LEADFREE Layman's Report

1 Background: Environment Initiatives

Environmental Legislation & Sustained Technology Improvement

- Hazardous Materials and The High-Tech Trash Problem

In the fashion- conscious mobile market, 98 million U.S. cell phones took their last call in 2005. All told, the EPA estimates that in the U.S. that year, between 1.5 and 1.9 million tons of computers, TVs, VCRs, monitors, cell phones, and other equipment were discarded. If all sources of electronic waste are tallied, it could total 50 million tons a year worldwide, according to the UN Environment Programme.

In Europe, it is estimated that more than 60 million new PCs enter the market and 12 million are disposed of each year in the European Union. Like in the U.S. the unknown numbers of old computer products hidden in basements or garages, results is a staggering mass of plastic, metal, chemical, and glass "junk". The waste will contain more than 4 billion pounds of plastic, 1 billion pounds of lead, 1.9 million pounds of cadmium, 1.2 million pounds of chromium, and nearly 400,000 pounds of mercury.

All efforts to reduce hazardous materials in electronics are motivated in part to address the global issue of consumer electronics waste. As newer technology arrives at an ever increasing rate, consumers are discarding their obsolete products sooner than ever. This waste ends up in landfills and in countries like China to be "recycled."

Recycling efforts may be doing more harm than good. Not only are adult and child workers in these jobs being poisoned by heavy metals, but these metals are returning to Europe and U.S. “The U.S. right now is shipping large quantities of leaded materials to China, and China is the world's major manufacturing center," Jeffrey Weidenhamer says, a chemist at Ashland University in Ohio. "It's not all that surprising things are coming full circle and now we're getting contaminated products back."

A key to recognizing the importance of increasing competencies in lead- free soldering processes is found in the fact that the motor of the European electronics assembly industry is not the high-volume mass production sector, but in the low-volume series production. This sector thrives by virtue of its ability to adapt to the different production requirements made by diverse products, which is especially challenging in terms of process technology. Expert process knowledge and control combined with process flexibility is the key to success of the sector.

- WEEE and RoHS

The Waste Electrical and Electronic Equipment (WEEE) Directive was agreed on 13 February 2003, along with the related Directive on Restrictions of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS). The WEEE aims to minimize the impacts of electrical and electronic equipment on the environment during their life times and when they become waste. It applies to a huge spectrum of products. It encourages and sets criteria for the collection, treatment, recycling and recovery of waste electrical and electronic equipment. It makes producers responsible for financing most of these activities (producer responsibility). Private householders are to be able to return WEEE without charge. WEEE cost are

estimated to be 350-500. Mio €. The disposal of the appliences have different deadlines. Substances covered by RoHS are:

- Lead (meaning especially solder joints and solderable finishes of electronics components and circuit boards)
- Mercury
- Cadmium
- Hexavalent chromium (Cr^{6+})
- Polybrominated biphenyls (PBB)
- Polybrominated diphenyl ether (PBDE)

PBB and PBDE are flame retardants used in several plastics.

RoHS applies to these products in the EU whether made within the EU or imported. Certain exemptions apply, and these are updated on occasion by the EU.

The maximum permitted concentrations are 0.1% or 1000 ppm (except for cadmium, which is limited to 0.01% or 100 ppm) by weight of homogeneous material. This means that the limits do not apply to the weight of the finished product, or even to a component, but to any single substance that could (theoretically) be separated mechanically—for example, the sheath on a cable or the tinning on a component lead.

Everything that can be identified as a homogeneous material must meet the limit. So if it turns out that the case was made of plastic with 2,300 ppm (0.23%) PBB used as a flame retardant, then the entire radio would fail the requirements of the directive.

In an effort to close RoHS loopholes, in May 2006 the European Commission was asked to review two currently excluded product categories (monitoring and control equipment, and medical devices) for future inclusion in the products that must fall into RoHS compliance. In addition the commission entertains requests for deadline extensions or for exclusions by substance categories, substance location or weight.

The directive applies to equipment as defined by a section of the WEEE directive. The following numeric categories apply:

- Large and small household appliances.
- IT equipment.
- Different countries
- Consumer equipment.
- Lighting equipment—including light bulbs.
- Electronic and electrical tools.
- Toys, leisure, and sports equipment.
- Medical devices (currently exempt)
- Monitoring and control instruments (currently exempt)
- Automatic dispensers.

It does not apply to fixed industrial plant and tools. Compliance is the responsibility of the company that puts the product on the market, as defined in the Directive; components and sub- assemblies are not responsible for product compliance. Of course, given the fact that the regulation is applied at the homogeneous material level, data on substance concentrations needs to be transferred through the supply chain to the final producer.

2 Scope: Matching Skills and Technology

2.1 Leadfree Solder Alloys

On July 1, 2006, the WEEE and RoHS came into effect prohibiting the intentional addition of lead to most consumer electronics produced in the EU. No such legislation is in place in the United States or other countries. Most lead-free replacements for conventional Sn60/Pb40 and Sn63/Pb37 solder have melting points from 5–20 ℃ higher, though solders with much lower melting points are available. The benefit to public health and the environment has its price, namely in increased manufacturing costs. Cost factors include:

- Capital investments
- Incomplete availability of RoHS and process compliant components
- Lack of compatibility of lead-free processing at higher temperature with existing device specifications
- Lack of experience with lead-free- specific inspection and repair routines
- Significant deficits of personnel skills regarding lead- free soldering
- Disruption of running commercial production during experimental introduction, feasibility tests and in-house training lead- free technologies not only in RoHS relevant, but also RoHS exempted applications.

Generally speaking, restricting lead content in solder for electronics requires expensive retooling of assembly lines and different coatings for the leads of the electronic parts. Lead- free solders have a higher melting point requiring higher process temperatures (e.g. a 30℃ typical differenc e for tin-silver-copper alloys), driving changes to materials for chip packages, for some printed circuit boards and components.

2.2 no professional degree assembly education

Through the 1990s, while SMT (surface mount technology) gained massive ground in electronic products, automation seemed to be the way to solve all problems of mass production. More elaborate equipment seemed to need less skilled operators. Intellectual property seemed to lie exclusively in product functional evolution, thus technology know-how was sent into early retirement. The holistic view on product development, production, and qualification was lost in favour of tayloring the process flow into small independently managed stages. Up to now there is no professional education neither for design nor for assembly of electronics products. Most employees in electronics design and assembly come from completely different professions. The LEADFREE project aims on these employees to offer up- to-date technology and skills training for a life-long-learning society.

Individual skills: Better education means more responsibility in fault finding and process improvement.

Reduced defect rate means less waste, more success, better motivation

2.3 thrive for zero defects

The LEADFREE project has established a competence centre of the highest caliber, which represents a significant competitive advantage for the European electronics manufacturing industry by supporting the optimization of personnel adjustments and production processes.

A significant advantage in terms of investment costs is the out-of-house production training facilities available at Fraunhofer ISIT. Training takes place with today's industry equipment and can be carried out in cooperation with representatives of the equipment manufacturer: A fully functional production facility which represents an investment volume of 2 Mio. Euro is available for training purposes. The sub- optimal production runs associated with the usual alternative, on-the-job training which takes place in- house and now can be completely avoided, without the capital investment levels associated with manufacturing training infrastructure.

Offers:

- Training for process technology and working behaviour
- Training under supervision
- Free Training, coached by ISIT employees
- Non-destructive testing for solder defects
- Metallographic analysis

- Consulting for environmental friendly design and design for manufacturing

2.4 improved assembly equipment

Equipment was improved further, especially with regard to wave solder machines. All materials in continuous touch with lead-free solder is prone to drastically more liquid-metal corrosion. Therefore, coating materials were developed to shield the surface of solder pot, pump and nozzle parts. This is even more important for selective solder equipment, as the solder temperature is even higher than in the conventional wave solder process. More precise temperature control, enhancement of preheating, moving the solder pot closer to the preheating zones, and reducing the distance between first and second wave solder nozzle were further measures taken by the equipment manufacturers. Both reflow and wave solder equipment were enhanced by better thermal insulation, so as to save on energy, which was driven by energy cost, but also serves the environment. The closer temperature control is needed because of the smaller process window between solder heat demand and solder heat resistance of the materials.

2.5 improved materials

On the material side, soldering flux and paste, component plastics, and PCB laminate and coating or mask materials were improved to withstand longer times at the higher working temperature needed for lead-free soldering.

This also lead to the need to match test standards for solder heat resistance and solderability tests, such as wetting balance tests. New requirements were e.g. test temperature of 245℃ for SAC test, in comparison to 235℃ for tin-lead solders.

--> test equipment

--> test procedures

--> mediation of new requirements to product development and production personnell

3 Concept: LEADFREE Training Line and Knowledge Base

3.1 Line Setup

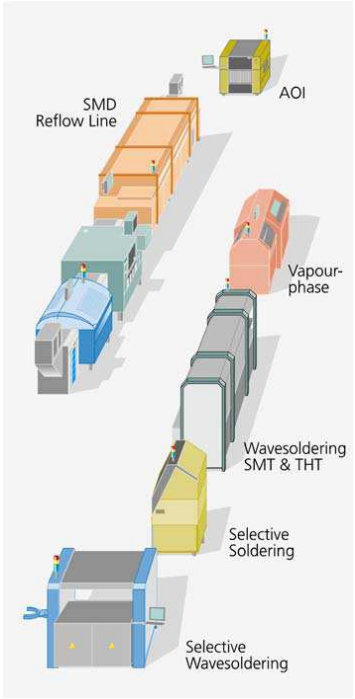
A purpose-built industrial scale production line has been implemented at Fraunhofer ISIT in Itzehoe, Germany, which provides facilities for on- the-job training with electronics assemblies of a size from ca. 50mm to ca. 300mm width and max. ca. 400mm length in accordance with the requirements of RoHS legislation. The first year of the project was used for the set-up of this assembly equipment, complemented with suitable analysis laboratory to test solderability and solder heat resistance of solder materials, components, and PCB laminates.

To this end, the LEADFREE project has birthed a not-for-profit, pre-competitive European competence centre for demonstration, training and exercises to be used by European electronics manufacturers, who bring their own materials and test vehicles to practice with state-of-the-art lead- free soldering equipment, assisted by scientific engineering supervision and analysis including hands-on training.

3.2 process & product qualification

Suppliers and electronics manufacturers are invited to perform tests and get process and analysis assistance to investigate suitable parameters, up to qualification testing, e. g. by temperature cycling as in accelerated reliability testing. The competence of the training center lies in the following activities:

- design experiments for establishment of process windows
- detect materials defects and verify materials and equipment process limits
- consult clients in test runs for equipment comparison and optimization
- design experiments and consult in materials benchmarking for minimum defect levels using RoHS compliant solder pastes and PCB laminates.



The main competence is attributed to the evaluation of the manufacturing quality and the reliability of microelectronic assemblies and modules including the as-delivered quality of components and circuit boards. Methods are destructive metallographic principles and Non destructive (e.g. x-ray) principles. The evaluation of the long-time behaviour of the assemblies is based on the matrix of requirements using model calculations, environmental and load tests up to failure analyses. For optimization of manufacturing processes the institute applies process models and fabricates samples on in-line equipment including mass production as well as rework systems. Furthermore, in the field of thermal management and reliability ISIT works on customer specific power modules.

3.3 knowledge collection

The knowledge gained in joint research performed on the training line is usually available in the shape of freely accessable reports, namely when the project was sponsored from a public source. This knowledge base plus other non classified information is entered into seminar contents and cast into presentations as a preparation for seminars and training.

Further experience in industry needs stemmed from activities as Master IPC Trainer for the industry standard IPC A-610 "Acceptability of Electronic Assemblies". This is a globally recognized certified training program performed mostly on-site for production and inspection personnel.

During the LEADFREE project, industry standards were constantly reviewed to track the introduction of requirements on materials, processes, and skills from environmental friendly design and production of electronics. IPC standardization committees were quickly adopting changes, entering new "lead-free" criteria in workmanship, design, and performance standards. The IPC-A- 610 Training was adopted during the LEADFREE project. Following were IEC and EN standards

3.4 seminar & training contents & styles

These presentations are sorted by topics starting with DfX ("Design for Excellence"), where the variable X means design oriented topics, followed by topics with focus on process, and finally a focus on reliability of environmental friendly soldered assemblies. Target groups are development and product management engineers for design and reliability, process engineering and operators for the soldering and assembly topics, and unskilled or semiskilled personnel for hand soldering and repair. Special seminars are offered on manual soldering, machine oriented assembly, and rework/repair practice on dedicated rework stations.

The seminar and consultancy programme for lead-free adaptation has been broadened during the duration of the project to include paste printing, component placement, and AOI (automated optical inspection), and further on design and logistics measures such as LCA (life cycle analysis) and EMAS (Environmental Management & Audit- System: http://ec.europa.eu/environment/emas/index_en.htm).

All these seminars are offered at least twice a year on the site of the LEADFREE training line. These Center Seminars are widely advertised and performed on the training line site (multiple clients). The second seminar mode are customer specific seminars or workshops performed at customer's or at training line site, for one client at a time. In the third mode, seminars are performed externally, organized in a suitable show-room type environment. For solder process seminars, this is a joint effort of equipment manufacturers and distributors together with the LEADFREE personnel.

Theory based Design for Manufacturing / Environment-Friendly Products seminars

The process topics are performed as hands-on training to mediate Good Practise and enhance individual operator's skills. Materials selection and handling, process improvement practise, and fault cause-and- effect localization are practised on testboards with deliberate mal- designs, or with out- of- window process parameters. Participants have to locate and document the defects properly, make suggestions for parameter changes, and run trials to fix these problems.

Training success enhance the feeling of mastering the daily tasks, thus increasing responsibility and flexibility of process specialist and quality personnel.

4 Results I: Certified Courses on Environment-Friendly Electronics Production

In accord with Tasks C and D of the LEADFREE proposal, an industry compatible curriculum was developed. The base was 15 years of experience with conventional solder seminars, participation in applied research projects on leadfree soldering technology, and multi- client projects with focus on process and materials. All of these acticities where joint efforts with industry experts, partly conducted on site in production lines. Several of the mentioned applied research projects were carried out in conjunction with technical committees from DVS (Deutscher Verband für Schweißen und verwandte Verfahren, i.e. German Welding Society). DVS has half a century tradition of welding practice and technology education, and over a decade of experience with adhesive practitioner, specialist, and engineering advanced training. On the background of this tradition, and on the experience with one year of environment- friendly solder assembly technology training, the last year of the LEADFREE project saw the foundation of the new working group DVS AG V 6.3 "training soldering in electronics". This working group wrote guidelines on basic and advanced training for

- manual soldering labour, starting from unskilled level; duration is one week
- solder assembly specialist, starting from semi-skilled labour; duration is three weeks, which may be singled and spread week by week over up to 36 months
- requirements on educational institutions for manual soldering, manual assembly with benchtop equipment, and for automated assembly of electronic products
- a framework for the specialist education as electronics solder assembly engineers; duration is two months.

The working group also compiled training manuals, with presentations and exam sections fit for certification of training participants.

The original leadfree test vehicle was modified to suit the different levels of skills training for hand and machine manufacturing. There are now three practice and examination assemblies, representing typical low, medium, and high levels of assembly complexity, combining through hole and surface mount technology. This program was complete and ready for certification at the end of the project runtime. Meanwhile, all types of courses have been run at least once, and the program was approved by the DVS working group for training and examination (AGSP).

5 Results II: Industry Response

During the course of the LEADFREE project, a need for skilled personnell in high-tech economy including electronics became obvious. It went through the media that the lack of engineers and technicians would retard new product and technology development.

Almost 900 participants from 570 companies joined the seminars and workshop training sessions in 2007. Compared to the number of participants in 2006 (app. 320) and firms (app. 240) the increase is impressing.

Especially SME’s are assisted with the implementation of environmentally-friendly electronics assembly, thus enabling them not only to cope with the new EU environmental legislation, but to benefit from the technological advantage gained on the global market in a long- term period.

This has been achieved through coordination, integration and optimisation of the critical mass of European research in lead-free soldering, providing pan- European support on implementation of the RoHS Directive.

This development is an evidence for the success of LEADFREE. It guarantees a promising and exciting outlook of the activities birthed beyond the projects' official deadline.

LEADFREE led to a variety of partnering contacts, which on the one hand supports the marketing activities for LEADFREE and on the other hand enables concrete sub-projects, such as workshops and seminars.

One of the most important successes is the acquisition of notable companies being involved in LEADFREE through the ISIT. An overview of names which participated in projects raised with the Hambuger Lötzirkel (Hamburg Solder Circle) is given in the company logo overview from one of the joint projects performed.

6 Results III: Dissemination and Training

6.1 courses performed

The scope, depth and commitment of the LEADFREE concept is demonstrated by the extent of the training programme for 2008, the final year of the project:

- January 2008, Stockholm: European Electronic Summit
- 12. February 2008 Product design: Design for Excellence
  Seminar for environment- friendly development, layout and technology / German language
- 13. February 2008 Assembly production with focus soldering process
  Lead-free seminar together with FED (Fachverband Elektronik- Design) / English language on demand
- 26.-29. February 2008 Lead-free solder process in the electronic manufacturing industry Seminar in theory and praxis / German language
- 11.-13. March 2008 Lead-free hand-soldering Praxis-orientated training / German language
- 11. - 13. March 2008 SMT- rework-practical training Praxis- orientated training - lead- free / German language
- 07. - 11. April 2008 Soldering process II - praxis orientated training "LEADFREE specialist" at the ISIT-LEADFREE training line / German language

- 18. - 19. June 2008 Tutorial and Training "Reliable Soldering for Power Electronics Manufacturing" Basics in theory and hands-on experience; a Joint programme with ECPE / English language
- 7. – 18. July 2008 LEADFREE STEW Solder Training and Exhibition Weeks in Timisoara, Romania in co operation with the Timisoara Chamber of Commerce and Agriculture and the Universitatea Politehnica din Timisoara, Faculty of Electronics and Telecommunication; this event was run over two weeks. The first week provided theory seminars, namely two days focusing on development, one day exhibition, followed by two days with focus on assembly. The second week was a five day assembly practice session.
  - 7.-8.07.08: Design Optimisation - DfX, Verification, Pad Shapes, Lead- Free, Materials
  - 9.07.08: Life LEADFREE Training Line: Equipment & Materials Exhibition
  - 10.-11.07.08: PCB Assembly - Holistic View on Materials, Process and Solder Joint Quality
  - 14.-18.07.08: Assembly Specialist II - Complex Practice Training on Industry Scale Equipment
- 25. - 27. September 2008, 16. FED- Konferenz, Bamberg: Elektronik- Design - Leiterplatten – Baugruppen: „Neue Fachkräfte braucht das Land – Weichlöten in der Elektronikfertigung“
- 7. - 10. October 2008 Lead free solder process in the electronic manufacturing industry Seminar in theory and praxis / German language
- 22.-24. October 2008 European Electronics Assembly Reliability Summit Tallin, Estonia
- 4. - 6. November 2008 SMT- Rework workshop Seminar in theory and praxis / German language
- 3. - 7. November 2008 Lead- free hand- soldering Praxis orientated training / German language
- 17.-18. November 2008 Technology World 2008 exhibition: “Technology Breakthroughs – Bending the Design Rules”
- 24. - 28. November 2008 Soldering process II – praxis orientated training ”Leadfree Specialist” at the ISIT- LEADFREE trainings line / German language
- 2. December 2008 Product design: Design for Excellence Seminar for environment- friendly development, layout and technology / German language
- 3. December 2008 Assembly production with focus soldering process Lead- free seminar together with FED (Fachverband Elektronik- Design) / German language
- 8. - 12. December 2008 Soldering process III – praxis orientated training "LEADFREE specialist" at the ISIT- LEADFREE training line / German language

6.2 Marketing

LEADFREE addressed other scientific communities, regulatory authorities, multipliers and environmental policy stakeholders by involving them into the programme activities or by actively engage co operations, for example with the Universitatea

Politehnica din Timisoara, Faculty of Electronics and Telecommunication in Romania and the Timisoara Chamber of Commerce.

One of the most important organisation and multiplier that could be acquired is the DVS - Deutscher Verband für Schweißen und verwandte Verfahren e.V. Duesseldorf, because of it amount of members, namely 18,000 institutions form the industrial and private- individuals sector. As the certifier for the professional LEADFREE training concept of the ISIT the DVS enjoys high acceptance in the industrial community. Another important partner in terms of a multiplier function is the FED – Fachverband Eletronik Design e.V. in Berlin with 550 members including the entrepreneurial segment and private individuals. The emphasis of support is put on precise marketing activities in close synergetic cooperation. In addition, the LEADFREE professional training programme was presented by ISIT in a presentation during the 16th FED-conference on September 26th, 2008 in Bamberg, Bavaria.

Internationally, the European Centre for Power Electronics (ECPE) crystallized itself as a reliable and effective partner for LEADFREE. ECPE and ISIT are in close collaboration, which lead to a concept which is now implemented. On an annually basis a seminars is given at the Fraunhofer Institute ISIT in Itzehoe called: “Soldering for reliable power electronics” with a European-wide target group.

Further, active marketing is performed by placing notes and information on the seminar program via web pages into internet and into journals, by presentations in national and international conferences (see the list of event participation in 2008), and, last not least, organisation and presentation of the LEADFREE STEW in Timisoara, Romania.

6.3 Training Company Business Plan

The expansion of the LEADFREE training concept implies the chance to realize a business concept, offering a “Lead-free Training Line to Match Goals of Environmental Friendly Electronics Production”. Therefore, the activities are further developed and concluded in a LEADFREE business plan. The practical application to culminate the LEADFREE success story was in fact the foundation and installation of the new company Trainalytics GmbH in Lippstadt.

This enables the training program and application to grow quickly with industry needs raised by the marketing activities of the joint group, still headed by the original LEADFREE project manager.

6.4 Transfer to external center location

The LEADFRE STEW in July 2008 was the crest event of the project to test successfully the transfer of the training line concept to another European country. The short presentation appended to this report gives an overview of the two weeks of LEADFREE STEW (Solder Training and Exhibition Weeks).

Also in July 2008, two workshops were performed for selected companies with high performance requirements on their products. The topic in these 2-day workshops was reliability of lead-free products, an issue which is not sufficiently solved yet.

6.5 Portable Training

Benchtop equipment is used to teach basic materials behaviour, apparatus characterisation and process step optimisation. This enables equipment to be moved with little effort to different training locations.

Beyond manual soldering with solder iron there is prototype and rework/repair equipment capable for manufacturing SMT & THT mixed assembly. Both manual soldering and benchtop manufacturing teach truly craftsman skills, promoting the combination of physical individual skills with basic knowledge on the physics and chemistry behind soldering of electronics assembly.

Doing this on portable equipment enables for in-house sessions, i.e. to carry the training to the workplace instead of forcing employees to travel to central training places. This keeps the training costs low for the companies who want to educate groups of their personnel.

7 Outlook: - A New Technology Training Business Network

In today's highly competitive global economy, the top performing regions are built on the innovative use of strong and dynamic knowledge bases. Although there are no European norms regulating electronic assembly production processes, the ISIT and the IZET together with Life-LEADFREE have established a competence centre of the highest caliber, which represents a significant competitive advantage for the European electronics manufacturing industry by offering the highest state-of-the-art process technology.

To maximise the economic and societal benefits of the region's world class knowledge base in terms of competitiveness, LEADFREE is the most important tool for the ISIT for implementing the lead- free process into the industrial sector. Therefore the ISIT and the IZET have worked collaboratively with the region's businesses and universities to promote training, innovation and knowledge transfer and to

- speed up the development of new products, processes and services, through increased knowledge transfer
- increase the competitiveness of businesses through promoting innovation
- increase the supply of technically and scientifically skilled people

Training plays an essential role in a knowledge-based economy by supporting the growth and employment by providing highly qualified and adaptable labour. They also strengthen social cohesion and active citizenship. LEADFREE gives employees and unemployed worker a (second) chance to step into the world of employment. High-level qualified employees are better invested in processes, which match their qualification and lead to a best-use- benefits for the companies. It helps to optimize work-force allocation and reduces personnel and production costs by supporting the optimization of personnel adjustments and production processes.

This is especially important in the growing European community, to standardize skills and knowledge. Otherwise their will be a danger of social unbalance when high and low level jobs are biased between countries. LEADFREE training offers the chance for life long learning in future oriented technology, converging generations with job opportunities which ask for fine skills and enhancing spiritual mobility without age limits.

During the LEADFREE project, the new DVS working group AG V 6.3 "Soldering in Electronics Education" was constituted to write new guidelines to describe training contents and requirements on training institutions suitable for standardisation in accord with DVS training experiences in the fields of welding, brazing, and adhesive joining. After the numerous seminars executed during the course of the LEADFREE

project, a pilot course of the manual solder training and the skilled worker program was practised successfully at the end of the LEADFREE project. At the same time, the guidelines developed for this program were cleared by the DVS working group for training and examination for publication in May 2009.

On this background, five companies and one institute opted to jointly offer the new training to electronics industries. The members are

- ERSA, Wertheim
- Hannusch, Laichingen
- Rafi, Ravensburg
- Trainalytics, Lippstadt & Itzehoe / ISIT
- Zollner, Zandt
- ZVE, Oberpfaffenhofen