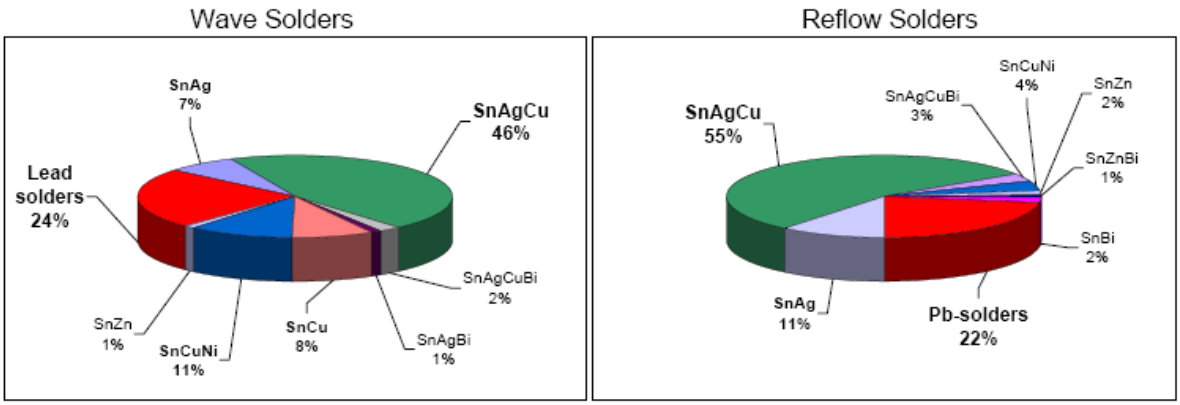


Figure 10 - Results from 2006-7 ELFNET Lead-Free Implementation Status Survey

1.3 Achievements in Relation to State-of-the-Art

1.3.1 Background

In February 2003 the EC published Directive 2002/95/EC - Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS). This required that by 1st July 2006 at the latest, Member States should ensure that new electrical and electronic equipment in major use categories does not contain lead and other hazardous substances. This required implementation by virtually the entire European electronics industry of a new environmental technology - lead-free soldering - within 3 years.

The Directive not only followed global trends in lead substitution across the board, but also targeted the major electrical and electronic equipment waste stream, currently disposed of mainly by landfill or incineration. The RoHS Directive accompanied the Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC giving producers responsibility for collection and recycling. The two Directives are linked in that the presence of hazardous materials in electronics scrap increases the costs and difficulties of recycling.

6 million tons of electronic scrap is produced in the EU and this is expected to nearly double over the next decade. The problem is matched across the world and has been highlighted in Japan where landfill is severely restricted and, for example, in the US where there has been concern from environmental groups at the shipment of large quantities of scrap to China for primitive and hazardous material recovery operations.

The original work on lead-free soldering technology began as a result of the Reid Bill in the US in 1990. Senator Reid was calling for a broad-based lead ban, including lead in electronic solders. After strong opposition from the US electronics industry this aspect was eventually dropped.

However Japanese researchers began to develop new alloys and soldering process technologies. This move resulted in Japan being the world leader in implementation of lead-free electronics technology. Panasonic led the world with production of the world's first mass-produced lead-free product – a Minidisc player – in 1999. The majority of Japanese production, including that exported into the EU, was reported to be lead-free by 2005.

The Reid Bill also initiated work in Europe, pioneered by ITRI, the coordinator of the ELFNET project. ITRI is an R&D organisation, funded by the tin-producing countries of the world and following technology developments with potential impact on tin markets. ITRI coordinated what was probably the world's first collaborative project in lead-free soldering in 1991-1993. It was a UK National project with GEC, Multicore Solders and BNR Europe (now-Nortel), based on earlier ITRI work on lead-free plumbing solders in the 1980s. The project initiated the process of alloy selection, screening many candidates using a broad range of tests including solderability,

mechanical properties and supply potential. ITRI and others, mainly in the UK and Scandinavia, continued this work throughout the 1990s.

A major milestone for Europe was the BRITE-EURAM-funded IDEALS project in 1996-1999, evaluating the candidate alloys in production scale trials.

By 1999 driving forces for lead-free soldering technology were growing rapidly with the draft of the WEEE Directive tabling a date of 2004 for implementation and Japanese progress beginning to add market pressures. ITRI launched SOLDERTEC, the Lead-Free Soldering Technology Centre, and at the same time recommended the use of SnAgCu alloy as a general purpose replacement for SnPb alloy. This lead was followed by iNEMI, a major industry research group in the US, meeting at the 1999 US IPC Lead-Free Conference 'Get the Lead Out'. SnAgCu alloy is now the major alloy in use for lead-free assembly.

ITRI and others in Scandinavia and additionally in Germany began to be involved in technology status research, awareness activities such as websites and publications, training, and new research focussed on process and implementation issues. Links were made with Japanese and US research and industry organisations. Technology development began to accelerate.

ELFNET – the European Lead-Free Soldering Network – began in May 2000 at a meeting of the COMPETE Thematic Network, called after an IDEALS follow-on EU project proposal had been rejected. Working Groups were established in the various fields of lead-free research and a networking group, led by ITRI was initiated. It initially included 6 RTDs and 12 industry players.

The activity was submitted for funding as a part of the unsuccessful COMPETE PI3 proposal in April 2001. ITRI held ELFNET meetings in October 2001 and October 2002, at which all EU and many National and Regional lead-free soldering projects were represented and the future of the network discussed. This resulted in submission to the Framework 6 Programme of an EoI for CONNECT (European Electronics Interconnection Network) in June 2002, subsequently re-formed into the Coordination Action ELFNET, with 19 RTD's from 19 Member States and 16 electronics industry players, including market leaders. The project began in April 2004.

1.3.2 State-of-the-Art in 2004

The IDEALS project was the first and only EU-funded project until it finished in 1999, apart from the ASTRAL project 1998-2001 that attempted to develop a novel and rather esoteric lead-free alloy.

Nationally-funded projects had continued, mainly associated with Universities and focussing on alloy development and characterisation as well as solder joint modelling and reliability aspects. Examples were:

- IMR Lead-Free project developing lead-free soldering technology mainly for telecoms, coordinated by Helsinki University of Technology, Finland

- INNOLOT project developing lead-free solders for automotive and other heavy-duty applications, coordinated by University of Bayreuth, Germany

- DESREL project developing lead-free solder interconnects for portable ICT applications, coordinated by University of Limerick, Ireland

- NORDIC Lead-Free Project – coordinating lead-free research and dissemination in Sweden, Norway, Finland and Denmark.

There were no further EU-funded projects until IMECAT began in April 2002. This was a large-scale assembly-based project coordinated by IMEC, Belgium. A further project, PROTIN, began in June 2002 studying the tin whisker phenomenon associated with lead-free component coatings. A CRAFT project – LFS-for-SME's, looking at hand, condensation and laser soldering with an SME perspective, began in April 2003, although its work was delayed for about a year. GREENROSE was a major SME dissemination and training project, commencing in June 2004. All of these projects would not deliver until 2005-2007, with the industry RoHS Directive implementation deadline at 2006.

Two other major projects funded under other initiatives were:

- LEADFREE – EUREKA project - a detailed study of reliability issues, coordinated by EMPA, Switzerland

- EFSOT – IMS project – a basic assembly project with emphasis on environmental aspects such as LCA, recycling and biological impact. Linked to Japanese and Korean research.

This illustrates both the sparsity, fragmentation and belated nature of the European research effort in the field as it was when ELFNET started. Most of the projects had arisen independently and there was no existing effective mechanism for coordination or communication of research activity on the pan-Europe scale. The urgent need for a pan-European network to fulfil this role in the run-up to 2006 was obvious and ELFNET was created to address these issues.

The pace of lead-free soldering technology development was accelerating rapidly and there was a very significant gap between industry research and research by RTD's and Universities. Industry research was flexible, shorter-term and closely followed the industry need for action. For example, in the Automotive sector the German industry was already networking strongly and making significant research progress. On the other hand, as illustrated above, RTD/University research involved time lags of up to year for initiation and 2-3 years to deliver, fixed within the particular programme orientation of the funding body and a long way behind industry progress. A clear example of this was a continued generation of proposals by universities to develop new lead-free alloy formulations when 10 years of research and industry implementation had already determined this issue.

The Nordic group referred to above and German groups such as the Blei-Frie Electronik Expert Circle coordinated by Technolab GmbH, represented Regional networks that had already developed over the previous 2-3 years.

There was additionally the COST 531 Network, coordinated by University of Vienna, representing a significant body of university expertise in solder alloy metallurgy, including thermodynamic modelling and property measurement. These groups were to find significant synergy within ELFNET.

Disseminated information on lead-free soldering was available but from a number of different sources and usually on a National basis. Some RTD's and industry associations were involved in lead-free training, seminars and workshops, particularly in the UK, Scandinavia and Germany. Some review or specialist articles had been published in the trade press. Most solder companies and some RTD's had been involved in customer trials and 1:1 presentations. There were some lead-free soldering websites, notably the ITRI-hosted website www.lead-free.org.

1.3.3 ELFNET Impact

Industry implementation of lead-free soldering technology accelerated markedly towards 2006 as expected. ELFNET became a primary reference source for technical and legislative information, as well as an infrastructure capable of coherently communicating on a national level. Participation in its collaborative activities was enthusiastic and both research and industry communities were open about their own work.

The expected large-scale publicity and urgency around the July 2006 deadline did not in fact materialise. This could be due to industry being better prepared than predicted, a smaller affected proportion then estimated or perhaps low-key enforcement by member states. Almost certainly ELFNET played a part.

The pace of industry take-up meant that much of the work became locked into major industry consortia or made proprietary, leaving more academic research groups seeking a useful role. ELFNET worked hard to leverage its strengths in bridging this gap, demonstrating examples of targeting academic outputs towards direct use for industry and at the same time giving focussed industry guidance on priority topics.

ELFNET successfully identified and engaged key players from research, industry and standards organisations in relation to the issues under discussion and created opportunities for them to present key information to the wider audience. In this way critical information known by the few was communicated to the many.

There were in fact few new large-scale projects. On the European scale, Framework 6 expired, giving a virtual 2-year funding gap until early 2007, as ELFNET ended. Some new National projects were initiated, focussing on high reliability.

By contrast with Europe, work in the US by groups such as NEMI, IPC and JG-PP acquired a high profile and is now leading much of the work, including that on standardisation, for example. In the case of standards there is still much disharmony globally, and this is likely to continue for some time. The greater and faster investment and more coordinated approach in the US are having an impact. As mentioned above, Japanese industry was reported to be fully lead-free by 2005. ELFNET reported on rapid moves in China, Taiwan, Hong Kong, Korea and latterly the US, towards similar legislation and these are also now in advanced stages of implementation.

By putting in place a coherent pan-Europe research and industry-based infrastructure ELFNET intervened directly in the research agenda, signposted business-critical information, unified the knowledge base, provided vital networking and added significant value to research projects.

Economically, ELFNET aimed to significantly minimise technology transition costs at both company and European level. It actively promoted the development of real-world solutions to implementation obstacles, and gave pan-European support to an electronics industry facing the July 2006 deadline for compliance.

Technically, the ELFNET Roadmap and other reports will provide lasting guidance and a future vision for electronics interconnection to the European research community in completion of the global transition to lead-free soldering over the next decade. The Roadmap includes extensive information on state-of-the-art in 34 key interconnection topics and is offered as a major contribution to European industry and research communities to aligning future research efforts.

The greatest challenge remains the lack of knowledge on reliability technologies associated with lead-free soldering. This is of particular concern to high reliability sectors such as aerospace and defence, currently not included in the RoHS Directive scope but under pressure to conform. The ELFNET Reliability network has held several meetings in the final year of the project resulting in the publication on the Colour Books as an important step forward in the key issue of harmonising test methods. This network is now seeking ways to continue operations beyond EU ELFNET funding, where an important step will be linking with parallel efforts in the US.

Ultimately much of the impact of a coordination project such as ELFNET is intangible and unmeasurable. Traffic to the website increased rapidly over the term to a very significant level. Information was relayed globally through the press, internet and connected personal and industry networks. Knowledge and visibility of each of the partners was raised throughout the project and has already resulted in increased opportunity in terms of new research proposals, improved information and training offerings as well as more cost-effective industry implementation.

The main result of ELFNET has to be the unquantifiable but lasting benefit of getting to know others in the field. ELFNET was a unique experiment in bringing together Europe’s key players in electronics interconnection, including university professors, workers in Europe’s leading research centre and researchers from Europe’s

electronics industry leaders. These came from at least 19 member states, with most being represented at ELFNET meetings. Those who took advantage of these unique opportunities will hopefully reap benefits for years to come.

1.4 More information

More details and access to the ELFNET knowledge base are provided on the ELFNET website: http://www.europeanleadfree.net

2. Dissemination and Use

ELFNET was a networking project, without funding for research. It is thus not possible to describe results as specific new technologies developed for further exploitation by individual partners.

2.1 ELFNET Knowledge Base

Instead the project partners, along with other Affiliate members of the project, built a collective knowledge base from independently funded sources and/or the public domain. This collated knowledge was disseminated actively during the lifetime of the project, using the routes described above in Section 1.2.3 Communication.

Details of the ELFNET knowledge are given in Table 1.

Table 1 - ELFNET Knowledge Base

Result	Description	Dissemination
World's leading website on lead-free soldering research information	http://www.europeanleadfree.net Virtual community tool with extensive knowledge base on European expertise in lead-free soldering technology	- ~250,000 visitors per year - Electronic newsletters and bulletins - RSS feeds - Web/email forums
Database of lead-free soldering research projects	120 records. A reasonably comprehensive database of lead-free soldering related collaborative research projects. European focus, with some US and Japanese projects. Full details including contact details and some disseminated reports.	ELFNET website
Directory of 400 European experts	Searchable profiles of ELFNET Affiliate members including some information on expertise and linked company profiles. Contact details available to other members.	ELFNET website
News and Events on lead-free soldering	Leading source of news on lead-free and RoHS Directive developments. Diary with details of major conferences and seminars across Europe. 236 Events and 276 News items posted.	ELFNET Website News ELFNET Website Events RSS feeds to other websites e.g. RoHSWell.com and desktop news aggregators.
Library of lead-free soldering information	General library with key documents. Additional categorised libraries for each ELFNET network, including some non-English documents.	ELFNET Website
Industry & Technical Review Reports	Authoritative reviews of state-of-the-art in each technical/industry sector. Details of key contacts and network activities.	ELFNET Website: - March 2007 - March 2006 - September 2004/March 2005 o Solders o Components o Assembly

		o Reliability o Recycling o Aerospace/Defence o Automotive/Industrial o IT/Telecoms o Consumer (Affiliate members only)
Analysis of lead-free soldering implementation issues and a Roadmap for future research	Matrix of Issues, with links to public webpages and Solutions working group pages. Later evolved into the ELFNET Roadmap with detailed state-of-the-art data and 50 high priority challenges for electronics interconnection research over the next decade.	ELFNET Website: - ELFNET Issues to Solutions Matrix - ELFNET Roadmap – 'The Future of Electronics Interconnection' Press Release (Roadmap), Email bulletin
Presentations from key industry players on key lead-free soldering topics	Made by invitation at ELFNET meetings & industry 2004-2007.	ELFNET Website: - Amsterdam, June 2004* - Eindhoven, March 2005* - Leuven, September 2005* - SEMICON, April 2006 - SEMICON (Networks), April 2006* - Electronix Fair, September 2006 - ELFNET Dissemination Event, March 2007 *Affiliate members only
Sponsored RoHS Guidance Booklet	Produced by Components Obsolescence Group – 'The Lead-Free Minefield'	Press Release 500 hard booklet copies, distributed at SEMICON Europa, April 2006 and elsewhere COG Website
Database of lead-free solder alloy properties	Joint initiative with COST 531. Comprehensive published and unpublished data on physical properties of SnAgCu and binary lead-free alloys, including test methods	Press Release, Email bulletin ELFNET Website COST 531 Website
Reports on status of lead-free soldering implementation	Annual reports based on analysis of survey questionnaires – materials selection, equipment, information needs etc	ELFNET website: - 2004/5 - 2005/6 - 2006/7 Press Release (2005 Report)
ELFNET Quality & Reliability Colour Books	Expert reviews of state-of-the-art and test methods for every known lead-free soldering quality defect and reliability failure mechanism. Results of 11 meetings of the ELFNET Reliability network. To support initiative to harmonise reliability test methods.	ELFNET Website, Email Bulletin - ELFNET Quality Colour Book - ELFNET Reliability Colour Book Book publication is discussion with Springer and/or IPC, US.

2.2 Exploitation of ELFNET Knowledge

All partners and many others in the industry used the knowledge base in intangible ways to further their organisational interests. Potential exploitation routes are shown in Table 2.

Table 2 - Exploitation Routes for ELFNET Knowledge

Organisation Type	Exploitation Routes
Research organisations	Prior art, latest data and contact information relevant to ongoing or potential research projects, new research project opportunities
Electronics industry	Contacts, latest data, events for own research and development activities and customer liaison in relation to implementation of lead-free soldering technology, new research project opportunities
Information and technical service providers	News and latest data for inclusion in own information products, training materials and consultancy

The ELFNET website will remain online as the repository of the ELFNET Knowledge, hosted by ITRI for at least one year after the project end.

http://www.europeanleadfree.net

Opportunities for new large-scale collaborative research projects during the project term were limited by the coincidence with an effective 2-year EU funding gap between Framework 6 and Framework 7 funding rounds. Further, the topic of lead-free soldering itself was increasingly perceived as a mature technology for industry development rather than as innovative research for public funding.

However, the work of ELFNET in identifying research gaps, bringing together new research communities and publishing its Roadmap has stimulated some new research projects and produced a number of new proposals for Framework 7 funding. Some non-confidential examples are given in Table 3 below.

Table 3 – Examples of New Research Projects Stimulated by ELFNET

Project Title/Acronym, Topic Details, Partners, Funding Source	Planned value (€)
Heterogeneous Assembly. Advanced processing of boards with very large and also very small components Partners: IZM/TUB, TU Gent/IMEC, TU Eindhoven, Thales, Heraeus, MyData Funding: FP7	4M€
MEMORA, Simulation of structural changes of a crystalline material due to thermomechanical load. Partners: Thales, TU Eindhoven, EMPA Funding: FP7	3- 8M€
VIA, Degradation mechanisms of through hole and via plating due to the stress induced during the lead free soldering process Partners: Variosystem, IMEC, ISQ, EMPA Funding: FP7	1.5M€
No acronym defined jet. Degradation effects in lead free interconnects due to combined thermomechanical and mechanical load Partners: Siemens, Thales, ABB, IMEC, IVF, ISQ, EMPA, IZM, IMMG Funding: FP7	3- 8M€

No acronym defined jet. A project to investigate the incorporation of carbon nanotubes in electrically conductive high strength adhesives Partners: IMMG, EMPA, Funding: FP7 RELCON. Reliability network for interconnects Partners: IMEC, IVF, NLP, ISQ, HUT, IMMG, EMPA, IZM, IMEC, INASMET, Enseirb, TU Delft, IXL, TU Warsaw. Funding: ?COST	3- 8M€ 0.1M€

Extensive efforts have been made to secure funding for continuation of the coordination activities of ELFNET on the European scale, aimed at nurturing remaining technology implementation, notably into high reliability sectors, and expanding the scope of the action towards electronics interconnection generally. Ultimately this was not successful.

Instead, it is expected that some of the individual networks operating within ELFNET will continue to operate, coordinated by RTD partners. Two clear examples are:

- Reliability network, labelled RELCON, as mentioned in Table 3, possibly with COST funding, coordinated by EMPA, Switzerland
- Solders network, as the continued membership network Soldertec Global, coordinated by ITRI, UK

In addition to this a Virtual Institute concept is being developed, possibly using the EEIG (European Economic Interest Group) model. A management group 'CONNECT' is being established, based on a core group of project partners, to explore this and other collaborative exploitation options.