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Supplement to the Treatise

WOLFGANG RUNGE: TECHNOLOGY ENTREPRENEURSHIP

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Wolfgang Runge

Novaled AG

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Novaled AG, founded in 2001 as a spin-out from the Technical University and Fraunhofer Institute in Dresden (Germany), sees itself as a leader in the research, development and commercialization of technologies and materials that enhance the performance of organic light-emitting diodes (OLEDs). OLEDs are solid-state devices composed of multiple thin layers of organic materials, collectively known as the *OLED stack*, that emit light when electricity is applied to them.

Core competencies of Novaled cover a unique combination of organic conductivity doping technology, proprietary materials and OLED stack development expertise.

They believe to be currently the only company licensing and selling organic conductivity doping technology and materials for use in the commercial mass production of display products in the OLED industry.

Novaled offers to OLED *display and lighting* manufacturers *customized solutions* to optimize the performance, power efficiency, stability and lifetime of their products while decreasing their manufacturing complexity and cost.

As compared to existing liquid crystal displays (LCDs) OLED displays offer superior image quality, increased power efficiency and a thinner, lighter form factor. For instance, AMOLED (active matrix OLED) and AMLCD display characteristics and obstacles and solutions for AMOLED are presented by Colegrove [2012].

As will be seen the foundation and development process of Novaled as an internationally operating multi-disciplinary RBSU (research-based startup) has a number of special situations and approaches of the entrepreneurship process from the beginning.

By August 2013 Samsung acquired Novaled for €260 million ($347 million) [Filtz 2013].

The Korean company will directly acquire a 40 percent stake in the venture-backed materials company. That will add to the 10 percent stake already owned by Samsung's own venture investment arm, while Cheil Industries – a Samsung affiliate company – will take a majority stake of approximately 50 percent. Jan Blochwitz-Nimoth, one of the founders of Novaled is also set to sell his share in the firm. Novaled generated revenues of €26 million in 2012, meaning that the deal values the company at around ten times its annual revenues [Optics.org 2013] which means in mergers & acquisition language so-called "multiples" of ten.

The Technology and the Market

The transition of lighting which is already happening for light emitting diode (LED) technology [Runge:Figure I.165, Figure I.166] and organic light emitting diode (OLED) technology [Runge:Figure I.148, Figure I.149] is one of the last *analogue-to-digital transitions*. It was generally expected that digitization will change the lighting market similarly to digitization of the camera market at an average growth of ca. 30 percent [Runge:p. 461].

LEDs provide *point (spot) lighting*. On the other hand, for *area lighting* OLEDs would be better suited rather than point lighting LED. Think entire lighting ceiling tiles rather than spots – or even luminous wallpaper. OLED displays are the next generation of emissive technology. Related displays are composed of self-luminous pixels and require no backlights.

OLED technology is among the most promising possibilities for the next generation of flat-panel displays (FPDs) and lighting technologies. Since early 2000 OLED products were projected to generate a market potential of several billions of dollars [Leo and Blochwitz-Nimoth 2004; Der Stern 2005]. As the infrastructure in existing liquid crystal display (LCD) production facilities can be adapted technically rather easily for the new technology, researchers are convinced the new technique will allow for very cost-effective display manufacture.

OLEDs as a promising new light source also for white-light systems has the technical potential to contribute significantly to *energy savings in professional and industrial environments*. Hence, OLEDs show also up in the context of energy efficiency and CleanTech [Hong et al. 2005]. It is estimated that in the developed countries ca. 15 percent of electrical power is used for lighting. CleanTech aspects include: No mercury, fewer components, and more energy saving.

Hence, OLED represents a key technology. But simultaneously it is also a *generic technology* [Runge:Table I.51] with the potential to substitute LCDs partially and LED luminaries.

It was estimated that around 2000 LED/OLED products accounted for ca. 1 percent of the overall very huge lighting market [Runge:Table I.81] and ca. 3 percent of the flat panel display (FPD) market [Leo and Blochwitz-Nimoth 2004].

Technology

An OLED utilizes the principle of *electroluminescence, an optical phenomenon and electrical phenomenon* in which a material emits light in response to the passage of an electric current or to a strong electric field.

An OLED is a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compound which emits light in response to an electric current. This layer or layers of organic semiconductor(s) is situated between two electrodes [Wikipedia-1].

Generally, at least one of these electrodes is transparent. Indium tin oxide (ITO) is a common transparent anode, while aluminum or calcium is common cathode materials. Between the emissive layer and the cathode or the anode, manufacturers add other materials to enhance OLED efficiency.

Following Wikipedia-1 the key to the operation of an OLED is an *organic luminophore*. An exciton, which consists of a bound, excited electron and hole pair forms inside the emissive layer. When the exciton's electron and hole combine, the exciton can emit a photon. Excitons are the main mechanism for light emission in semiconductors. [1]

A challenge in OLED manufacture is tuning the device. The object of tuning is having an equal number of holes and electrons meet in the emissive layer. In an organic compound, this equal balance is difficult. In such compounds, the mobility of an electron is much lower than that of a hole (Figure 1).

An exciton can be in one of two states, singlet or triplet. Only one in four excitons is a singlet. The materials in the emissive layer are typically fluorophors. A fluorophore is a fluorescent chemical compound that can re-emit light upon light excitation. These materials can only emit light when a singlet exciton forms. This situation reduces the OLED's efficiency. But, for instance, by incorporating transition metals into a small-molecule OLED, the triplet and singlet states can mix by spin-orbit coupling.

There are also *phosphorescent based OLEDs* (PHOLEDs) with a phosphorophore that use the principle of phosphorescence (generating light from both triplet and singlet excitons). [3]

To create the excitons a thin film of the luminophore resides between electrodes of differing work functions. A metal cathode injects electrons into one side. An anode injects holes in the other one. An electron and hole move into the emissive layer. There, they can meet to form an exciton (Figure 1).

The main challenge was to pixelate the emissive layer of an OLED display as there are three competing requirements:

- Being compatible with large substrates to satisfy the customer’s demand for increasingly larger displays
- Defining extremely fine pixel structures to meet the resolution requirements for the new generation of HDTV- and micro-displays
- Significantly reducing production costs compared to existing display technologies.

So far display companies, in entering the OLED arena, have had a choice in manufacturing strategy either choosing fluorescent small molecule (SM) vacuum technology or fluorescent conjugated polymer (PLED) solution technology.

Substrates may be glass, metals or plastics. When flexible AMOLEDs will be fabricated, for instance, on a polyimide plastic [Runge 2006:139,336], they will be shatterproof, and will also be lighter and thinner compared to glass based OLEDs [Wikipedia-2].

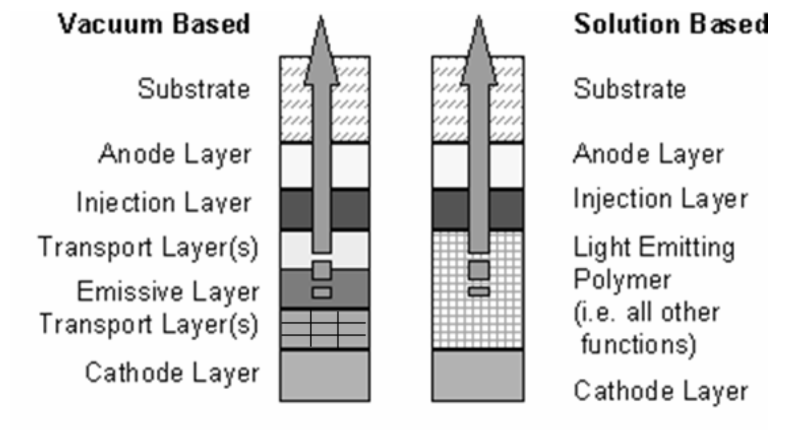
OLED Structure:	
Substrate Anode Conductive Layer (Organic Molecules or Polymers) Emissive Layer (Organic Molecules or Polymers) Cathode	

Figure 1: General principles of OLED technology.

OLED materials generally fall into two classes each with characteristic processing routes:

- *Evaporable materials*: small molecule materials – low molecular weight compounds with standard processing by vacuum or carrier gas deposition
- *Solution processable materials*: macromolecular materials (for instance, polymers, high molecular weight oligomers, and simple solubilized heavy metal chelate materials) can be fabricated by a range of solution deposition techniques from simple coating such as spin and roll coating to printing techniques, such as ink jetting.

Both technologies have developed rapidly and there now exists a number of different viable process options for each. Moreover, the materials' situation has become even more complex with the emergence of phosphorescent (triplet) technology. This offers the prospect of OLED development with exceptionally high efficiency (a factor of 3-4 times over fluorescents) while, except for a difficult Blue challenge, maintaining color purity and long lifetime for R and G. Indeed this promising triplet approach has been shown to be capable of being adapted to either vacuum or solution processes (cf. Competition).

The first observations of electroluminescence in organic materials were in the early 1950s by André Bernanose and co-workers at the Nancy-Université, France. The first diode device was reported at Eastman Kodak in 1987. Kodak developed Small Molecule OLEDs. This device used a novel two-layer structure with separate hole transporting and electron transporting layers such that recombination and light emission occurred in the middle of the organic layer (cf. also Figure 3). This resulted in a reduction in operating voltage and improvements in efficiency and led to the current era of OLED research and device production. Research into polymer electroluminescence culminated in 1990 at the Cavendish Laboratory in Cambridge reporting a high efficiency green light-emitting polymer-based device [Wikipedia-1].

Novaled addresses 2nd generation OLEDs.

PMOLED (passive matrix OLED) started shipments in 1999; AMOLED started at the end of 2002. AMOLED is expected to be the growth force for OLED in the future [Colegrove 2012].

By 2004 Samsung, South Korea's largest conglomerate, was the world's largest OLED manufacturer, producing 40 percent of the OLED displays made in the world, and as of 2010 had a 98 percent share of the global AMOLED market. The company is leading the world of OLED industry, generating $100.2 million out of the total $475 million revenues in the global OLED market in 2006 [Wikipedia-1].

Markets

The introductory remarks about the high growth expectations of OLED markets indeed materialized. Turnover with OLEDs in the European markets in 2009 was ca. $120 mio. per year and was projected to increase to more than $680 mio. Global revenues were assumed to reach $2.45 bil. in 2008 [BMFB 2010].

Related to its state-of-the-art by 2008 OLED technology exhibited the following benefits compared to existing technologies [Böhme 2008]:

- Ultra Thin (<150 nanometer)
- Excellent color and contrast
- Nearly 180° viewing angle
- Large area diffuse light source
- Transparent.

But in the lighting world there emerged a *new paradigm* [Muth 2010]:

- Flat thin area light source which emits light over the whole surface
- Dual nature of OLED: Fusion of lamps and luminaries, reducing system complexity.

According to market research firm NanoMarket characteristics of the developments of corresponding markets in February 2007 are given in Table 1.

Table 1: Growth forecasts of OLED markets when Novaled was in an early phase of growth [Böhme 2008].

Market	2008	2012
Total OLED Display Revenue Forecast ($ bill.)	2.680	10.115
Worldwide OLED TV Revenue Forecast ($ mil.)	42	3,391
OLED Lighting and Signage Revenue Forecast ($ mil.)	75	846

As given by Böhme [2008] the global lighting market was over $90 mil. in 2006 (supplier level). The lighting market is concentrated at front-end (lamps) and fragmented at back-end (luminaries). There are few lamp types but a wide variety of luminaries' types. Lamps as a light source account for ca. 20 percent of the whole market with three big players: Dutch Philips, German Osram and US General Electric (GE). Luminaries (lighting systems) comprising ca. 63 percent has many smaller players and a high level of regional and domestic luminaries' production.

Generically, the opportunities for lighting products comprised [Böhme 2008]:

- Light to illuminate "things" (designed objects, architectural elements etc.)
- Special lighting (decorative, machine vision…)
- General illumination (office lighting, room lighting…)
- Transparent windows.

And people are convinced that *OLED will modify the value system for lighting* [Muth 2010, Blochwitz-Nimoth 2011]. Lamps and luminaries will converge and induce

1. Flat (and flexible) area light sources for revolutionary designs
2. Light sources with low power consumption
3. New players
4. New business opportunities.

OLED can also be combined with other hot technologies, such as touch screens, e-paper displays, and 3D [Colegrove 2012].

Recent market research corroborates what was expected around 2000 concerning market developments and opportunities of OLED [Colegrove 2012; SEC 2012].

The market for *OLED flat panel display products* is growing rapidly and is rapidly gaining market share in the flat panel display market. Market research firm DisplaySearch set the market share of OLED displays as having grown from $0.6 billion (in 2008 1 percent of the flat panel display market) to $3.7 billion in 2011 (almost 4 percent of the flat panel display market) which represents a compound annual growth rate (CAGR) [Runge:Equation I.10] of 83 percent.

Although OLED displays are currently more expensive to manufacture than LCD and plasma displays, many industry analysts believe that *OLED displays represent the future of the display market* due to their superior image quality, form factor and power efficiency as compared to existing liquid crystal displays (LCDs) and plasma displays. Market research projected global OLED display revenues to increase from $1.6 billion in 2010 to $25.5 billion in 2018 at a CAGR of 41 percent.

Transparency Market Research [2013] expected the global OLED displays market to reach $25.9 billion by 2018 from $4.9 billion in 2012 growing at a CAGR of 31.7 percent from 2012 to 2018. *Mobile phones* are the largest end use application and accounted for 71 percent of the total OLED displays market in 2012, but the share of OLED TV displays are expected to surpass the shares of mobile phone displays by 2015.

According to Colegrove [2012] *small-sized OLED displays* (primarily the active-matrix OLED, AMOLED) have achieved significant penetration in the *smartphone market*, and, according to data also provided by International Data Corporation and DisplaySearch, are estimated to *account for approximately 17 percent of total smartphone sales in 2011*. They are also used for digital cameras (DSCs – digital still cameras), mobile media players (PMP) and car audio display.

Medium-sized OLED displays are being introduced in *tablet personal computers* (tablets). Samsung Mobile Display (SMD) and LG Display, the leading flat panel display manufacturers, have recently announced plans to launch *large-sized OLED televisions for the high-end consumer market.* Large-scale displays for promotional and advertising purposes (public signage) are also of interest.

Overall OLED shipments are forecasted to be $250 million in 2012, reaching $776 million in 2018 [Colegrove 2012].

Commercial interest in *OLED lighting products* is also strong. As OLED devices efficiently produce *diffuse, homogenous light from a flat, thin surface*, they offer new opportunities for *lighting installation and design*. It is estimated that the nascent OLED lighting market will develop into at least a $3.5 billion global market by 2018, and DisplaySearch and NanoMarkets project that the OLED lighting market will be $1.5 billion by 2015 and develop into a $6.2 billion and $9.9-billion global market, respectively, over the same period. The Dutch firm Philips, for example, recently confirmed its intention to offer decorative and performance lighting products based on OLED technology [Colegrove 2012].

The opportunity for OLED lighting is evolving. Europe is currently the leading participant in the OLED lighting in terms of organization/projects numbers, government funding, and participating companies. Over 100 companies and universities are working on OLED lighting currently, notably Osram, Philips, Lumiotec, GE, and Kinoca Minolta. Opportunities emerge by diversification of OLED lighting for different applications [Colegrove 2012].

OLED display revenue will continue to be bigger than OLED lighting in the forecast period.

Overall OLED lighting advantages are now seen to cover [Colegrove 2012]:

- High efficiency for energy saving
- Thin, light weight
- Area/surface lighting: flexible or rigid form factor
- Long life time for less frequent replacement
- Tunable color for decorative use and color matching
- Fast switch on
- Wide temperature operation range for use in extreme environments
- Low drive voltage for better power, smaller power supply
- No noise
- Environmentally friendly
- OLED lighting can be transparent like a window or reflective like mirrors.

OLED lighting faces different challenges from displays [Colegrove 2012:23].

Prices for OLEDs are decreasing continuously. By 2010 an area of 100 square centimeters cost ca. €1,000. By 2011 commercially available OLEDs with an area of 50 square centimeters cost ca. €200 per piece. For displays, production has tripled in the past twelve months, and will double again in the coming year [Miethke 2011].

Cost of using OLEDs for displays of smartphones means higher cost of 10 percent for production. But a smartphone does not consist solely of a display. Therefore, higher cost may be hidden or leveled off by other components. On the other hand, for TV screens production facilities using OLEDs need to be built to let cost sink (“economy of scale”) [Miethke 2011].

The Entrepreneur(s)

The research-based startup (RBSU) Novaled was founded as a spin-out from the Technical University of Dresden (TUD) and a Fraunhofer Institute in Dresden (Germany) in 2001, at first with the legal status of a limited liability company (LLC, GmbH in Germany).

The founders were [Blochwitz-Nimoth 2009; Blochwitz-Nimoth 2011] centered around the entrepreneurial professor Karl Leo providing links between OLED startup Novaled and organic semiconductor startup Heliatek and links between TUD and FhG-IPMS (Fraunhofer-Institut für Photonische Mikrosysteme – Fraunhofer Institute for Photonic Microsystems).

Table 2: The founder team of Novaled.

Prof. Dr. Karl Leo (Professorship for Optoelectronics at TUD and Deputy Director IPMS)	Prof. TUD-IAPP (Institute for Applied Photo Physics) and affiliated at a Fraunhofer Institute; involved in spin-outs: CreaPhys, Novaled, Heliatek, Sim4Tec, LedOnOLED
Dr. Jan Blochwitz-Nimoth	PhD at IAPP on PIN-OLEDs
Dr. Martin Pfeiffer	PhD at IAPP on doped organic semiconductors; co-founder of Heliatek
Jörg Amelung	Physics, University of Darmstadt, (FhG-IPMS) electronics; co-founder of LedOnOLED

Key characteristics of an entrepreneurial professor for technology entrepreneurship are not just a business mindset, but also revealing, supporting and encouraging entrepreneurial talents. In case of OLED it was Dr. Jan Blochwitz-Nimoth.

Founders of technology ventures need to be persistent and have much patience. According to Leo “*At the university focusing on know how of founding a venture being taught with praxis orientation, I think, is ideal*.” (An der Hochschule das Knowhow für eine Unternehmensgründung praxisorientiert vermittelt zu bekommen, halte ich für ideal.) [Eckold 2005].

His advice for technology entrepreneurs is:

> The be-all and end-all is people with the *right qualifications*! With us, they must not only be first-class physicist, but also communicative and entrepreneurial tip. (“Das A und O sind Leute mit der richtigen Qualifikation! Bei uns müssen sie nicht nur erstklassige Physiker, sondern auch kommunikativ und unternehmerisch spitze sein.”) [Eckold 2005]

Prof. Karl Leo is Germany’s poster child when it comes to co-founding new smart green startups out of university. His basic attitude is that for a scientist it is a great satisfaction when he sees that his physical concepts will be implemented commercially (Es ist “für einen Wissenschaftler eine große Genugtuung, wenn er sieht, dass seine physikalischen Konzepte wirtschaftlich umgesetzt werden.”) [Eckold 2005].

Karl Leo received his Dr. rer. nat. degree in 1988 at the University of Stuttgart. In 1993 he did his habilitation thesis at the Institut für Halbleitertechnik (Institute of Semiconductor Technology) of the Technical University (RWTH) of Aachen. In the same year he was appointed Professor for Optoelectronics at the Institute of Applied Photophysics (IAPP) of the Technical University Dresden. Since 2001 he was Head of the business unit "Organic Materials and Systems" at the Fraunhofer IPMS.

In September 2007 the Executive Board of Fraunhofer-Society appointed Prof. Leo as a further director of the Fraunhofer Institute for Photonic Microsystems with emphasis on "Organic Materials and Systems."

Since July 2012 he is the Leader of Fraunhofer COMEDD. The Fraunhofer Research Institute for Organics, Materials and Electronic Devices COMEDD was founded as an independent research institution of the Fraunhofer-Society in order to transfer results of research and development in the field of organic materials and systems to production.

Similar to Leo, in hindsight Blochwitz-Nimoth [2009] re-affirmed that the spin-out was a good decision. And he confirmed that it is a great pleasure and a big adventure to see such a firm growing, its employees further developing and pursue applied technology.

According to Novaled's Web site, Jan Blochwitz-Nimoth (born in 1970 in Dresden/Germany) studied physics at the TU Dresden and the University of Oldenburg. He completed his diploma thesis at the Institute for Applied Photo Physics (IAPP) of the TU Dresden in the field of ultra-short laser spectroscopy. Afterwards he worked for one year on inorganic optoelectronic and light projection devices. While working on his PhD at IAPP, he conducted intensive research on applications of doped charge transport layers for OLED. He successfully completed his PhD in July 2001. With his outstanding know-how of doped charge transport layers for OLED Jan Blochwitz-Nimoth is a key inventor of the Novaled PIN OLED technology and became a co-founder of Novaled.

Novaled showed a clear *pre-startup phase* of R&D which led ultimately to the idea to turn the R&D results into a business [Blochwitz-Nimoth 2009].

Novaled is based on the one hand on research on organic semiconductors of Martin Pfeifer at the IAPP TUD, during 1992-1995. He could rely on previous work on vapor-depositable dyes for CCD color filter (charge-coupled device). Another co-worker at IAPP already started to deal with organic transport materials. Early working conditions of these people were rather poor. That changed, however, drastically in 1993 when Karl Leo became professor at the IAPP and *organic electronics* became the focus of the institute.

Introducing organic chemistry into the electronics field, however, meant that completely different doping materials have to be used so that the premise behind Martin Pfeiffer's dissertation was initially a search for suitable doping materials. The first experiments already revealed that the principle of doping can also be transferred to organic semiconductors. In 1996 first results for using selectively large organic molecules for doping organic semiconductors were achieved. These showed a stable increase in conductivity of holes contrary to doping with gases and metals tried to far, but for which increased conductivity disappeared rather fast.

"Yet the work also met with a lot of skepticism. Experts were initially condescending when they heard about the idea from Dresden: One expert from a renowned institute even stated that the components could only become worse due to doping. … That was motivation enough for the team from Dresden to go on to prove that doping can considerably improve the components: They succeeded in *lowering the operating voltage of organic light-emitting diodes (OLEDs*) by more than a factor of two and thereby considerably improved component efficiency." [DZP11]

Skepticism referred also to "doubts whether you can ever thus come through production. Against these doubts we had to fight as a founder team which has now been nominated {for the German Future Award}. The headwind at the university was really very strong. But we have shown that it works. That let emerge imitators and envious persons," said Blochwitz-Nimoth [Miethke 2011].

This was the status of research when Jan Blochwitz-Nimoth joined the IAPP team to research doping effects in OLEDs. The goal was to construct OLEDs better than the existing ones. Transfer and EU financing became available to get more sophisticated facilities for research and correspondingly also better results were achieved.

The basic attitude and conviction generated by Jan Blochwitz-Nimoth during his dissertation work was that experimental physicists should work like engineers: much construction work, much tinkering, much development of methods and devices/instruments, but always with the goal to construct OLEDs which are better than those built before ("continuous improvement").

As Dr. Blochwitz-Nimoth then using this method was able to show in his thesis that highly efficient OLEDs can be prepared that surpass classic lighting elements such as the light bulb or even fluorescent lamps, the breakthrough of the technology was in sight [DZP11].

> In 2001 the OLED results of Blochwitz-Nimoth were summarized and consolidated establishing a basis: OLEDs with significantly lower operation voltage and competitive efficiencies can be obtained by doping.

During discussions between related IAPP people (Table 2) with Jörg Amelung from IPMS joining later the group agreed to the opinion that it would be a pity to stop working in the area and just to continue with "basic research" and to observe how others in the world will utilize their "doping technology" for OLED products. All were convinced that exactly that would happen with their enabling technology so that the focus on doping became quasi a dogma [Blochwitz-Nimoth 2009].

Simultaneously, in the global industry awareness of OLED as a key technology had emerged. And some firms, for instance, from the area of "public advertisement" (public signage), spelled out their will to the IAPP to contribute to financing OLED products.

The goal was commercial exploitation of research results of IAPP of TUD utilizing cooperation with the Fraunhofer institute IPMS in Dresden and focusing on development of technology for processing OLEDs in the vacuum [Leo and Blochwitz-Nimoth 2004]. By mid of 2001 before the dot-com bust and the recession financing did not appear to be a problem [Blochwitz-Nimoth 2009].

But before the successful development as reflected by awards and publicity could materialize a number of hurdles and barriers had to be overcome, in particular, *much technology development was still needed*.

Awards and Publicity

In 2012 Novaled made it into the prestigious *2012 Global Cleantech 100 List*, produced annually by research firm Cleantech Group. The list highlights the top private companies that represent the most innovative and promising ideas in CleanTech technology and are most likely to make the most significant market impact in the next five to ten years. In addition, Novaled has been awarded as the "European Company of the Year" [EETimes 2012].

In 2011 Prof. Dr. Karl Leo, Dr. Jan Blochwitz-Nimoth and Dr. Martin Pfeiffer won the Deutscher Zukunftspreis 2011 (German Future Award, [DZP11]). The prestigious Future Award of the German President rewards marketable ideas from technology and innovation, engineering and natural science and focuses on fundamental principles for commercial use. The award includes €250K prize money [Handelsblatt 2011]. It awards persons, not organizations or firms.

It is all about organic electronics, organic LED (OLED) and organic photovoltaic (OPV) made in Dresden, Europe's leading cluster for green photonics (Figure 6). The potential of organic electronics is tremendous, with experts expecting a global, multi-billion dollar market for the industry in just a few years.

> According to Dr. Blochwitz-Nimoth "We envision ultra-thin, large, long-lasting, even transparent and flexible displays and area lighting using technologies and materials from Novaled." [DZP11 2011]

The European Foundation for Quality Management (EFQM) awarded Novaled "Recognized for excellence". The company achieved the highest level with the score of 5 stars in the assessment by an independent expert team.

"Quality is the lifeblood of Novaled", said Gilda's Sorin, CEO of Novaled. "It is essential for our business when dealing with international corporations to be recognized for the quality of our organization. In addition as viewed by management it is Novaled's mission to support each of its employees in enhancing his/her own value. EFQM tools and methodologies bring the proper support to the teams for further progression." [Business Wire 2011]

In 2008 Novaled was revealed as the No. 1 of the fastest growing German mid-size companies by the business magazines Handelsblatt and Wirtschaftswoche [FhG Venture].

Novaled AG has been awarded as the Red Herring Europe 100 Winner 2008 [Novaled 2008a].

In 2006 the German "Land der Ideen" (Country of Ideas) Initiative named Novaled as a location of innovation.

In 2005 Novaled GmbH was a nominee for the prestigious German Founders Award (Deutscher Gründerpreis) in the Category of Visionary 2005 which raised publicity of the firm considerably and its direction and ambitions for future developments: "We dream that all displays will one day be labeled 'Novaled inside', just as Intel has managed to do it with its processors." [Novaled 2005a, Eckold 2005].

Novaled gained much publicity through publicly broad discussions about the future of lighting and displays in the media for consumers and in the scientific and technical communities by *continuous (world) records of technical achievements* for key performance characteristics of OLEDs, by the venture capital environment as well the markets and potential customers. The technical achievements are summarized in Figure 2 [Blochwitz-Nimoth 2011; Muth 2010].

In particular, Novaled developed a large area organic light emitting diode device that the company claims to meet international lighting specifications, for instance, meeting the US Department of Energy (DOE) lighting specs [Mokhoff 2009].

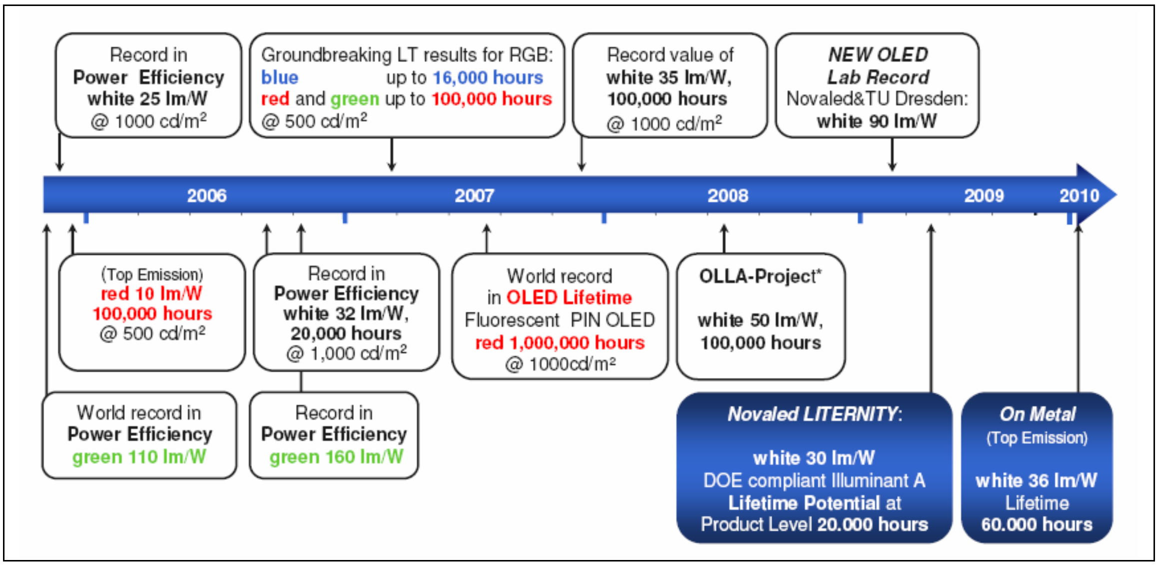


Figure 2: Novaled's world records through PIN-OLED® technology [Muth 2010].

It is interesting to note that some of these records exhibit a near coincidence with financing rounds of Novaled [Blochwitz-Nimoth 2011]. In particular, the third financing round was preceded by a notable track record of Novaled.

Early 2005	World records power efficiency OLED: Green 110 lm/W, White 25 lm/W	2nd Round (€15 mio., Table 3)
Mid of 2008	OLLA-Project: White OLED 100,000 hours, 51 lm/W @ 1,000 cd/m²	3rd financing round (€8.5 mio.)

Business Idea, Opportunity and Foundation Process

The Business Idea

For 2001-2003 Novaled was essentially a “mailbox company.” The founders were still at the university or FhG institute, respectively [Blochwitz-Nimoth 2011] and remained essentially “only” scientists [Leo and Blochwitz-Nimoth 2004].

Basically, the goal of the company was development and commercialization of “‘next generation small molecule OLED-technology” [Leo and Blochwitz-Nimoth 2004] with

- Low operating voltage and highest power efficiency,
- Great flexibility of OLED and OLED application designs (not just for display),
- High stability during manufacture meaning high yield and
- Fast and cost-effective production technology.

Whereas basic research was with TUD (IAPP) manufacturing of doped structures, *passive matrix* applications and OLED-drivers was with FhG IPMS.

The basis of foundation was patents and know-how of TUD (“science2business”). TUD provided the services of basic support of writing the patents, going for applications for the patents, and getting them fast through the corresponding processes [Leo and Blochwitz-Nimoth 2004].

In a next stage of the science2business process the scientists would become “potential founders” and look for collecting financial resources which would turn scientist also to entrepreneurs. And the scientists now would operate in an industrial environment but would remain scientists in a startup/spin-out. The spin-out must keep and develop the patents further, must apply for new ones and further develop and commercialize the technology [Leo and Blochwitz-Nimoth 2004].

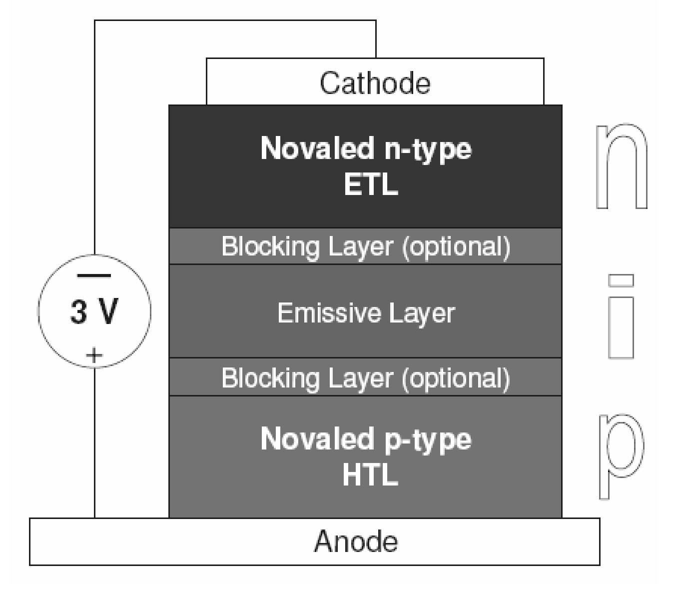
A roadmap for Novaled [Leo and Blochwitz-Nimoth 2004] is essentially a “*technology push approach*” [Runge:ch. 1.2.5.1, p. 120] R&D shall focus on new OLED structures, such as “top emission” and new materials needed for its technology. Commercialization by Novaled should follow technology transfer and licensing programs. Further envisioned revenue streams should be based on customer-specific OLED solutions and also production as a technology partner in joint ventures.

The fundamental technological constellations of Novaled comprised (cf. also Figure 1 and Figure 3):

- Doping of the transport layer [Blochwitz-Nimoth 2011:27,28] and
- High efficiency OLEDs to require pin-structure (“PIN concept” [Leo and Blochwitz-Nimoth 2004:14; Blochwitz-Nimoth 2011:26])
  - p-type doped hole transport layer (HTL)
  - intrinsic emission layer (may be emitter doped)
  - n-type doped electron transport layer (ETL).

Novaled’s proprietary PIN OLED® technology and its key features which make it a USP (Unique Selling Proposition) are illustrated in Figure 3.

Demonstrations of related technology were provided in cooperation with large firms, such as Optrex (Germany), ITRI (Taiwan) and Thomson (France) [Leo and Blochwitz-Nimoth 2004:17].



No injection layer between ETL (electron transport layer) or HTL (hole transport layer) and electrodes required!

No ITO treatment necessary due to doping technology

Results in maximum power efficiency, longest lifetime and freedom in OLED design

Doping of Transport Layers:

lower resistances,
lower driving voltage,
nearly no voltage increase

Figure 3: Novaled's PIN OLED® technology and its key features [Böhme 2008; Blochwitz-Nimoth 2011].

Figure 4 shows Novaled's innovative technology in context. Novaled develops an innovative highly efficient OLED structure based on proprietary doping materials.

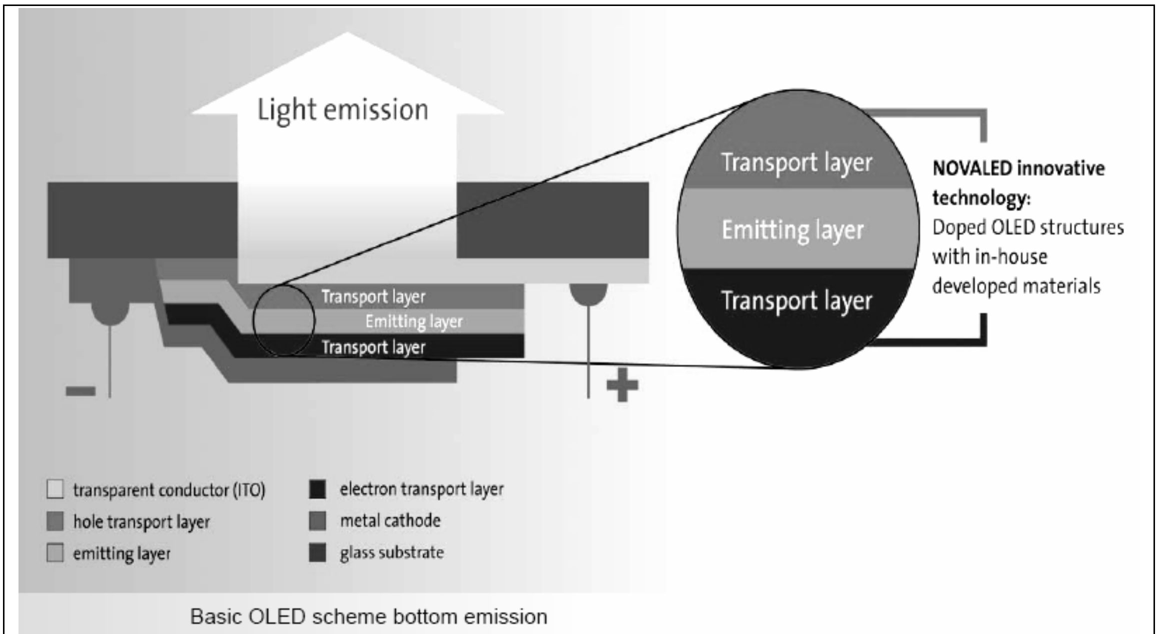


Figure 4: Novaled's innovative technology in context of a basic OLED scheme [Böhme 2008; Blochwitz-Nimoth 2011].

Novaled was founded in 2001 – just ca. one month before the "9/11" event in the US and the following recession – when financing did not appear to be a problem. But then envisioned financing options disappeared. And the founders had to change strategy. They started to write their own business plan expressing the need for *large capital requirements* and *urgency*. Then, overall several lucky situations turned out to be advantages for the firm's development [Blochwitz-Nimoth 2009]:

- R&D efforts at the IAPP could continue without interruption due to several projects financed by the German Research Foundation (DFG – Deutsche Forschungsgemeinschaft) and other projects.
- The local savings bank helped to write and distribute business plans.
- Venture capital firm TechnoStart engaged in the firm and acted as a lead investor.
- There were several (verbal) promises of backers from Saxony to support the "Novaled project" financially.
- Prior to financing the firm there was already signed a license agreement between TUD and Novaled clarifying the patent issue for Novaled: patents to Novaled in exchange of a stake in Novaled by TUDAG (the venture partner of TUD).

Concerning the involvement of the TU Dresden and Fraunhofer Society Framework Agreements were closed before the first financing round (Table 3). Novaled got the first right to purchase IAPP intellectual property (IP) on organic electronics. TUD profits from value development of Novaled without limiting freedom to operate for Novaled and intensive scientific cooperation was agreed upon [Blochwitz-Nimoth 2011].

Blochwitz-Nimoth became managing director (in German Geschäftsführer) of the firm; the other founders kept their functions at TUD or FhG, respectively, but had dedicated roles: Martin Pfeiffer as "the Brain," Prof. Leo as the "integrator", Jörg Amelung as the representative of production development at FhG.

Taking all these factors together in March 2003 Novaled GmbH could start addressing the market [Blochwitz-Nimoth 2009] and first revenues of €96,000 from selling offerings (first know-how transfer) was achieved and in 2004 revenue jumped to €1.593 mil. [Blochwitz-Nimoth 2011].

With the expectation of broad applicability and still many unforeseen new applications for OLEDs the founders, however, first had to do a lot of R&D work at IAPP. The role of the Fraunhofer IPMS was to help bridging the transition from idea to product [Blochwitz-Nimoth 2011].

Novaled's cooperation with TU Dresden related at the beginning to co-use of laboratories and offices and doing sample production for TUD; there was partially parallel development. The cooperation developed over time such that common discussion were on lower levels, making know-how available (for instance, equipment) in both directions [Blochwitz-Nimoth 2011].

But cooperation of Novaled and TUD changed. There emerged retroactive effects, systemic reflexivity [Runge:Figure I.43]. Novaled has developed processes for OLED preparation and characterization suitable for industrial use the university can benefit from. For instance, hardware and software developed by Novaled is used. Furthermore, Novaled finances long-term or very research intensive projects at TUD. Finally, Novaled also runs projects whose scientists in charge work at TUD for their doctoral theses. Now Novaled finances basic research project and cooperation is in local networks ("Organic Electronics Saxony", Figure 6) [Blochwitz-Nimoth 2011].

Novaled started *commercial activities* in 2003. To *fast develop products* Novaled needed resources and develop resources, respectively, in terms of finances, employees, leadership or management, organization and cooperation with external industrial partners.

It became clear that only sufficient *venture capital financing* will secure finances needed to *fast* develop their products for the markets (and hence the company).

If Novaled would have wanted to build an OLED manufacturing, it would require an investment of €2-€3 billion. Rather, they set up a small production line for the production of small series of OLED samples and prototypes *demonstrating the potential of the technology*. Here with 30 people it produced ca. 160,000 units per year. For larger series its Fraunhofer IPMS partner was responsible [Lachmann 2008].

Novaled's effective start was associated with closing its first €5.75 mio. financing round in March 2003 ([Novaled 2003a], Table 3). And in August of the same year Novaled hired a professional manager, Gildas Sorin, who became first Managing Director of the GmbH (LLC) and later CEO of the stock company (AG) and is currently still in this job. Dr. Blochwitz-Nimoth, Managing Director since 2001, became the second Managing Director of the GmbH and CTO.

Simultaneously Novaled decided to change its legal status from GmbH (LLC) to a stock corporation (in German Aktiengesellschaft, AG). It became effective in March 2006. As a stock company, Novaled would comply with international standards for institutional investors and provide greater transparency to its business partners [Business Wire 2006].

Gildas Sorin from Paris/France (56 years in 2008) spent half of his professional life in Germany. He studied electronics engineering [Lachmann 2008].

Gildas Sorin started his career with Thomson in 1977, holding several positions in R&D. In 1981, he moved to Germany and in 1986 he became deputy general manager of the worldwide Thomson R&D organization and in 1991 he became general manager Thomson strategic sourcing. He was a director of the joint venture Thomson/ST Microelectronics in 1991, of Thomson LCD in 1995, and president of Thomson plasma in 1997.

Sorin joined Philips in 1998 as a vice president of the Philips display division and general manager of Philips plasma displays. He attended the Thomson University in 1999, and the University granted him a degree in senior management [Novaled 2003b]. That means he has wide, deep and international experiences in R&D, management and in the area of microelectronics and flat panel displays (FPDs).

Sorin's change to the management of the young firm Novaled can also be regarded as a signal to the Novaled (financing) partners to use a technology leap and translate it into specific economic successes [Novaled 2003b].

Novaled’s managing directors and later Management Board 2003-2009 [Blochwitz-Nimoth 2011] included three *Management Board Members* (in German Vorstände). The triple included the jobs of CEO (Gildas Sorin), CTO (Jan Blochwitz-Nimoth) and later CFO (Harry Böhme).

From 2003 till 2006 there was implementation of first management tools. Business Balanced Scorecard (BBS) and Pay-Performance Sensitivity or Pay per Sale (PPS), respectively, occurred and later also Total Quality Management (TQM). However, as often observed, research staff was usually skeptical toward such kinds of “change management” which addresses also performance of researchers [Blochwitz-Nimoth 2011].

Novaled’s employees focus essentially on two topics [Blochwitz-Nimoth 2009]

- How to get the maximally possible performance efficiency out of an OLED.
- Which product technologies and products may be generated out of such OLEDs particularly for the lighting area?

The first issue was tackled by doping technology of the layers of organic semiconductors which are responsible for charge transportation. Then the OLED layer structure has to be optimized. This provides OLEDs with a minimal operating voltage and depends essentially on developing organic compounds/molecules and materials.

Therefore, Novaled set up early its “Chemistry Team” in 2004. The Chemistry Group was/is a materials synthesis group and employs chemists, chemical engineers and laboratory assistants/lab technicians. And there were first sales of technology programs and know-how packages to Asia on the basis of contract R&D [Blochwitz-Nimoth 2009].

Since 2005 Novaled’s *location* is in the BioInnovationsZentrum Dresden (BioZ) which is a technology park and offers at least initially favorable renting rates, also for necessary special facilities such as clean rooms. [Zitzmann 2011; Anonymus 2014]. Novaled envisioned to leave the BioZ in ca. two years [Zitzmann 2011]. This will happen in at least in 2015 [Anonymus 2014].

The *organization* of Novaled by 2005 relied essentially on three Groups: Physics, Chemistry, and Manufacturing & Testing. It used a project driven matrix structure [Blochwitz-Nimoth 2011].

In 2006 reinforcing its production of samples to better respond to the *increasing customer requests* Novaled ramped up its Manufacturing & Testing Group. In its clean rooms in Dresden, Germany, "We just recruited new production staff to be able to operate our equipment 24 hours a day seven days a week" said Kai Gilge, the Production Manager of Novaled. "These steps put us in the position to better meet customer needs in terms of quantity, quality and timing.” [Novaled 2006d]

Additionally Novaled started to develop its own *network*, expressed in terms of publicly supported R&D programs and European consortia [Blochwitz-Nimoth 2009].

- Novaled also worked on visibility and publicity of the firm.
- It showed up at fairs and exhibitions.
- Cooperation was with relevant organizations and contacts set up with media feeding them with news about Novaled’s world records for OLEDs (Figure 2).

Financing

Novaled closed its first financing round with €5.75 mio. from a consortium of international investors led by venture capital firms TechnoStart and TechFund Capital Europe from Germany and France and the second one two years later with €15 mio. (Table 3).

One would hypothesize that the establishment of Gilas Sorin, a previous manager for Thomson, as the CEO of Novaled facilitated Thomson’s corporate venturing in Novaled.

Both these rounds kept essentially the same private investors which were also observed for the third round (again by existing investors). This rather *stable constellation of investors* was definitely advantageous for managing the firm and building and executing strategy.

Table 3: Early financing rounds of Novaled GmbH [Novaled 2003a; Novaled 2005b; Novaled 2006a; Blochwitz-Nimoth 2011].

First Financing Round	Second Financing Round
€5.75 Million, March 1, 2003	€15 Million, November 22, 2005
▪ TUDAG, Dresden ▪ Fraunhofer Venture, Munich ▪ TechnoStart GmbH, Ludwigsburg ▪ Techfund Capital Europe, Paris ▪ FCPI 123 Multinova, Paris ▪ Thomson SA, Paris ▪ Dresden Fonds, Dresden [2] ▪ tbg Technologie-Beteiligungs-Gesellschaft mbH (now belonging to KfW Mittelstandsbank)	▪ CDC Entreprises Innovation, Paris ▪ KfW Bankengruppe, Bonn/Germany ▪ eCapital New Technologies Fonds, Münster/Germany ▪ German Private Investor ▪ TechnoStart, Ludwigsburg ▪ TechFund Capital Europe ▪ FCPI, 123 MultiNova II, Paris ▪ Dresden Fonds, Dresden

Actually tbg provided an equity contribution in terms of a silent participation [Runge:p. 218,224] based on a partial profit transfer agreement in January 2004 [Handelsregister]. Notably, when Novaled filed for an IPO in the US in 2012, it said it will terminate the silent participation of tbg in the company, and pay back tbg's equity contribution after the closing of the offering [Reuters 2012].

The second financing round was led by the venture branch of Crédit Agricole Private Equity, Paris, (asset management company of Crédit Agricole SA) and it stated "We believe that OLED will become in the near term a widespread technology. We have been strongly impressed by the management team, by the disruptive IP and the technology from Novaled. We are pleased to support Novaled in becoming a world leader in the OLED industry." The money was seen to secure Novaled’s growth to sustainable profitability and strengthen the credibility in front of its customers, which are the top tier display and lighting makers [Business Wire 2005].

Novaled wanted to use the proceeds of this financing round to further drive Marketing & Sales and to enhance customer support and its R&D operations. The main focus of the company remained the implementation of its world leading technology into the technology roadmaps of its customers [Business Wire 2005].

In the course of the second capital increase the shareholders agreed upon the conversion of Novaled GmbH into Novaled AG (stock cooperation in March 2006). Co-founder Prof. Dr. Karl Leo took a seat of the Supervisory Board of the AG (stock company) [Novaled 2006a].

Novaled's first *fast growth would not be possible without public funding* by the German Federal State of Saxony, the German Federal Government and the EU [Blochwitz-Nimoth 2011].

Prof. Karl Leo did much *lobbying with local policy* (especially of the Dresden area) and line of policy of Saxony. The State of Saxony was focused on early stage projects. Even before the first round of financing there was a verbal commitment by Saxony to support a Novaled project. The German Federal Ministries, particularly the Federal Ministry of Education and Research (BMBF) with its OLED and organic photovoltaic (OPV) Initiatives, but also the Federal Ministry of Economy and Labor (BMWA) provided smaller SME-related projects (small und mid-size enterprise, KMU in Germany) [Blochwitz-Nimoth 2011].

Together with the Dresden Technical University and the Fraunhofer Society Dresden Novaled developed a unique OLED Competency Center in Dresden, Germany.

By 2006 Novaled set up strong partnerships with experienced major global players in the display and lighting field. They established active *dialogs with all big and renowned enterprises of the display and lighting fields*. In particular, companies like Samsung, Pioneer or Philips showed much interest in Novaled for their own product innovations [Novaled 2006c].

On the level of the European Union (EU) Novaled's PIN OLED® technology has led to groundbreaking results for European key projects (FP6 – European Union's 6th Framework Programme and FP7 (mainly ICT program) and OLED lighting).

OLLA (Organic LEDs for ICT and Lighting Applications), officially finished on June 30, 2008, was a joint research project dedicated to the development of *white OLEDs for general lighting applications.* The consortium consisted of 24 entities in 8 European countries. OLLA was partially funded under the IST priority (Information Society Technologies) of the European Union's 6th Framework Programme (FP6).

Apart from Novaled a number of firms from Germany participated in the project, such as Aixtron AG, Aachen, Merck KGaA, Darmstad/Frankfurt a.M., Osram Opto Semiconductors GmbH, Regensburg, Siemens AG, Erlangen, and also universities (TUD, University of Kassel) and research institutes (Fraunhofer Institute for Photonic MicroSystems – IPMS).

The goal of the OLLA project was to demonstrate a *long-life and highly efficient white OLED light* with the following specifications: efficacy of 50 lm/W, lifetime of 10,000 hours from an initial brightness of 1,000 cd/m2, with a tile size of 15x15 cm2 based on the Novaled PIN OLED® technology.

The OLLA research consortium was headed by Philips Lighting. The lifetime of the Novaled device even exceeded the promised value by one order of magnitude. Apart from the record values listed above (Figure 2), the OLLA project delivered the first large sized ITO-free OLEDs, the first large-area printed OLEDs and several ICT demonstrators. Having achieved a service life of 100,000 hours for OLEDs makes them far superior to incandescent bulbs and neon tube equivalents [Novaled 2008b; Lachmann 2008].

Philips, Osram Opto Semiconductors, Siemens, Novaled and Fraunhofer IPMS continued the development of OLED lighting technology in a follow-up project entitled OLED100.eu.

The OLED100 project, for instance, had the goal to develop technologies for producing efficient OLED products for exploitation by the European lighting industry. Targets set by the project included achieving 100 lumens per watt *power efficiency*, more than 100,000 'l*ifetime* hours', a unit area of 100 cm by 100 cm and *costs* of €100 per square meter or less [Lachmann 2008].

The FlexiDis project aimed at the realization of *flexible active-matrix displays*. It was the largest research project in displays supported by the European Commission.

Public support for OLED continued [Hammerschmidt 2013; Novaled 2013]. For instance, the €14.7 mio. project “So-Light” completed by the end 2012 was supported by the German Ministry of Education and Research (BMBF) over a three and a half year period and addressed the complete value system, from primary OLED materials to OLED-lighting applications. Results were achieved in a large number of technology segments, including materials, processes and panel technologies.

The aim of So-Light was to combine as many of the materials and component related results into design studies and prototypes in order to strengthen Germany’s leading role in the growing OLED-market. The project partners included for-profit firms, but also a university and the Fraunhofer Institute COMEDD (of Prof. Karl Leo; Table 2). Dr. Blochwitz-Nimoth, CSO of Novaled AG, was So-Light’s Consortium Manager.

For instance, Novaled and the firm Sensient jointly developed a new p-doped hole transport system with potential for lower absorption and lower cost scalability than previous materials. The jointly developed materials would be commercialized by Novaled. Novaled made significant progress towards a fully air-stable n-doped electron transport layer.

In the process arena, semiconductor equipment manufacturer Aixtron and the Fraunhofer research institute for organic electronic materials, COMEDD, jointly optimized the OVPD (Organic Vapor Phase Deposition) process.

As a summary, Novaled has a complex financing (equity) structure with regard to the sources used [Runge:ch. 1.2.7.3] and the financing of internal R&D via public project money:

- Private venture capital or investment firms
- Private corporate venturing (Thomson; Samsung Venture Investment Corporation)
- An unknown private investor
- Venture arms of universities/public research organizations (TUDAG, Fraunhofer Venture)
- Public investment organizations (tbg – silent participation)
- Banks and Federal States involved in investment organizations (Dresden Fonds – SIB (savings bank) and the State Bank of Saxony (Sachsen LB)).

Corporate Culture

Novaled is a technology venture with ca. three quarters of its employees engaged in R&D (Table 11). The employees comprise highly qualified specialists, but also (chemistry and physics) lab technicians and operators. The 115 employees (by 2011) exhibit a large *diversity* of eleven different nationalities [Miethke 2011] and show *multi-disciplinarity*. More than 70 percent of Novaled’s employees have a scientific or an engineering education [Blochwitz-Nimoth 2009].

The employees work in materials development (requiring know-how of synthetic chemistry), OLED development (physicists with know-how of optics), manufacturing of OLEDs and other demonstration objects, and in the fields of materials testing and quality control. In all these areas knowledge of engineering and skillfulness is necessary [Blochwitz-Nimoth 2009].

"Quality is the lifeblood of Novaled", said Gildas Sorin, CEO of Novaled. "It is essential for our business when dealing with international corporations to be recognized for the quality of our organization.” [Business Wire 2011]

Novaled’s people show enthusiasm for technology, they identify with the company and the company's goals [Blochwitz-Nimoth 2009]. And communication of goals and strategies by management is the basis to hold everyone responsible for the company’s business objectives [Blochwitz-Nimoth 2011:18].

An open working atmosphere facilitates bringing in directly new ideas and their implementations [Blochwitz-Nimoth 2009]. This is the extension of Novaled’s early corporate culture when significant contributions occurred by employees with enough freedom to think and act [Leo and Blochwitz-Nimoth 2004].

None of Novaled’s employees are covered by labor unions or by a collective bargaining agreement, nor has Novaled experienced any work stoppages at its facilities in the past. Novaled’s leadership believes to have good relations with its employees [SEC 2012].

Innovation Persistence, Expansion and Diversification

Paths of Expansion

The period 2006 to 2007 was the "success window" for Novaled to conquer the market. In order to achieve its commercial goals Novaled considered Marketing & Sales as the prerequisite (a critical success factor – CSF) for its *business success*. Correspondingly, during 18 months Novaled's *management visited all the key display manufacturers* in Japan, Taiwan, South Korea, and China. [Novaled 2006a].

This means, as a *marketing strategy* the company established *direct contacts* to all of the major OLED players in the *display and lighting world*. *Novaled knows the market and is known* with 100 percent brand awareness. Potential customers indicated serious interest in Novaled technology. *Sales Agencies* were established in the Japanese, Taiwanese and Korean display market. A Branch Office was opened in Japan in 2008. For the lighting market the focus was on Europe, US and Asia (China) [Novaled 2006a].

Furthermore, in the sense of technology push for *promotion* Novaled offered on its Web site numerous brochures dealing with application and potential applications of OLED emphasizing its portfolio of products and services. It offers also an OLED Lighting User‘s Manual and individual trainings. Emphasizing lighting Novaled and partners provide regularly demonstrations by introducing designs at fairs [Muth 2010; Blochwitz-Nimoth 2011].

Additionally Ingo Maurer, an internationally recognized designer and producer of exceptional lamps and lighting systems, presented at the Light + Building trade fair in Frankfurt/Germany OLED luminaries created in collaboration with Novaled OLED lighting. Novaled had developed related highly efficient transparent OLED modules [Admin 2010].

Apart from the continuous R&D cooperation with TUD and FhG individually in 2007 and in networks and joint projects (Verbundprojekte [Runge:p. 180]) in the period 2007-2011 Novaled set up a number of *technical alliances or cooperation with industrial partners*, respectively, with well-defined goals.

But, it is also Novaled’s strategy to partner with key industry players, like Plextronics (see below), in order to *enlarge its business offerings for customers* [Novaled 2009b].

Ciba Specialty Chemicals (acquired 2008 by BASF, since March 2010 BASF Schweiz AG) will produce the unique organic dopants and transport materials developed by Novaled. While Ciba Specialty Chemicals will produce these materials using its specific know-how in the synthesis of organic materials in reliable highest purity, Novaled will continue to market the materials. “The agreement with Ciba Specialty Chemicals will secure delivery of our materials in high quality and volume to our customers worldwide,” stated Gildas Sorin [Novaled 2006b].

So far, OLEDs were fabricated on glass panes like those needed in LCD. This resulted in acceptable prices for (display) OLEDs. For lighting systems this is not enough. Here Novaled was working on new concepts that provide the option to deform the wafer-thin OLEDs [Lachmann 2008].

For the area of substrates in 2007 Novaled set up a cooperation with the steel sheet producer ArcelorMittal. The partners wanted to develop OLEDs with high radiation power on flexible substrates for lighting purposes and particularly signage. Metal substrates offer several advantages compared to conventional glass panels: They are more robust and durable and can be generally produced by a roll-to-roll process [Mühlbauer 2007].

The RGB OLEDs are directly processed on conventional steel sheets. And astonishing results of the cooperation showed that it is possible to use these plates as reflective bottom electrodes.

Also with an emphasis on substrates Novaled had a two-year research cooperation with *Saint-Gobain*, a globally operating producer, processor and distributor of materials (glass, ceramics, plastics, cast iron, etc.) and innovative metal layers for large lighting areas. Its expertise is in manufacturing metallic layers on glass [Business Wire 2008].

When combining the advantages of Novaled PIN OLED technology with Saint-Gobain's specific electrode expertise, the partners achieved lab samples with an increased efficiency of +30 percent. The lack of metallic grid made the whole processing much easier. Furthermore, improved lifetime has been demonstrated, as compared to the equivalent OLED device based on ITO.

Researchers at Saint-Gobain Recherche (SGR) created a highly conductive transparent electrode "Silverduct™", bringing up to 10 times better surface conductivity than traditional ITO (Indium Tin Oxide). Thanks to the Novaled PIN OLED technology for high efficiency OLEDs, samples were successfully manufactured on large area surfaces. SGR and Novaled saw the possibility to produce homogeneous OLED devices up to 100 cm/sq which will ease the manufacturing of large OLED lighting products.

Traditional ITO coated glass impeded the race to large area OLED, due to its limited ability to carry current over distances longer than a couple of centimeters. Therefore, for large area OLEDs, the ITO layer must be topped with a thick metallic grid to prevent gradient of light emission caused by the sheet resistance of ITO alone (typically 30 Ohm/sq).

Saint-Gobain and Novaled demonstrated the feasibility of large area OLEDs, based on a new high-performance metallic anode, with Saint-Gobain Recherche technology and Novaled OLED proprietary developments.

Novaled and Plextronics, Inc., an international company that specialized in conductive organic inks for printed lighting, solar and other electronics, agreed to jointly develop doped and solution processed organic materials for OLED applications [Jendrischik 2009; Novaled 2009b].

The collaboration agreement specified that the companies would combine their respective technologies to develop an advanced solution processable hole injection layer (HIL, Figure 3) technology for OLEDs. By leveraging Plextronics' organic conductive ink technology and Novaled's organic dopant technology, the companies targeted these advanced HIL materials for use with solution processed polymer and small molecule emitters, as well as with vacuum deposited small molecule emitters

Plextronics and Novaled wanted to co-market Plexcore® OC inks that incorporate Novaled dopant materials.

Plextronics, Inc. founded in 2002 as a spin-out from Carnegie Mellon University, based upon conductive polymer technology is an international technology company that specializes in printed solar, lighting and other organic electronics. Headquartered in Pittsburgh, PA, the company's focus is on organic solar cell (OPV) and organic light emitting diodes (OLED), specifically the conductive inks and process technologies that enable those and other similar applications. As a note, in 2014 Plextronics has filed for bankruptcy reorganization [Reisch 2014].

Novaled established already research and development, cooperation and licensing agreements with OLED product manufacturers, such as Philips in 2004, Pioneer in 2005, Samsung Mobile Display, Panasonic and Osram in 2006, Astron FIAMM in 2007 and LG Display in 2009. [SEC 2012]

In terms of R&D, materials and equipment manufacturers by 2010 Novaled had established an *industrial network* and PIN technology had been established with leading OEMs as a preferred solution for production (Figure 5). Its focus is on optimum results including relevant PIN® technology interfaces to produce manufacturing on different substrates [Muth 2010].

For optimizing OLEDs out-coupling is an important factor. Out-coupling means a gain of 30 – 70 percent in the total light emitted by the OLED, for instance, by a film. [4]

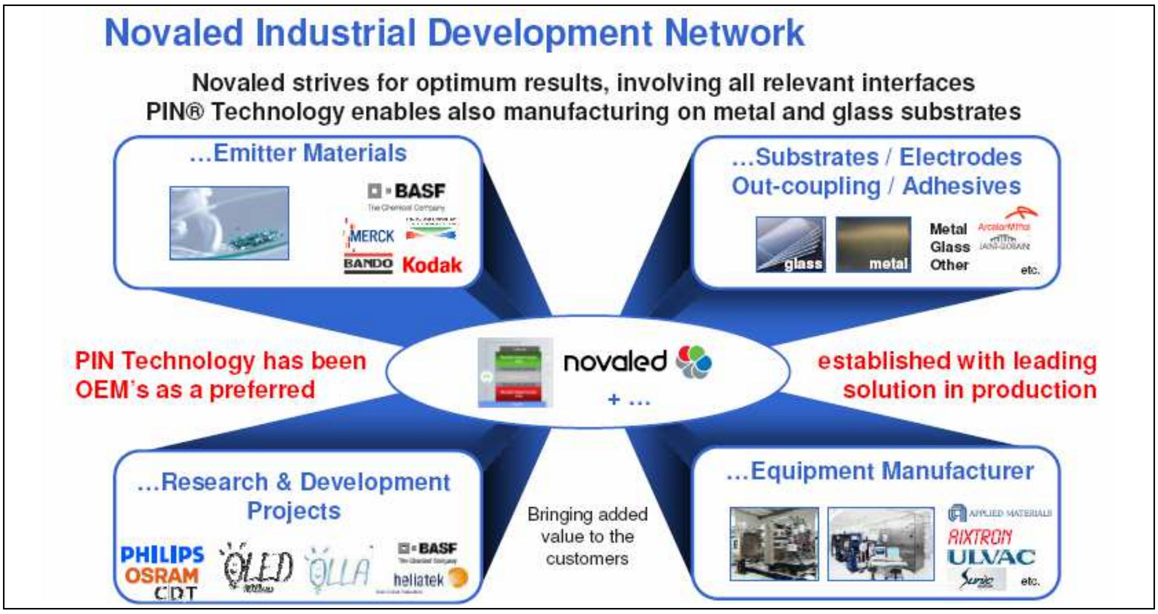


Figure 5: Novaled's industrial development network [Muth 2010].

In addition to the industrial development network Novaled is also embedded in the value system of the Organic Electronics Saxony local network (Figure 6) with links to other firms, for instance, its "partner firm" Heliatek (Table 2), and Fraunhofer and TUD institutes to comprise R&D and industry.

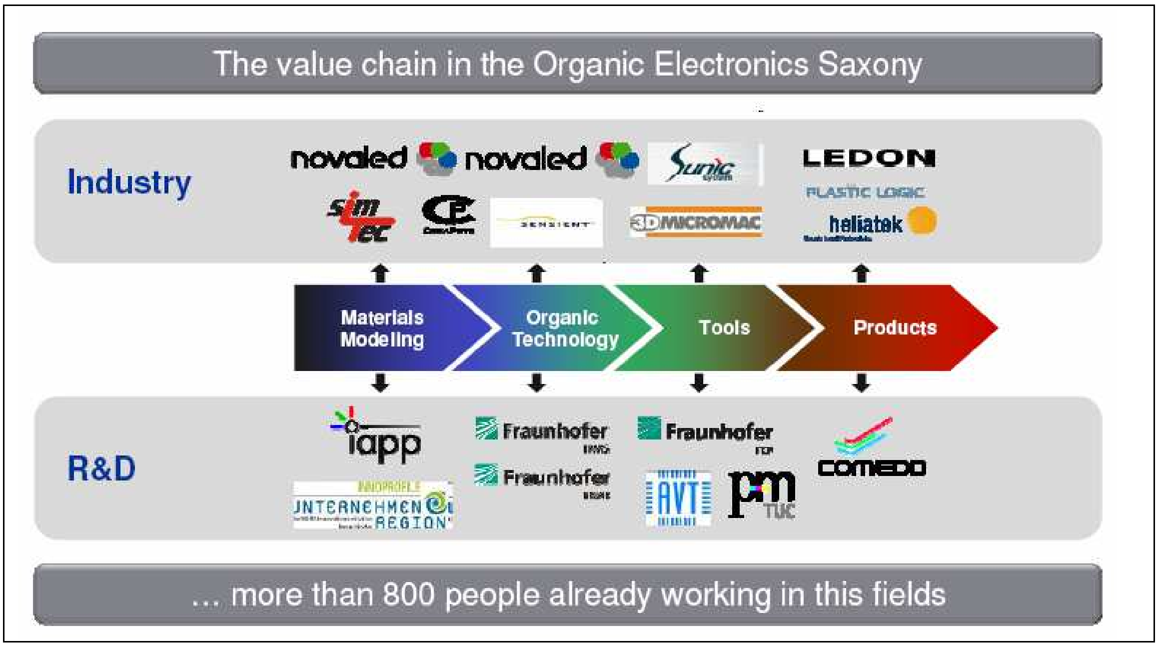


Figure 6: Novaled's position in the Organic Electronics Saxony local network [Blochwitz-Nimoth 2011].

For further development Novaled closed its *third round of financing* with a €8.5 million (ca. $11.2 million) investment in 2009 from the then existing shareholders (Figure 3). eCAPITAL acted as the lead investor [Novaled 2009a]. Novaled wanted to use the money to extend the commercialization of its OLED lighting and display technologies (PIN-OLED). In the tough financial environment of the Great Recession Novaled managed to raise this kind of money.

In September 2011, *Samsung Venture Investment Corporation* acquired what was then a 9.84 percent stake in Novaled, which Novaled believed to validate its market position as a leading provider of customized OLED stack solutions based on organic conductivity doping technology and materials [SEC 2012].

By 2012 Novaled AG had developed to offer materials, technologies and know-how in the area of *organic electronics* with a focus on OLEDs for display and lighting applications.

Doping is at the heart of organic electronics. Application of doping depends on business status of certain technology areas. Hence, Novaled [Blochwitz-Nimoth 2011]

- started with OLED displays,
- continued with OLED lighting,
- continued with more efforts in organic solar cells (OPV) and
- will be providing electronic devices, for instance, display drivers and organic radio frequency ID (ORFID).

By August 2013 Samsung acquired Novaled for €260 million ($347 million). According to Novaled, Samsung affiliate Cheil Industries, which specializes in electronic materials and chemicals, will acquire a majority stake of around 50 percent, while another 40 percent will be acquired by Samsung Electronics. The remaining 10 percent stake is already held by the Samsung Venture Investment arm, which invested in the company in 2011. The deal's €260m figure includes a €30m contingent payment, which is based on reaching "certain milestones." The deal is subject to approval from regulators and relevant authorities. Samsung has also begun introducing Novaled's technology to televisions, including a $15,000 curved 55-inch set that launched in the US [Filtz 2013].

Organization

Novaled showed a rather fast increase of the number of employees (Figure 10). Correspondingly, one observes also a fast changing organizational structure.

It usually comprised 3-4 Groups with project structure changing every 1-2 years. It is a business-driven organization with skills in Physics, Optics & Chemistry, Assembly & Manufacturing; Marketing & Sales [Blochwitz-Nimoth 2011].

Around 2006 with 50 employees the Management/Leadership Team consisted of

- Gildas Sorin (CEO)
- Dr. Jan Blochwitz-Nimoth (CTO)
- Gerd Günther (VP Marketing & Sales)
- Dirk Schwipper (General Secretary).

50 employees were distributed functionally between General & Administration (G&A), Selling and R&D on the basis of three groups, Chemistry, Physics and Tool Operations [Novaled 2006a].

After 2003-2009 in 2011 the Management Board emerged as consisting of a CEO (Gildas Sorin), CFO (Harry Böhme, Chief Financial Officer) and CMO (Gerd Günther; Chief Marketing Officer) [Blochwitz-Nimoth 2011]. Dr. Jan Blochwitz- Nimoth kept a special role as Chief Scientific Officer (CSO) considering that ca. 75 percent of Novaled's employees belongs to R&D (Table 11). Harry Böhme entered Novaled 2006 as Managing Director before becoming the CFO [Blochwitz-Nimoth 2011].

Novaled with the goal and necessity of fast and sustainable development of the firm relied already during its early stage on experienced managers with regard to subjects, disciplines and leading/managing large firms with scientific or engineering education and more than 15 years of management experience in industry, preferably in the fields the NTBF is operating in. This is the "veterans approach", as seen and discussed broadly for biofuels NTBFs [Runge:A.1.1].

As a firm's organization should reflect its business processes Novaled's organization around 2007 (Figure 7) is represented by a "matrix structure I" related to functional and research and "producing" groups. Relating customer orientation and requirements to projects provide a second matrix structure [Blochwitz-Nimoth 2011].

As expected for a "veterans approach" for management, to control development and growth of the firm management tools as in large companies are applied. For instance, the Business Balanced Scorecard (BBS) tool targets

- Performance Measurement
- Managing Performance
- To hold everyone responsible for the Company's business objectives.

The focus is on the crucial factors – Critical Success Factors (CSF) – for business success and achieving the strategic goals and creating value. The corresponding factors are presented in a chain of four perspectives: Vision and strategy related to customers, internal business processes, financial state and learning and growth.

Specifically, Novaled's Total Quality Approach follows the EFQM-Model of Excellence of the European Foundation for Quality Management (EFQM) as the management framework [Blochwitz-Nimoth 2011].

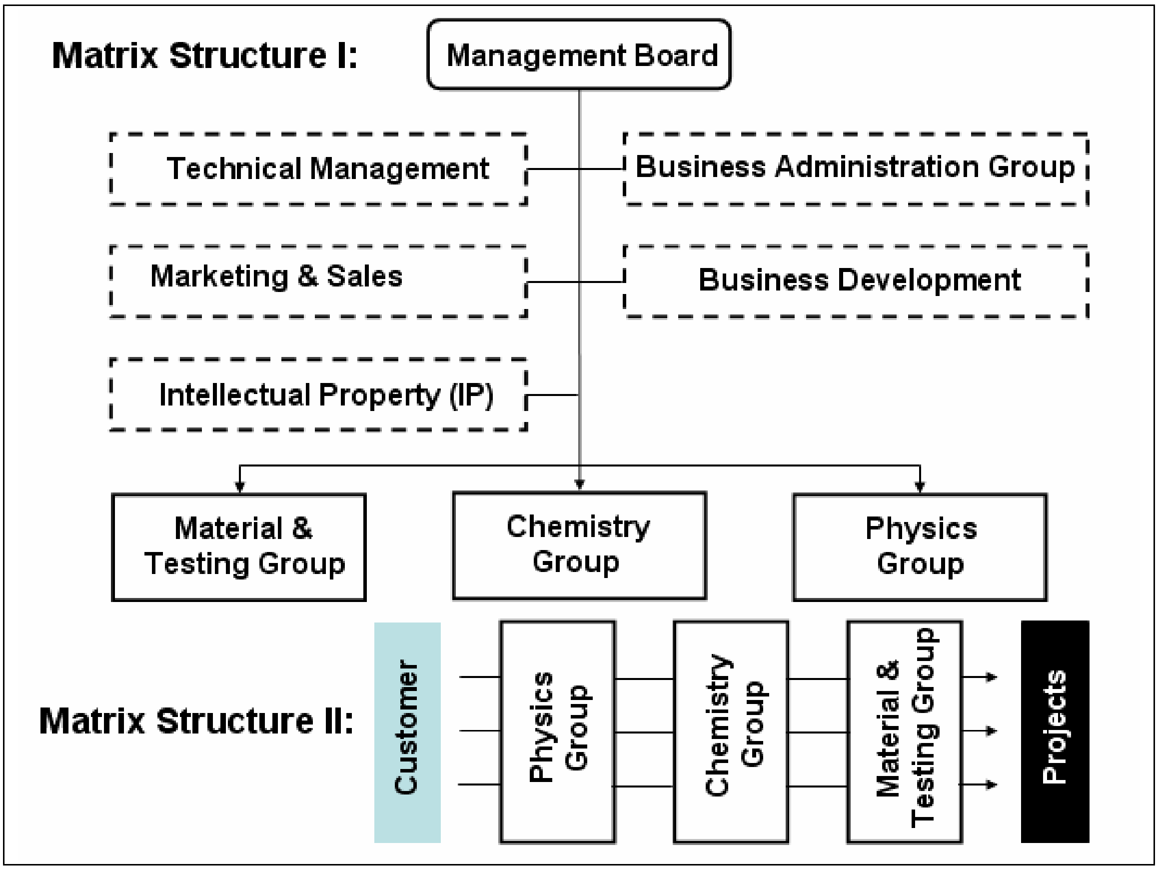


Figure 7: Novaled's organizational structure around 2007 in terms of matrix structures [Blochwitz-Nimoth 2011].

In 2009 Novaled stopped the matrix organization and created a business line (BL) structure [Blochwitz-Nimoth 2011]. Organizational structures centered still on customer support and projects [Muth 2010].

All these figures do not take into account the organization, utilization and management of external resources of Novaled through the local network Organic Electronics Saxony (Figure 6), in which Novaled, TUD and FhG play key roles and participation in publicly financed projects.

Customers	Projects	
	Business Line Material	Business Line Technology & Products
	Business Line Engineering	Marketing & Sales

The overall organization of Novaled in 2010 (including funded projects) displayed in Figure 8.

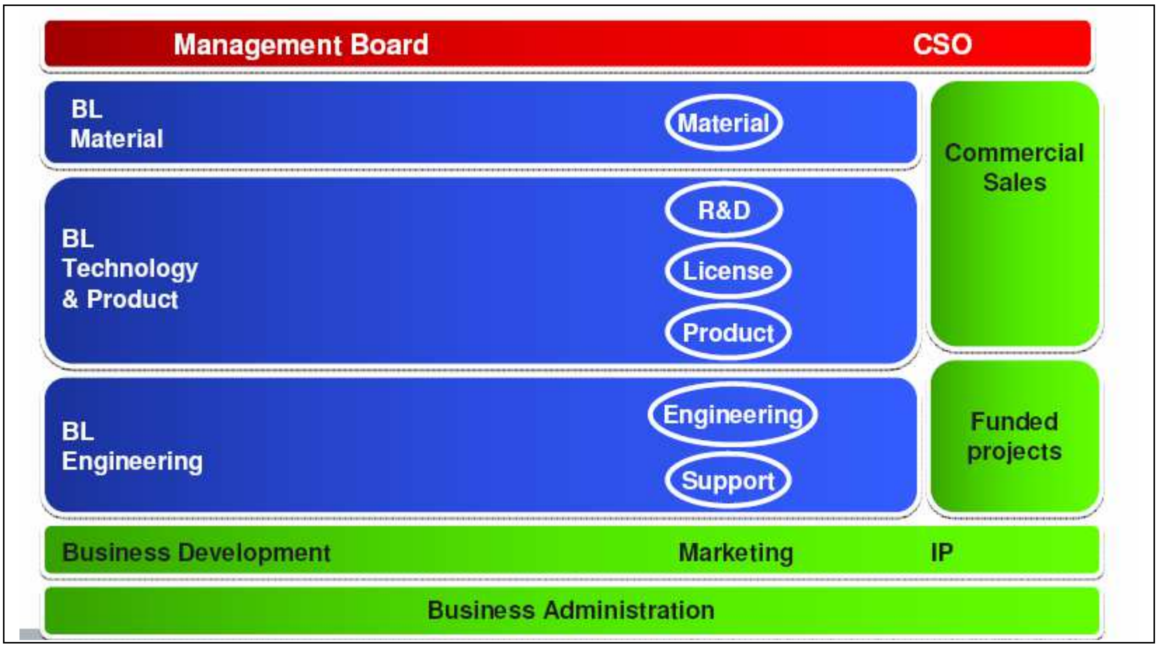


Figure 8: Novaled's organization in 2010 [Blochwitz-Nimoth 2011].

Vision/Mission, Business Model and Risks

Vision, Mission and Business Model

Vision or mission of a firm may change over time – mission by years, not only decades. Whereas in 2010 Novaled's view was "OLED – The (R)Evolution in Lighting" [Muth 2010:8] its Web site around 2011 spoke of "Creating the OLED Revolution."

A **corporate vision** is a short, succinct, and inspiring statement of what the organization intends to become and to achieve at some point in the future [Runge:ch. 2.1.2.7].

The fundamental vision for Novaled in 2005 was actually a *dream* focusing on a generic situation used in terms of a "catch expression" by Intel. It was still focused on displays and did not mention the lighting application. Later the reference to particular applications was given up.

> "We dream that all displays will one day be labeled *'Novaled inside'*, just as Intel has managed to do it with its processors." [Novaled 2005, Eckold 2005].

By 2010 the vision of Novaled became much more explicit emphasizing the future of OLEDs in terms of significant properties. "We are dreaming of … transparent, curved, bendable, rollable, almost everlasting, large area OLEDs." [Muth 2010]

The market research firm Lux Research (Boston) confirmed in 2013 that globally Novaled belongs to the top ten in its field of technology [Wirtschaftsförderung Sachsen 2013].

Novaled's early mission from 2006/2007 was

"Novaled is a fabless technology and material provider engaged in R&D and commercialization of OLED (organic light-emitting diode) technologies, committed to the development of a new OLED generation, focusing on achieving highest power efficiencies. Novaled strives for being recognized as a company to trade with, to join, and to invest in. Novaled is focused on creating value to our customers by developing and marketing small molecule OLED technologies." [Novaled 2006a]

In particular, Novaled was working to establish Novaled PIN OLED® technology as one of the leading techniques in the OLED industry.

Hence, Novaled is a materials and technology supplier and does not manufacture itself the products. It focuses on *low volume, high value* material as products like Merck KGaA with its liquid crystals for liquid crystal displays (LCDs) [Runge 2006:455-456] with additional revenue streams of selling licenses and know-how and services like consulting and production support.

By 2006/2007 Novaled's *value proposition* focused essentially on *OLED for display and lighting* and *proprietary technology* as the basis for its offerings and *customers targeting OLED for mass production:*

"Novaled aims to generate revenues from licensing and royalties, know how transfer of its proprietary OLED PIN structure and OLED materials and from customization for display and lighting manufacturers. By selling its know-how upfront Novaled aims to win the "design-in" of its IP and/or its proprietary OLED materials for its customer's mass production of OLED based products. Novaled offers know-how transfer and OLED materials at competitive pricing." [Novaled 2006a]

Originally, Novaled marketed its PIN OLED® technology and related offerings essentially to European lighting makers and Asian display makers.

By 2011 Novaled has extended its spectrum of offerings using organic semiconductors and organic electronics as the common framework in line with its core competency. By 2011 Novaled served four markets given in Table 4.

The company capitalizes still on the rapidly growing multi-billion dollar display market, and on the OLED lighting market as is develops. Novaled anticipates that its future growth will be driven in part by the adoption of OLED technology within the lighting market.

Novaled brings together **three key disciplines in the field of organic electronics:**

- Organic chemistry: discovery, testing and scaling of organic electronic materials
- Device physics: development of OLED technology and devices.
- Manufacturing: processes for the testing and development of materials and devices.

Table 4: Novaled's markets as given by significance and stage of market development [Blochwitz-Nimoth 2011].

Optics	
1st: Displays ▪ Now (mobile) and future (TV) ▪ Trend to AMOLED displays	**2nd: Lighting/signage** ▪ Starts now ▪ Highest power efficiency a must
Energy	**Electronics**
3rd: Organic Photovoltaic (OPV) ▪ Technology development ▪ Pilot production in 2011	**4th: Organic electronics** ▪ Organic circuitries featuring organic CMOS OTFTs (Organic Thin Film Transistors), memory, RFID, battery... ▪ With Heliatek

The focus of addressed and promoted benefits for customers in Novaled's USP changed over time induced by the stages of technical development and its market knowledge as given in Table 5.

Table 5: Time development of Novaled's USP and explicitly addressed customer benefits.

Novaled USP	Customer Benefits
[Böhme 2008]	
Extremely low operating voltage	Less ohmic heating, better product stability
High power efficiency	Energy saving (up to 50 percent)
Top-emitting OLEDs	OLED lighting based on metal foils
Transparent OLEDs	Transparent lighting applications
Thicker layers possible	Better out-coupling efficiency
Product know-how (out-coupling, electrodes etc.)	Customer dedicated development
[Blochwitz-Nimoth 2011]	
Ultra Thin (<150 nanometer)	Extremely low operating voltage
Excellent color and contrast	Highest efficiency
180° viewing angle	Inverted, top-emitting structures
Large area diffuse light source	Transparent, metal-free OLEDs
Transparent	Easy integration on all substrates
Glass and metal substrates possible	Suitability for LCD TFT active matrix.

OLED applications for the developing lighting and signage fields include essentially the following segments [Muth 2010]:

- Lighting & signage
- Signage and advertisement
- Design lighting (decorative, functional)
- Automotive / Aerospace (cabin, dash)
- Domestic appliances, white goods
- General illumination
- Healthcare (medical & cosmetics)
- Backlighting units (e.g. for LCD)

Muth [2010] has specified customer segments, applications and markets (Table 6).

Table 6: Novaled's customer segments [Muth 2010].

Manufacturers OEM's e.g. OLED Display or Lighting, OPV, OTFT (Organic Thin Film Transistors), etc.	**Designers** Architects, Planners Lighting Specialists
Equipment Makers, for instance, Tools Suppliers e.g. Substrates Integrators e.g. Lighting Fixtures, Automotive, Aviation, Home Appliance	**End Customers of High End Luminaires** Manufacturers of Luxury Products

Blochwitz-Nimoth [2011] addressed not only Novaled's (direct) customers but also customers-of-customers (end users of the value system).The values Novaled assumes to add for its chain of customers of the display and lighting areas are given in Table 7.

Table 7: Bringing added value to displays and lighting customers [Blochwitz-Nimoth 2011].

Display	Lighting
LCD Manufacturer Advantage ▪ Keep LCD momentum ▪ Potential to be cheaper in the future	**Luminaire Maker Advantage** ▪ New Business Opportunities ▪ Re-arrangement of value chain ▪ Integrated reflector: fixture and luminaries become obsolete
End Customer Advantage ▪ Better performance ▪ Advanced design ▪ Energy saving potential	**End Customer Advantage** ▪ Flat (and flexible) means light source for revolutionary designs ▪ Offering NEW features ▪ Green approach: low power consumption and mercury free

Sales of offerings is supported by common marketing methods, in particular, using the media and informing potential customers on potential applications and demonstration objects by Novaled's brochures introducing the portfolio of products and services [Muth 2010].

Novaled's overall scope of streams of revenue is summarized in Table 8 – revenue from participation in publicly funded R&D projects not being listed (cf. Key Metrics).

Table 8: Potential sources of revenue for Novaled [Muth 2010].

High Performance Materials & PIN Structure Know-How Transfer Patents / IP / Licensing	Taylor made OLED Solutions on Glass & Metal Substrates Demonstrators (Demonstration Objects) Prototyping
Contract R&D Product Development Consulting / Tool Time Engineering Solutions	Concepts & Designs OLED Product Integration Limited Editions Volume Transition Support

Novaled's technology is licensed to various customer markets (display, OPV), and Novaled® materials are used in volume production of applications, such as mobile phones and displays.

The ability to generate revenues depends upon the ability to commercially exploit OLED technologies and materials. This, in turn, depends essentially on the growth of the display and lighting markets as well as the adoption of Novaled's technology and materials within these markets.

The primary sources of revenue are the sales of the proprietary materials and the licensing of technologies to display manufacturers for incorporation into the OLED display products that they sell. Consequently, Novaled's success depends on the ability and willingness of those manufacturers to develop, manufacture and sell commercial products integrating OLED technologies and materials generally [SEC 2012].

Following Blochwitz-Nimoth [2011] structural features of Novaled's *business model* are shown in Figure 9.

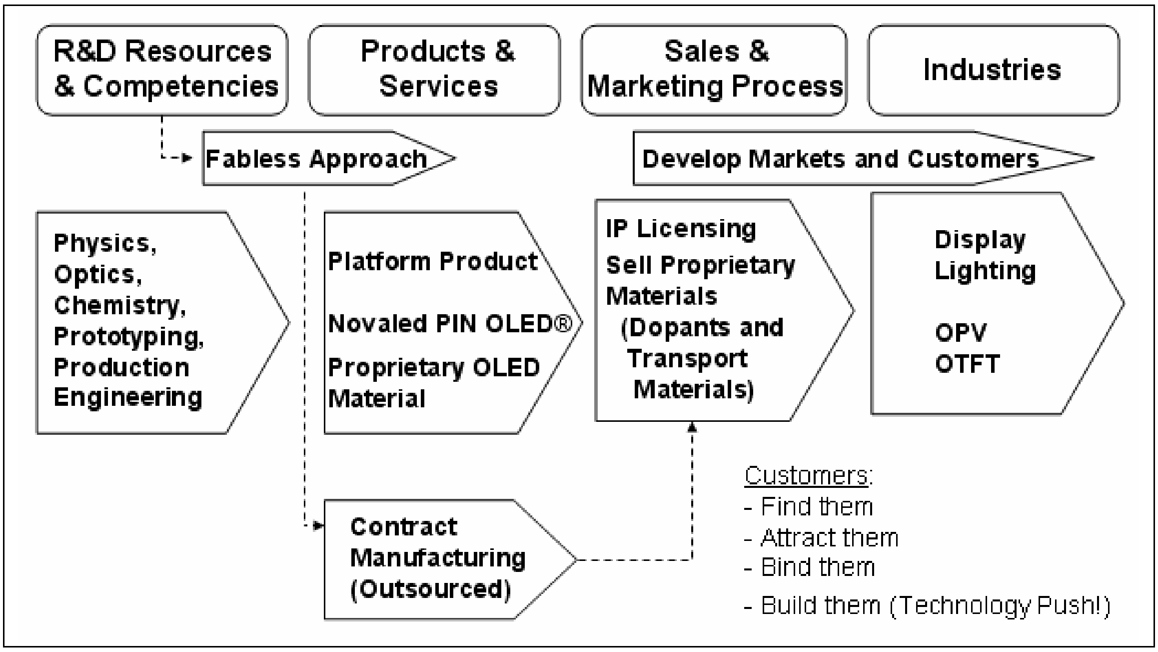


Figure 9: The structure of Novaled's business model.

The *technical* critical success factors (CSFs) for OLEDs as seen by [Muth 2010] are in Table 9.

Table 9: Technical critical success factors (CSFs) for OLEDs [Muth 2010].

Power Efficiency	**← OLED Performance →**	Out-Coupling Efficiency
OLED Reliability	**← Life Time →**	Encapsulation
Production Cost Substrate Cost Material Yield	**← Price →**	Encapsulation Material Cost Device Yield

As the markets for OLED technology, and particularly OLED display technology, are changing rapidly, Novaled's ability to *develop innovative technologies and materials* is crucial for continued *business success*. To maintain a competitive position in the OLED marketplace, it will have to complete further research and development with respect to OLED technologies and materials.

Advances in current and future technologies will require proceeding with *innovation persistence* [Runge:ch. 4.2.3, Figures 114,115,117] with a sense of *urgency* to offer compelling and cost-effective OLED technologies and materials [SEC 2012]. This means also an *innovative workforce*.

Novaled must be perceived and valued as a supplier of *high-quality products*.

It is also mandatory to protect *technical value* [Runge:ch. 1.2.5.2] essentially via continuously expanding *intellectual properties* (patents and trademarks).

Marketing and sales is a critical business success factor for Novaled with its weight indicated by the early establishment of a CMO (Chief Marketing Officer) position. Market development is particularly crucial for lighting (customer development: Find them, attract them, bind them – and build them for technology push situations) [Runge:ch. 4.2.3].

Many of the CSFs of a new firm may be derived from its awareness and assessments of its associated risks.

Selected Risks

Some of the risks associated with Novaled's development are intrinsic to new technology ventures, others are related specifically to Novaled's technology and field of operation.

The *recent global financial crisis* and the 2007-2009 "Great Recession" have contributed to a reduction in consumer and corporate spending. These *macroeconomic developments* may have a substantial negative impact on Novaled's future business by reducing demand for its technologies and materials. Furthermore, the *consumer electronics industry* experiences significant downturns from time to time, which may adversely affect the demand for and pricing of OLED technologies and materials.

As Novaled does not manufacture OLED products itself, it is solely dependent on the manufacturing capacities of its purchasers and licensees. Any disruption or delay in their manufacturing processes or businesses may have a substantial negative impact on business and revenues.

Generally, risk is associated with a firm having only a *single supplier of input* which is the prerequisite for the firm's operations [Runge:Figure I.114, Figure I.115]. Although Novaled is able to manufacture small quantities of OLED materials itself, its business model relies on the use of sub-contractors for the commercial production of OLED materials [SEC 2012].

While Novaled currently distributes certain materials from one manufacturer, it is entirely reliant on BASF to manufacture its proprietary materials on a large scale. Any change in relationship with BASF may have a substantial negative impact on the business. In particular, BASF is currently the sole manufacturer of the proprietary doping materials that Novaled sells to Samsung Mobile Display, LG Display, and other OLED product manufacturers [SEC 2012].

If BASF does not produce sufficient quantities of materials or does not maintain a high production standard with respect to Novaled's materials, Samsung Mobile Display or LG Display may end its relationship with Novaled, and its business may fail. In addition, other product manufacturers may refuse to purchase or license OLED technologies or materials from Novaled [SEC 2012].

In addition, due to the monopoly, BASF as the *single supplier* has and may execute a strong *bargaining position* [Runge:Figure I.33, Table I.16] which may determine cost of input significantly.

A structurally related risk concerns *having only one or very few customers*. Novaled's business is highly dependent on the sale of a single doping material to SMD (Samsung Mobile Display), which may limit its ability to grow and to commercialize technologies or materials in the future.

In 2011, approximately 59 percent of revenue came from the sale of a single doping material to Samsung Mobile Display (SMD). SMD uses this doping material in the production of its OLED mobile phone displays, and Novaled anticipates that its short- to medium-term revenue growth in the display market will be significantly driven by SMD's increased sales of OLED display products {SEC 2012}

In addition, due to its large size and strong market position, SMD has a strong *bargaining position as a customer* [Runge:Figure I.33, Table I.16] to exercise considerable influence over the conduct of the business.

SMD has yet to enter into a licensing agreement with Novaled. Were Samsung Mobile Display to begin purchasing alternative doping materials from another supplier, its use of such materials may infringe Novaled's intellectual property related to OLED stacks and OLED devices. Without a licensing agreement, Novaled may be unable to collect revenues from SMD for its use of its intellectual property without resorting to litigation [SEC 2012].

As the market for small- and medium-sized OLED displays is currently dominated by a single manufacturer, SMD, OLED display technology may become a niche market and may eventually be superseded by other more widely accepted display technologies if other manufacturers do not follow Samsung Mobile Display into the OLED display market.

Generic technologies, particularly *alternative display technologies* may limit the acceptance of Novaled's OLED display products and incumbent technologies may be squeezed to achieve better performance [Runge:Figure I.22]. Due to LCD's widespread market and manufacturing base, manufacturers have considerable incentives to improve and develop LCD technology rather than to invest in OLED.

LCD will remain the dominant display technology and recent advances in LCD technology may allow LCD products to successfully compete with OLED products on a variety of factors, including image quality, viewing angle, form factor and power efficiency [SEC 2012].

Furthermore, it seems unlikely that LCD manufacturers change over to OLED before their extremely expensive investments in LCD plants are almost fully depreciated.

Manufacturing OLED products is currently quite expensive, in part as OLED fabrication requires substantial new investments by product manufacturers to either convert their existing LCD production facilities to OLED technology or to build new OLED production facilities [SEC 2012].

The developments of recent years have shown that the previously expected take-off of OLED technology in the display market has failed to occur several times. Although OLED displays have been commercially introduced in televisions of up to fifteen inches in size, these products have not yet gained widespread acceptance or usage due to their high cost.

Although many manufacturers plan to introduce these products in the future, *customers may be slow to accept this new technology* and may be unwilling to pay a higher price for products containing OLED displays. Some manufacturers may also refuse to integrate the *new production processes OLED technologies require*, preferring to wait until a later date to determine consumer demand, or may decide not to implement them at all.

Although OLED technology has been successfully adopted in the small- and medium-sized display market, it has yet to be commercially adopted within any segment of the lighting market. Only a few OLED lighting products are currently available, including products designed by Novaled and other OLED technology and manufacturing companies; and there has been no widespread commercial adoption or availability of OLED lighting products.

However, LED lighting technology can also be used to manufacture large-area lighting products that produce diffuse light similar to that of OLED lighting products [Runge:Table I.81, Figure I.165, Figure I.166]. With further development, these LED lighting products may challenge or even displace OLED lighting products in the large-area lighting market in the future.

While OLED is seen as an evolutionary technological development within the display market, *OLED lighting products represent a fundamental change in the lighting market*. *Current lighting products consist of two components, light sources*, which generate the light, *and luminaries* which distribute it. Manufacturing and installation standards have been developed that allow manufacturers of light sources and manufacturers of luminaries to create products that work together easily, and the visual appearance of a current lighting product is largely a function of its luminaries.

In contrast, the manufacture of OLED lighting products applies the light source, the OLEDs, directly to the surface of a substrate material, and, as a result, combines light source and luminaries in a manner distinct from current lighting products. The appearance of an OLED lighting product is both a function of the materials used in the production of the OLED panels and of the arrangement of the panels themselves [SEC 2012].

Before product manufacturers will agree to use Noveled’s OLED technologies or materials for widespread commercial production, they will likely require seeing convincing demonstrations its technologies or materials to be suitable for broad-based product applications. This may require proving the suitability or superiority of its OLED technologies or materials [SEC 2012].

Intellectual Properties

Basically, the use of OLEDs may be subject to patents held by Eastman Kodak, DuPont, General Electric, Royal Philips Electronics, numerous universities and others. There are by now thousands of patents associated with OLEDs, both from larger corporations and smaller technology companies [Wikipedia-1].

Strong *protection* and the will and potential to *enforce intellectual property* are essential to the present and future success of Novaled's business model and the ongoing commercialization of its technology. Since the company depends essentially on revenue generated through the licensing of its technology to manufacturers, effective intellectual property protection is as important to the company as its innovative workforce and creative strategies.

Novaled's *organic conductivity doping technology* and *proprietary materials* significantly enhance the performance of OLED devices. By adding its proprietary doping materials to certain layers of the OLED stack through a process known as organic conductivity doping Novaled improves the injection and transport of electrical charges to the emission layer in the OLED stack (Figure 1). Combining its proprietary doping materials with its proprietary host materials can further increase the conductivity of the transport layers and produce what the firm believes to be the highest performing OLED devices [SEC 2012].

Novaled has also developed *proprietary out-coupling materials* (Table 5, Table 9) that complement the organic conductivity doping technology and proprietary materials by improving the extraction of light that would otherwise remain trapped in the OLED stack. The organic conductivity doping technology and proprietary materials are designed to work with all existing emission layer technologies and are protected by a broad patent portfolio [SEC 2012].

Novaled's business is based on its strong IP position. In 2005 Novaled had more than 130 patents granted and filed [Business Wire 2005]. Whereas by 2006/2007 Novaled had ca. 150 patents and spent approximately € 0.5 mio. per year for these [Leo and Blochwitz-Nimoth] the patent portfolio of Novaled by 2012 included more than 400 patents granted or pending worldwide in about 80 patent families [Blochwitz-Nimoth 2011]. This set of patents represents the largest number in the molecular (organic) doping field [Muth 2010; Blochwitz-Nimoth 2011].

By 2010 31 patent families of TU Dresden have been transferred to Novaled which are commercially exploited by the firm [Sachsen 2011].

As a result of Novaled's ongoing research and development, it anticipates developing also technologies and materials applicable to organic photovoltaics (OPV), organic thin-film transistors (OTFTs) and other organic electronics. In order to successfully commercially exploit these developments, it needs to obtain and defend patents and other intellectual property rights [SEC 2012].

Novaled owns trademarks for certain products and brands in various jurisdictions. However, it has not applied for or obtained trademark registrations for its products and brands in all or even all major OLED market jurisdictions. As a result, it may not have recourse against third parties which use Novaled's trademarks in such jurisdictions. Any such use may weaken the value of current trademarks or have a substantial negative impact on its reputation or business [SEC 2012].

Key Metrics

Novaled provides a remarkable growth story, if revenue and number of employees are used as growth indicators.

Novaled's revenue primarily comprises

- Sales of its proprietary materials,
- License fees and royalties received from licensing proprietary technology,
- Consulting services,
- Fees from research and development projects that are conducted on a contractual basis for third parties (called customer-sponsored research and development projects).

Contributions of income from publicly funded R&D projects varied between €2.8 mio. (2009) and €2.2 mio. (2011) [SEC 2012].

In 2011, Novaled recorded revenues of €17.4 million and a first time net profit. Time lines for profit and loss are given for 2004-2007 by Böhme [2008:21] and for recent years by SEC [2012].

Although Novaled had a first time net profit of €3.6 mil. in the year ended December 31, 2011, it has a history of operating and net losses, and it may continue to suffer losses until such time, if ever, when it is in a position to achieve sufficient levels of revenue from the commercial exploitation of its technology and materials to support the business operations [SEC 2012].

The time line for Novaled's revenue and number of employees are listed in Table 10 and displayed in Figure 10.

Table 10: Revenue (€, thousand) and number of employees of Novaled [Blochwitz-Nimoth 2011].

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Revenue			98	1,593	2,609	3,494	5,840	7,300	8,130	11,200	17,405
Number of Employees	1	4	17	37	50	68	85	100	90	100	115

Notably, revenue is reported according to German accounting rules. For instance, according to US according rules revenue of 2010 is 6.856 mio. (cf. details in [SEC 2012]).

In 2012, Novaled generated revenues of €27.6 million and had ca. 130 employees [Anonymus 2014].

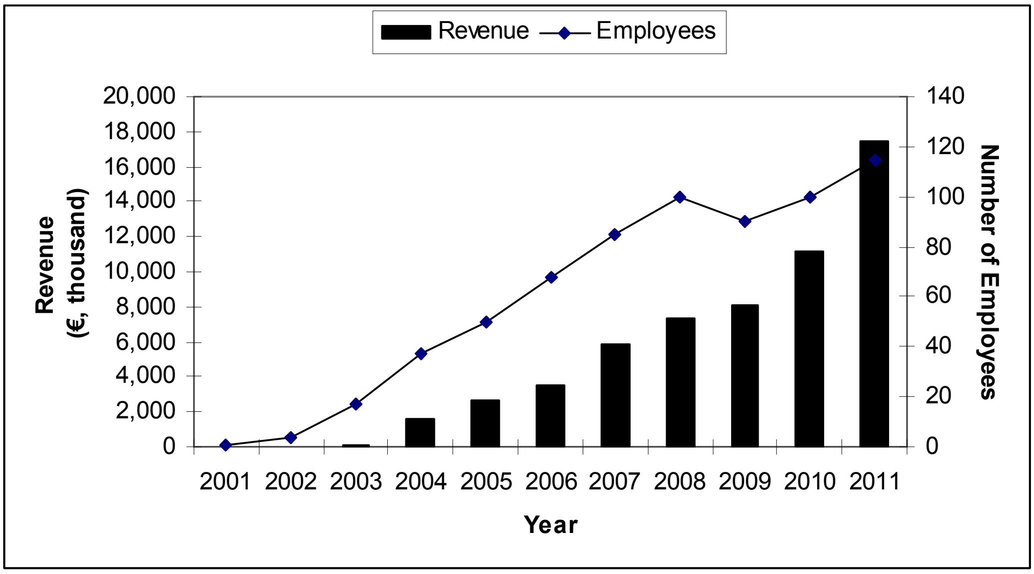


Figure 10: Growth of revenue and number of employees of Novaled since its foundation [Blochwitz-Nimoth 2011].

As of May 11, 2012, Novaled had a total of 129 employees [SEC 2012]. The following Table 11 provides the breakdown of numbers of the workforce by main category over the period 2009-2011. The table shows that Novaled with ca. 75 percent of the employees in R&D is essentially a "*research and development firm*."

Table 11: Showing Novaled's R&D personnel to cover three quarters of its workforce [SEC 2012].

	2009	2010	2011
Research & Development (R&D)	68	74	86
General & Administration	21	25	29
Total	89	99	115
Percent R&D	76	75	75

Novaled generates revenues primarily from the sales of its proprietary materials, the manufacture of which is outsourced primarily to BASF (through the acquired Ciba venture) on a contract basis [SEC 2012].

The vast majority of Novaled's revenues currently come from the sales of just one of its doping materials. Sales of this particular doping material to Samsung Mobile Display for use in its OLED smartphone displays accounted for approximately 10 percent, 35 percent and 59 percent of the revenue in 2009, 2010 and 2011. LG Display has also recently begun using the same doping material in its OLED smartphone displays, and both manufacturers are testing this doping material for use in their future OLED televisions [SEC 2012].

Apart from the 59 percent of Novaled's revenues in 2011 by sales of a specific doping material to Samsung Mobile Display approximately 14 percent of revenues came from sales of the same doping material to LG Display [SEC 2012].

The *design of high-performance OLED devices* is a rapidly changing field, and new developments may eliminate the need for its doping materials in the future. In addition, other companies may develop OLED technologies or materials that offer alternatives to Novaled's doping materials [SEC 2012].

The following list shows Novaled's 2011 revenue *by major category:*

- Sales of materials (€15,185; 87 percent)
- Research and development services (€2,220; 13 percent).

But it was publicly funded R&D projects which contributed €2.2 mio. to income in 2011 [SEC 2012].

Hence, for its main source of revenue Novaled depends on only one supplier (contract manufacturer) and has just few customers. Both factors represent a notable risk for the development of NTBFs [Runge:Table I.65, Figure I.115].

Approximately 75 percent of Novaled's revenue comes from Korean firms; much of its remaining revenue came from Europe. But it seems it did not doing much work with Japanese, Taiwanese, and Chinese OLED display developers though it opened an office already in 2008 in Japan. The other players may begin to take OLED display market share from Samsung Mobile Display and LG Display.

Competition

The *competitive strengths* of Novaled are its *proprietary* technologies and materials. Novaled views itself as one of the world *leading firms in the field of energy saving and long-lived OLEDs*. With regard to sales it claims to be the largest firm with a continuous trend of growth [Miethke 2011]. "We are well positioned in the field of OLED smartphones. But are not allowed to report details." [Miethke 2011]

Concerning *competitive advantage* the Novaled OLED PIN technology is based on ten years of research and development at the Dresden University in the field, setting high barriers to entry for new players.

Novaled OLED PIN® structure and OLED materials enable a 2-fold increase in power efficiency. This advantage makes it very difficult for manufacturers to go without. According to Novaled "we are not currently aware of any other manufacturers which produce alternative doping materials on a commercial scale." However, other companies may develop such materials in the future [SEC 2012].

According to its Web site (of 2013) competitive advantage is given by

- Double Uniqueness:
  1. Combination of organic materials, device development and engineering support
  2. Unique capacity to deliver doping materials in an industrial mode
- Doping and transport materials for an OLED+ performance

- Playing in different early-stage markets such as display, lighting, photovoltaic
- Business relationship to customers who are global players in their segment
- Outstanding development team with professional staff
- Close research cooperation with well-known universities.

Novaled is aware of competition. Among the most direct competitors two firms are notable. From the US it is Universal Display Corporation and Merck KGaA from Germany.

Universal Display Corporation (UDC), founded in 1994, is an OLED *research* company, and one of the field's pioneers. UDC is *involved in OLED IP*, and holds many patents related to the commercialization of *phosphorescent based OLEDs* (PHOLEDs) and also flexible, transparent and stacked OLEDs – for both display and lighting applications. Its phosphorescent OLED technologies and materials are licensed and supplied to companies, such as Samsung, LG Display, AU Optronics CMEL, Pioneer, Panasonic, Idemitsu OLED lighting and Konica Minolta (KM).

UDC is said to work also with Novaled [Wikipedia-2]. And Novaled confirmed UDC as a producer of other OLED materials to be a partner of Novaled [SEC 2012].

According to UDC's Web site:

"Universal Display has one of the largest patent portfolios in the OLED field with licensing rights to over 1000 issued and pending patents worldwide in a broad array of OLED technologies, materials and processes. This portfolio is the result of highly-productive collaborations between Universal Display and university partners at Princeton University, the University of the Southern California and the University of Michigan. Additionally, it contains OLED patents from Motorola Inc., for which we control sole sublicensing rights."

In 2012 Novaled filed plans for IPO (at NASDAQ) of up to $200 million (ca. €153 mio.). Novaled planned to use proceeds from the offering to improve its capitalization and financial flexibility while boosting its visibility in the marketplace [Reuters 2012]. Novaled hoped to get a higher evaluation in the US. The US rival Universal Display with a turnover of $61 million in 2011 has achieved a market capitalization of $1.9 billion on NASDAQ. A banker said Novaled could be valued at $500 to $800 million [APA 2012].

In Germany, Merck KGaA's efforts reflect its approach to become also strong in the new field of OLEDs, particularly for FPDs, as it is a leader for the LCD technology for many years [Runge 2006:455-456].

Merck now is the world leader of LC technology with sales of €833 mio. in 2009 and a profit of €225 mio. By 2002 Merck had a global market share of ca. 60 percent of the total liquid crystals market [Runge:Table I.48].

Merck has more than ten years of experience in manufacturing OLED materials and a strong portfolio of global patents give Merck a solid foundation for its range of high-purity and high-stability materials that are customized to meet customer requirements precisely. Furthermore, Merck cooperates closely with market leaders, such as Mitsubishi, and is an attractive partner in the development of innovative materials for the future technology of OLEDs.

The display manufacturers to which Novaled sells materials or licenses technology operate in a highly competitive environment; if they fail to compete successfully, or decide to discontinue or reduce their display manufacturing businesses, Novaled's business will be harmed [SEC 2012]

For instance, US chemical giant DuPont stated in a press release in May 2010 that they can produce a 50-inch OLED TV in two minutes with a new printing technology. If this can be scaled up in terms of manufacturing, then the total cost of OLED TVs would be greatly reduced. Dupont also stated that OLED TVs made with this less expensive technology can last up to 15 years if left on for a normal eight hour day [Wikipedia-1].

Furthermore, GE Global Research, the technology development arm for the General Electric Company, GE Lighting and Konica Minolta (KM) have achieved a major breakthrough that brings the companies closer to making high-efficiency OLED lighting devices a reality. GE and KM scientists have demonstrated illumination-quality white OLEDs using "solution-coatable" materials that are essential for producing OLEDs at a low cost. Researchers and product development teams from GE and KM have been working together on OLED technology since 2007 [SpecialChem 2010].

"GE and KM have done what many in the OLED research community thought was not possible," noted GE's OLED lighting technology leader Duggal. "We have produced high-performance white OLED lighting devices with a commercially viable lifetime using 'solution coating' rather than 'vacuum coating' processes. This allows us to make use of the high volume roll-to-roll manufacturing infrastructure that already has been perfected in the printing industry." [SpecialChem 2010]

GE and KM plan to manufacture OLEDs using high-speed, roll-to-roll processes rather than the vacuum-based batch processes used by companies in the OLED display industry. Roll-to-roll processing is a key to making OLEDs commercially viable for general lighting applications. Solution, or wet coating, is the highest throughput manufacturing method for coating the organic layers that are the essence of an OLED lighting device. GE Lighting will be the business that will commercialize GE OLEDs,

An Envisioned Future of Novaled

Already in 2011 Novaled envisioned for 2013 an exit of its investors which means usually by an IPO or selling the firm to another one.

According to CFO Harry Böhme, “Within the next two years, also the exit of our venture capital investors is to be realized, who have accompanied us well in the past, but their participation is of course limited in time.” (Innerhalb der nächsten zwei Jahre soll dann auch der Exit unserer Venture Capital-Investoren realisiert werden, die uns in der Vergangenheit hervorragend begleitet haben, aber deren Beteiligung natürlich zeitlich begrenzt ist.) [Zitzmann 2011]

That means Novaled followed a “dual track” which is a strategy to prepare a VC-backed NTBF simultaneously for two different paths for an exit.

Novaled filed for an IPO on the NASQAQ in the US in 2012 [SEC]. The IPO did not materialize, but the sales of Novaled to Samsung did.

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Notes

1. Exciton: http://en.wikipedia.org/wiki/Exciton.
2. The Dresden Fonds is a joint fund of the local savings bank in Dresden (Stadtsparkasse Dresden) and the State Bank of Saxony (Sachsen LB). It is managed by their venture capital subsidiaries SIB Innovations- und Beteiligungsgesellschaft mbH, Dresden, and Sachsen LB Corporate Finance Holding (CFH) GmbH, Leipzig. SIB Dresden.

3. Phosphorescent organic light-emitting diode: http://en.wikipedia.org/wiki/Phosphorescent_organic_light-emitting_diode.
4. OLED outcoupling films: http://www.microsharp.co.uk/index.php/oled-out-coupling-films.html.

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