Joining forces – a market transformation network for pushing white LED-technology in North Rhine-Westphalia

Claus Barthel
Wuppertal Institute for Climate, Environment, Energy
Döppersberg 19
D-42103 Wuppertal
claus.barthel@wupperinst.org

Stephan Ramesohl
Wuppertal Institute for Climate, Environment, Energy
Döppersberg 19
D-42103 Wuppertal
Stephan.ramesohl@wupperinst.org

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Abstract
The paper presents the activities of the LED (light-emitting diodes) competence network in North Rhine-Westphalia and its role for enhancing market transformation.

With the recent development of the LED, new lighting applications have been arisen such as space lighting, object illumination, headlamps for cars and others. Current R&D aims at taking advantage from the specific features of the LED-technology, as there are high energy efficiency and extreme long lifetime.

In order to foster this development and to strengthen the competitiveness of domestic players, the State of North Rhine-Westphalia has founded a LED competence network. It serves as a platform to coordinate actors from policy, science, research and industry. Market players along the whole product chain are bundled in key projects to develop or to improve products of strategic importance for future market growth. Examples are daylight headlamps for cars, OLEDs (organic LEDs) for space illumination, the development of a very bright white source of LED-light, the so called white LED power chip, and the project "LED instead of neon light". Furthermore a design competition for the best LED lamp has been launched, and in order to generate practical value for its participants the LED-network undertakes patent investigations and organizes information events.

In this context, the paper outlines recent and future developments of the white LED technology and its advantages, estimates possible energy savings, describes the process of launching the LED-network and illustrates some outstanding examples, discusses the performance of the network as a tool for market transformation policies and points out general lessons concerning the success of market transformation networks.

Introduction
Efforts for efficient use of electricity play a key role for achieving climate and resource protection goals. Numerous activities in research and development aim at increasing energy efficiency for users of all technical appliances. Among these, lighting plays a specific role due to its general importance in all domains of life, commerce and industry. Artificial lighting not only entails high electricity consumption but also influences the quality of life and working performance of human beings.

Apart from rare exceptions, the lighting systems known to us today are either based on the principle of light bulbs with filaments or that of gas discharge such as fluorescent lamps (including variants with high or low pressure). Since its invention 100 years ago the filament bulb experienced only one notable leap in efficiency - the development of the halogen bulb - whereas gas discharge lamps have been continually improved since the 1940´s. Today, the latter have achieved high energy-efficiency. Accordingly, gas discharge lamps have gained ground in a variety of fields. Since a more compact variant was developed with the low-energy bulb,

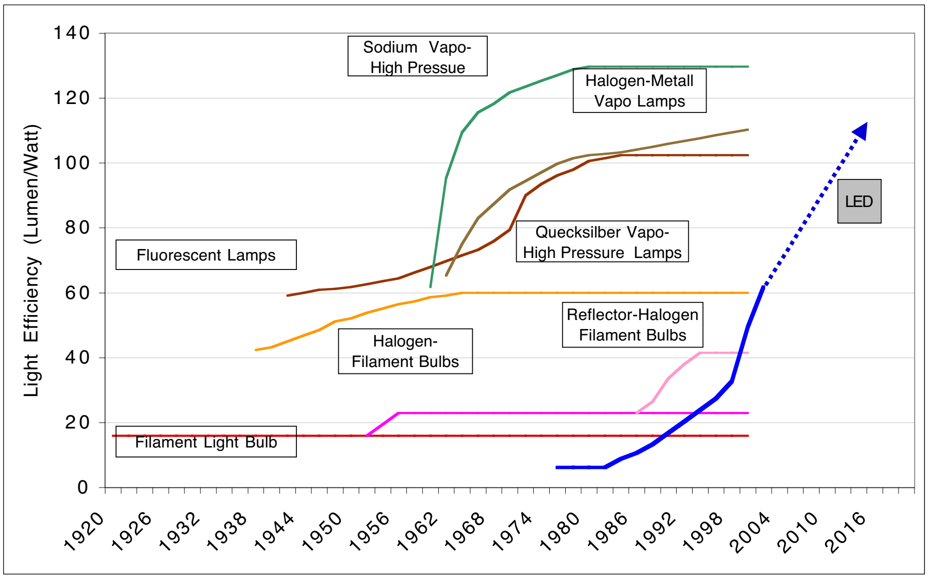

***Figure 1.** Development of the efficiency of different lamp types over time (Source: Haitz et al. 1999)*

these lamps increasingly substitute the less efficient filament bulbs.

At the same time, however, all lighting systems predominant today incorporate characteristic weaknesses. While filament bulbs lost popularity due to their low energy efficiency in Europe, discharge lamps are often associated with disagreeable working conditions. Furthermore, the topic of electromagnetic fields (electric smog) and the potential effect on the human organism is debated controversially. Moreover, many discharge lamps contain low amounts of mercury. Though used lamps can be carefully purged of this substance, which can then be recycled or disposed of in a suitable manner, a prerequisite for this process is that the lamps do indeed enter the disposal cycle. This may be the case with companies and public enterprises, but not necessarily with private households.

This background explains the great interest in an entirely new kind of lighting technology: light-emitting diodes, LED for short. Because of the particular characteristics of LED light, some disadvantages of existing systems can be avoided. They demonstrate an average lifetime up to 100 000 hours (corresponds to 11.4 years continuous operation) with high reliability. In comparison to fluorescent lamps the light flux (a measure for the brightness of a luminaire) will be less diminish while aging. Moreover, LED are extremely robust, cause no problems in use, have a high energy saving potential and are even resource efficient.

Though LEDs have existed since about 40 years, they were only available in the colours red and green and moreover failed to produce a sufficient amount of light, so that their use remained restricted to the narrow field of displays and warning lights. However, the situation has improved and today the brightness of the green, yellow and the red LEDs is about 40 Lumen/Watt at very low prices of about some Eurocent.

Moreover, a technology breakthrough could be achieved by the development of blue LEDs in the early 1990s. For the first time ever it became possible to produce white LED light by combining red, green and blue LEDs or using fluorescent substances.

State of the art and energy saving potentials of white LED

Being still in a rather pre-matured stage the efficiency of the blue LED is not yet as high as the other colours and the price is still about 50 Eurocent. Taking the strong R&D efforts worldwide into account, however, future advances can be expected that challenge traditional lighting technologies. In Figure 1 the development over time of the efficiency of several light sources is presented.

At the moment, the lighting efficiency of white LEDs is about 15 to 20 lm/W, with 25 lm/W expected in the near future. From the energy point of view, such lighting efficiency suffices to replace filament bulbs as well as halogen bulbs. Due to their high price, however, LEDs are still restricted to applications where maintenance costs savings due to the significantly longer lifetime are the core decision criteria.

To surpass the performance of the very efficient fluorescent lamps – compact fluorescent lamps or even triphosphor linear fluorescent lamps, a level of 40 or 65 lm/W will have to be achieved what will take another 5 or 10 years. In a time frame of 20 years, however, we may expect levels up to 150 or even 200 lm/W, corresponding an energy efficiency of more than 50% compared to 7% of a standard incandescent light bulb and 30% of a compact fluorescent lamp.

In addition, when assessing the prospects of LED another effect has to be taken into account. In conventional systems, the efficiency of the entire lighting system is mainly determined by the efficiency of the luminaire. By contrast, in the case of LED the luminous efficiency of the LED is dominant due to their type of construction LEDs send their light directly to the places where needed. No or nearly no loss of effectiveness will occur by transmission or reflexion on the material of the luminaire. For instance, even reflexivity-enhanced aluminium, as used for the reflectors of the modern

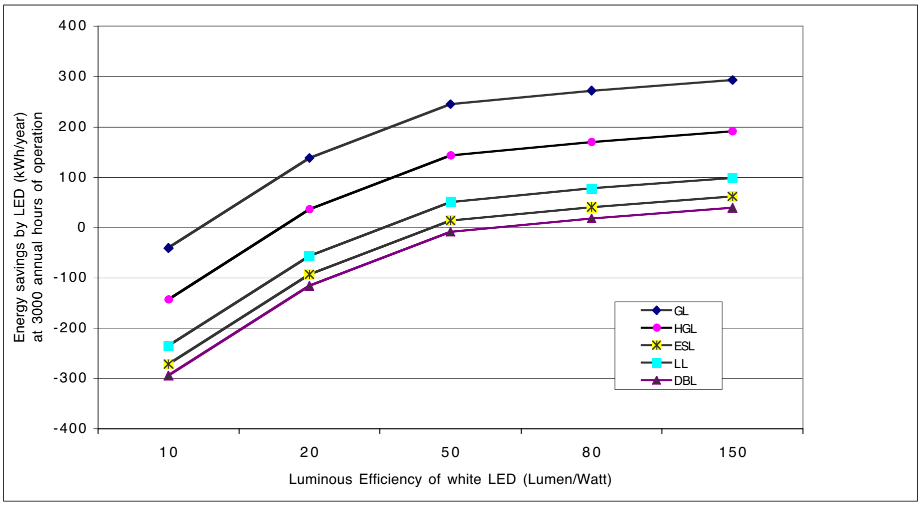

Figure 2. *Annual energy savings of LED systems with a luminous efficiency from 10 to 150 lm/W in comparison to different conventional lighting systems:*
GL: Filament bulb, luminous efficiency ca. 12 lm/W; loss off efficiency by the luminaire: 30%,
HGL: Reflector-halogen-filament bulb; luminous efficiency ca. 18 lm/W; loss off efficiency by the luminaire: 25%,
ESL: Compact gas discharge lamp with integrated high frequency ballast ("Low energy bulb"), luminous efficiency ca. 45 lm/W; loss off efficiency by the luminaire: 30%,
LL: Standard gas discharge lamp with integrated conventional converter, opal bowl, luminous efficiency ca. 55 lm/W; loss off efficiency by the luminaire: 50%,
DBL: Triphosphor lamp with integrated high frequency ballast, reflexivity enhanced Aluminium reflector, luminous efficiency ca. 75 lm/W; loss off efficiency by the luminaire: 25%.

three-band gas discharge lamps, absorbs still 2% of the lighting power. With opal bowls or even open luminaires (where the light is reflected by the walls) the loss can amount to 50%. Accounting for these systems losses in theory LEDs can compete with other lamp types on a lower level of luminous efficiency.

Figure 2 illustrates the achievable energy savings of a typical workplace illumination requiring a light flux of 900 lm. It compares LEDs with several conventional systems and specifies the net savings as a function of the LED's luminous efficiency. For example the threshold to realise positive energy savings with LEDs in comparison with filament bulbs lies at 12 lm/Watt whereas the luminous efficiency benchmark to beat triphosphor lamps is 60 lm/Watt.

For the means of calculation, different assumptions for the luminous efficiency of future white LEDs are made: 10, 20, 50, 80 and 150 lm/W. Up to now 10 lm/W are lower standard, a level of 20 lm/W is expected for the next year and already realised in prototypes, 50 – 80 lm/W appear to be realistic within the next 10 years whereas 150 – 200 lm/W might be possible on the long run (20 years). The analysis indicates that in order to outperform the best available system at the moment, the triphosphor lamps with high frequency ballast in an optimized luminaire, the luminous efficiency of the white LED has at least to increase to 65 lm/W (in the example above). As estimated by LED-experts this performance can be achieved in the next 5 to 10 years (Haitz et al. 1999).

It can be summarized that from an energy policy point of view LEDs are the better alternative in many applications where nowadays bulbs are still used. These effects, however, can only be realised when a diffusion of LED takes place. This requires further progress with regard to the luminous efficiency and especially with regard to the dedicated fixtures and of luminaires designed for LEDs. Only when a reasonable offer of a variety of goods exists that meets the customers' expectations concerning design, functionality and price, the market can be penetrated and thus the energy saving potentials be fully exhausted.

Triggered by the economic and ecological prospects of LED lighting systems, strong R&D efforts can be found worldwide. The world market experiences a continuous growth, especially in the segment of the so-called, "high brightness" LED with high luminance, that qualify for general lighting. From 1997 to 1998 the number of units soled worldwide have increased by almost 10%, which corresponds to an increase in sale by 5% from 1.839 billion US$ to 1.924 billion US$ (Fig. 3).

The LED competence network

In line with this technical and commercial development LED has become a topic of interest for the energy and technology policy in the German Bundesland North Rhine-Westphalia. Within the context of the State initiative for future energy options (Landesinitiative Zukunftsenergien), new and promising energy technologies are investigated and promoted. The initiative provides the frame for various activities such as competence-networks. In general, these networks focus on one technology field and they generate a platform to coordinate actors from policy, science, research, and industry.

Examples for such competence-networks in North Rhine-Westphalia are the competence-networks "Fuel Cells", "Biomass", "Hydrogen economy" and "50 solar housing estates".

The issue of LED appeared to be a possible area of activity for a new competence network. In order to explore the

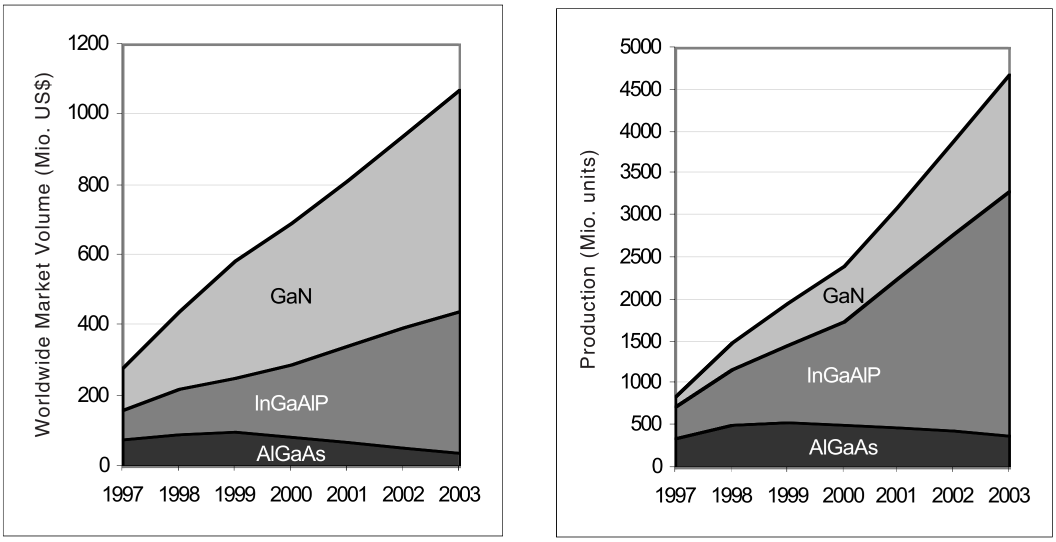

Figure 3. *Status quo (values till 1999) and prognosis (from 2000 on) of the market volume in US-$ and in Million. units of the "high brightness" LED market and its future development. The abbreviations AlGaAs, InGaAlP and GaN stand for the different chemical elements the LEDs are made of (Source: Dudda 2000).*

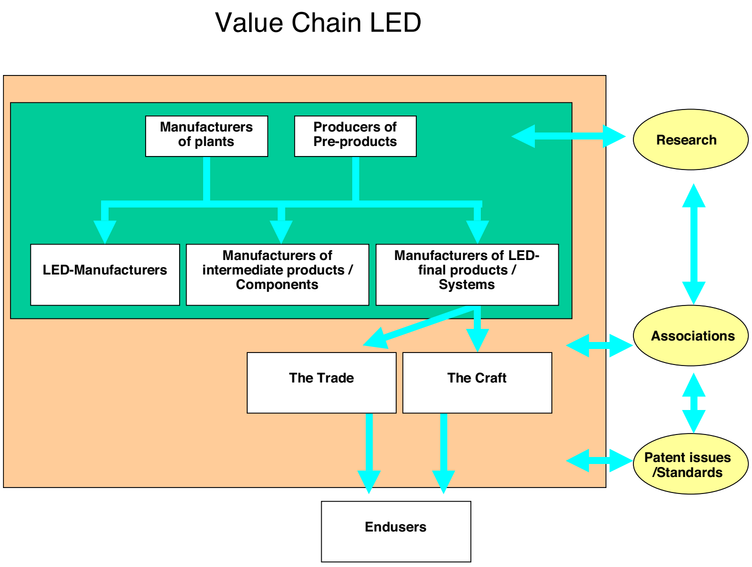

Figure 4. *Value chain LED (Source: Wuppertal Institute 2001).*

prospects and suitable thematic outline of such a network in North Rhine-Westphalia, a screening study was made by the Wuppertal Institute, see step 1 below. This was followed by additional steps for the development of such a network, see step 2-4 below.

Step 1: Screening study on technical and economic potentials in North-Rhine Westphalia

The screening study sketched a quite ambivalent picture of the LED landscape in NRW (North Rhine-Westphalia) in 2000. On the one hand, first investigations (Dudda 2000) backed the assumption of interesting potentials in various fields of applications. Moreover the study revealed an interesting commercial potential because many firms in North Rhine-Westphalia produce markings, signs, way lighting, light tiles, built-in lights, architecture lighting, work-place lights, information systems, car and traffic applications and specific applications on customers demand on LED basis. Although the core technology is dominated by foreign world market players from the semiconductor industries, a wide range of institutions and companies can be found in NRW that may serve as the nucleus of a competitive LED sector. On the other hand, private and public activities tend to be isolated and lack a strategic coordination for focussing the resources. Often, actors do not enter the needed co-operations that are necessary to advance in the field so that innovation cannot take place. Hence, the screening study strongly pointed out the demand for networking of actors in NRW and bundling forces all along the value chain (Figure 4).

Step 2: "Impulse Workshop"

The screening study revealed a strategic potential of LED. Encouraged by these findings the state North-Rhine Westphalia took the initiative to strengthen the technological basis and competitiveness of domestic players. As the first impulse to mobilise the relevant players, in May 2001 more than 20 participants from trade and industry, policy and science met in Wuppertal for the impulse workshop "LED in NRW" under the auspices of the Ministry of Science of North-Rhine Westphalia. This event, which was moderated by the Energy Division of the Wuppertal Institute, provided for the first time a forum to explore the different perspectives and to identify fields of action and strategic foci of future LED-activities in NRW. The discussions revealed a series of problems at the different stages of the value chain – both technical as well as administrative obstacles could be specified.

Step 3: Initiation of the competence network LED

The results of the impulse workshop formed the basis for initiating a "competence network LED" by the State of North-Rhine Westphalia.

It is the objective that the network supports and accompanies the development of one ore more concrete products from research to the commercial market introduction (so called key projects). Special emphasis is put on the fact that

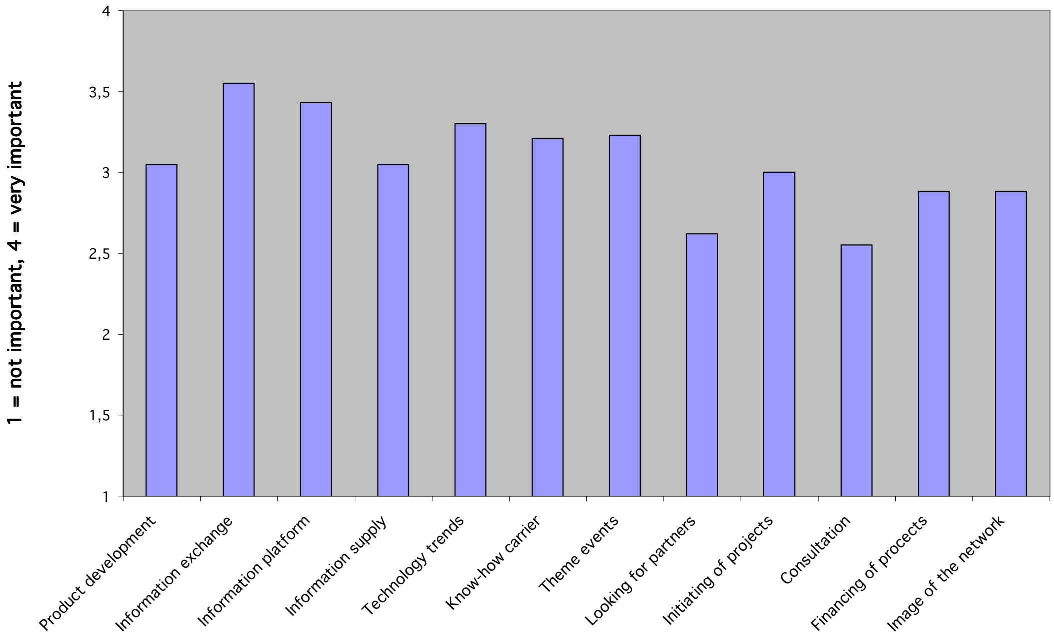

Figure 5. *Results of the inquiry (Source: Kristof et al. 2001).*

these products not only substitute recent lighting systems but underline specific advantages of LEDs as low maintenance costs because of the long lifetime of LEDs, insensitiveness to outer disturbances, the harmlessness in operation because of low voltage and of low heat generation, the freedom of shaping by designers and the possibility to realize each colour by combining different coloured LEDs.

Step 4: Inquiry of market participants

For the preparation of the network an inquiry of the market participants was carried out (Kristof et al. 2001), aiming at receiving information about the expectations to such a network and the role of politics. The response revealed a strong interest in information supply as well as support for R&D actions. Figure 5 shows in detail the answers to the core question "Which advantages do you expect by the competence network LED?" As can seen in the figure, information (information exchange, information platform, information supply, technology trends, know-how carrier, theme events) is the most important issue, followed by initiating of projects (project development) and product development.

PERFORMANCE OF THE NETWORK

Regular meetings

In autumn 2001 the competence network held a Kick-Off Workshop in Düsseldorf. About 60 guests attended this starting signal for the 18th network of the State-Initiative-Program for future technologies. Most of the participants came from research and enterprises but also from administration. A very important task of the Kick-Off Workshop was the determination of a coordinator who should be a renowned person from practice. Further meetings that take place regularly three to four times a year have followed this first meeting. In these meetings, general activities as well as information exchange between the participants regarding special key projects occur.

The general activities of the network include talks and discussions about technical information, market surveys, future trends and development funds. Tasks of the network also include providing support with application for funds, patent issues and public relation. The activities of the network are presented on fairs and in a special magazine of the State-Initiative-Program for future technologies. For the future it is planned to launch a design competition for LED lamps.

Key projects

During the discussions of the impulse workshop five key projects were specified by consortia of various partners. The participants present the progress of the key projects during the regular meetings of the competence network. The five projects cover a wide range of applications but the network is always open for further key projects.

Power chip

In the recent ten years LEDs could tenfold their brightness and nowadays achieve an excellent efficiency. In the near future High-Power-LEDs will be bright enough to carry out the change from the classical display to the energy efficient illuminator. However this requires a paradigm shift regarding the size of LEDs. Classical LEDs have a size of 0.25x0.25 mm^2 and a light flux of 1 lumen and they are fixed on round 5 mm casings. In order to meet the requirements illuminators, however, LED have to achieve at same size much higher light fluxes above 30 lumen, for high performance applications even above 80 lumen. Such a LED-based light source with a high brightness is called "Power Chip" (often referred to as High-Power LEDs, power LEDs and high-performance power-chip). The market introduction of a high-performance power-chip is the mandatory prerequisite to take benefit from the specific advantages of LED-illuminators such as high energy efficiency, long lifetime, little warming up, extreme robustness against mechanical loads and freedom in lamp design.

For this reason, the development of the power LED as a primary light-engine is an indispensable condition for nearly all of the projects of the competence network "LED in NRW". The power chip is standing in the centre of the value chain of automobile applications (e.g. daytime running lights), illumination applications (e.g. LED instead of Neon) and other LED-based solutions.

The technical development of the power chip would allow the industry of North-Rhine Westphalia to take a leading position concerning innovative, high-quality and efficient light-engines. Before this can take place, numerous scientific and technical advances have to be realised, e.g. in terms of quantum efficiency, luminous efficiency, size of the chip, distribution of current, thermal management, assembly technique and injection moulding for big optical systems.

Daytime running lights for cars

To enhance the safety of road traffic, the automobile industry has committed itself in near future to fit out the cars with daylight running lights. An argument against the daytime running lights has been the extra fuel consumption of 0.1 to 0.2 l per 100 km. This would lead to an extra consumption of 280 million litre fuel each year in Europe.

The idea is to have extra lamps only for the daytime running light, because this lamp has only to generate the scattering light and not to illuminate the street. So the wattage of the lamp can be reduced. Further reductions are expected by using LEDs in the daytime running lights. Reductions in the wattage and so in the fuel consumption for the daytime running light of more than a factor ten could be realized with LEDs. Further advantages are the long lifetime and the small shape of LED based lights.

In this key project, the tasks are to develop a very powerful white LED source; in so far this key project is connected with the key project power chip, and an appropriate optical system. If this project would be successful a new safety enhancing and energy saving LED-application would be developed. Besides this the partners could strengthen their market position and so the position of North-Rhine Westphalia as an attractive site for future industry.

Dynamic Roadmarking

Illumination systems get more and more importance for optimising traffic fluxes und at enhancing the road traffic safety. In this regard LED based systems will replace various conventional technologies in the future.

A new application in this field is "Dynamic Roadmarking". Aim of this technology is to steer the number of lanes dynamically on highly loaded streets. For example, an uninterrupted line that separates two lanes and consists of switched-on LED-modules (see Figure 6) can be partly switched-off so that the line becomes interrupted and so allows the traffic to pass the line. In this way e.g. the hard shoulder of a highway could become an extra lane or lanes could be made smaller to get an additional lane. In a test in the Netherlands it could be proved that the traffic flux could be raised. The new construction of highways could possibly be avoided by dynamic roadmarking.

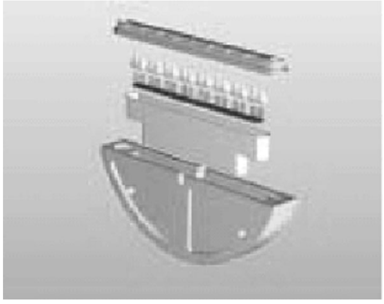

Figure 6. *Module for dynamic road marking (Source: Philips Outdoor Lighting 2001).*

In first tests the technical realization has to be shown as problematic, because the demand on a lighting system that is built into the street is extremely critical due to the mechanical and thermal stress, etc. LEDs seem to offer a possibility to integrate efficiency, lifetime, small size and low costs with this system.
Problems to be solved are:

- New materials have to be developed to limit the wear and tear of the optical systems.
- New technical solutions are necessary to reduce dirt on the module – because of weather.
- High energy efficiency power LEDs and special optical systems have to be developed.
- The installation also has to be guaranteed in order to reduce the risk for the safety of the drivers.

LED instead of Neon

In each city there are advertising writings on facades and buildings, which are called "neonsigns". They are made of a tin or plastic box with inner or outer lighting means. As lighting means, high voltage lamps, halogen filament bulbs or energy saving lamps are used.

Normally the neonsigns are handmade: glastubes are formed over a flame and electrodes are fitted. Then the illuminant is brought in, the tube is evacuated and a noble gas is filled in. The illuminants contain mercury and therefore are problematic at the production and the disposal. Most of the lamps run with high voltage, so the installation and the maintenance require special staff that is trained to handle high voltage installations. Further problems arise from the short lifetime and the limited range of colours available.

A new development process could be available based on LED technology, see Figure 7. The process will start with an "on screen design" of a logo or writing and a following automatic production of a LED-sign. The software determines the kind of LEDs to be used and their position. After that the special form will be shaped. Problems that still have to be solved are that for a wide market share the luminous efficiency of the LEDs has to rise and the costs for LEDs have to go down.

OLEDs (Organic LEDs)

Organic LEDs are based on polymers. They are dotted in such a way that they emit light if they are put under voltage. There advantage is that they are very thin and flexible.

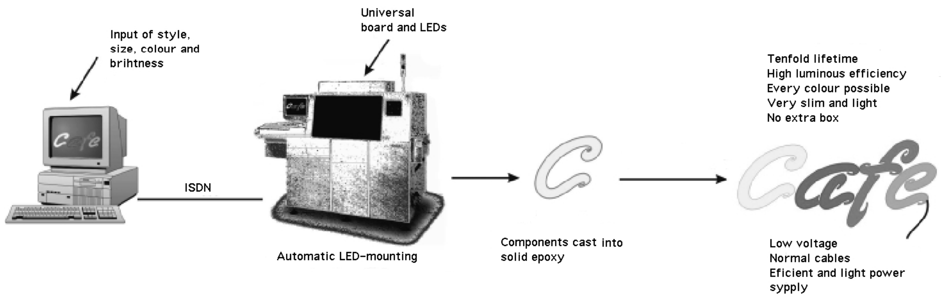

Figure 7. *Production of a LED sign (Source: Lumino 2001).*

Based on the technology of organic LEDs components for lighting applications shall be optimised in this project. Already today, the organic materials exceed the efficiency of normal light bulbs. The present record for white organic LEDs is at 10 lm/W but organic materials up to 50 lm/W seem to be possible, which would lead to huge energy savings. By simple modifications it is furthermore possible to double the light production, so that the efficiency of organic LEDs is even better than for halogen light bulbs. Theoretically possible is a lighting source with a higher efficiency than a fluorescent lamp that means >100 lm/W. Great progress is also made in the lifetime of such LEDs. Lifetimes of 10 000 hours are already achieved and can certainly be enlarged by a factor ten. With that organic LEDs are marketable for common illumination applications. A better efficiency and lifetime of OLEDs are the tasks of this project. In order to realise the mentioned benchmarks a new production technology has to be developed.

Further scientific and technical tasks are:

- Evaluation of organic materials for applications in the lighting technique.
- Research on and optimising of coating methods from the gas-phase.
- Research on the influence of the production process on the illuminants.

A success in the OLED technology is considered to be another significant breakthrough towards a new illumination technology. New possibilities will emerge for architecture, for workplace and interior illumination as well as for the display technique.

Experiences from the network launch and hitherto activities

In North Rhine-Westphalia a broad range of companies and research institutions can be found that are dealing with the LED technology. Due to the widespread activities, however, these actors have barely known each other. To a certain extent, the situation before the network was initiated could be characterised by splendid isolation.

When the network was launched it became clear very early that the various actors want to overcome this situation. Surprising enough, from the very beginning it was easier than expected to find participants and partners – a strong indicator that the idea of a competence network met a hidden demand in NRW.

During the conceptual preparation it became very clear that several stages are necessary to launch and establish such a network. In this regard, the experiences indicate the value of a sound conceptual and organisational preparation.

As a first step, the screening study was undertaken in order to investigate the market potential specifically suited for participants of North-Rhine Westphalia, followed by a calculating of the achievable economic and ecologic potentials.

Second, the impulse workshop provided the forum to validate the results of the screening study. More important, the event served to clarify many ideas for the tasks of a LED network such as information exchange, patent issues and help with funding for projects. In this regard, the workshop was an indispensable step to convince the participating market actors that the initiative may result in practical benefits valuable for their business – a key to gain industry's commitment.

Furthermore it can be stated, that external inputs to launch the network was indispensable, because the organisation of a network demands for a lot of personnel resources for e.g. organisation of the impulse workshop. In this regard, the start-up support by the NRW Ministry for Science turned out to be another key factor of success and illustrated the State government's commitment. Bundling the LED network to the North Rhine-Westphalian State-Initiative-Program for future technologies gave an additional impetus to stimulate industries' interest.

In a third step, an inquiry of the possible participants was made before the start of the network in order to get even more information about the expected role of a competence network. So it became even more evident, that such a network should be a platform for all questions of the participants regarding LED and the proposals for future work could be better designed to meet the expectations.

As known from many examples the performance of any comparable network will be strongly effected by the interior structure. In order to generate benefits for the members the organisation of the network has to be lean and efficient. A key role for the network plays the network coordinator. Acting as the *primus inter pares* he or she should be a widely repudiated expert of high competence. Moreover, he or she need to keep in balance his own interests in the field while giving room for activities of other participants.

Closely linked to this it is very important for success that an open atmosphere of commitment and common engagement can be created by the participants. Here, the key projects play an important role as the gravity centres of common interest. Being all more or less involved in these key topics, the participants of the network have a strong incentive to join one or more the four strategic projects (key projects) in order to advance in particularly important areas.

From the very beginning it became clear that the government could not provide continuous funding nor dedicated special R&D funds to the network. So the network has no own money, but the contacts among participants, the information exchange and the support by the network helps participants to prepare carefully for the general funding schemes, i.e. the probability of acceptance of the projects increases though officially the project are not preferred to others.

The limited evidence from the first meetings supports the assumption that the most important task of the network is information exchange among participants, followed by the opportunity to meet the people involved in LED technology face to face. It could be observed several times, that if the participants have to solve a problem, it has been very easy to find someone in the network who can help. These effects, however, are growing gradually and apparently it takes time to establish workable relations. Especially the beginning stage of the network the interaction between participants is still hampered, so that the preparation of actions, the pro-active role of the moderator and further services are very important for the success. Again, this underlines the importance of external resources for the initial phase. It is up to the further development in how far the participants will be able to twist self-maintaining relations so that the network will work out alone.

Conclusions

It can be summarized that the process of launching the competence network LED has created a common understanding within the scene concerning the strategic value of a North Rhine-Westphalian initiative. During the first year of operation, a first feedback is positive and participants report, that they benefit from network supports by realizing own benefits in their projects. It seems to be that altogether the mixture of all activities creates supportive conditions that contribute to enhance activities by market players from NRW. This is a success of the competence network LED in North-Rhine Westphalia.

Although these first observations appear to be quite encouraging, however, it is still far too early to come to comprehensive evaluation judgements. For these reasons the further development is still unclear and the future will show if the present key projects will be successful and if further key projects will be launched.

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