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Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting
Part 1 - Non-Directional Light Sources

Draft final task reports
Task 6: Technical Analysis BAT And BNAT

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Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

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0 PREFACE

VITO and its partners are performing the preparatory study for the new upcoming eco-design directive for Energy Using Products (EuP) related to domestic lighting, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/eco_design/index_en.htm).

The environmental impacts of Energy-using Products such as domestic lighting take various forms, including: energy consumption and the related negative contribution to climate change, consumption of materials and natural resources, waste generation and release of hazardous substances. Eco-design, which means the integration of environmental considerations at the design phase, is arguably the best way to improve the environmental performance of products.

The creation of a coherent framework for environmental product policy avoids the adoption of uncoordinated measures that could lead to an overall negative result; for example eliminating a toxic substance from a product, such as mercury from lamps, might lead to increased energy consumption, which could in total have a negative impact on the environment. A Community framework also ensures that divergent national or regional measures, which could hinder the free movement of products and reduce the competitiveness of businesses, are not taken. It is not the intention to decrease the quality of domestic lighting.

The objective of this interim draft document is to present preliminary data for discussion with stakeholders related to the EuP preparatory study for the lot 19.
You can follow the progress of our study and find general information related to lot 19 on the project website when you register as stakeholder: http://www.eup4light.net
Please, also consult the website for timing and organisation of the tasks.

1 PRODUCT DEFINITION

For more info see website www.eup4light.net.

2 ECONOMIC AND MARKET ANALYSIS

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3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

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5 DEFINITION OF BASE-CASE

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6 TECHNICAL ANALYSIS BAT

Scope: This entails a technical analysis and description of the Best Available Technology (BAT) and Best Not yet Available Technology (BNAT) that can be implemented on product or component level. The described BAT is in many cases already available on the market, but is less frequently used because of the purchase price. It partly provides the input for the identification of part of the improvement potential (task 7), i.e. especially the part that relates to the best available technology. In chapter 7, also cost, intellectual property and availability are taken into account for the selection of options. This is not the case in this chapter and many of the presented technologies are intellectual property or linked to individual companies. The input of this chapter is partially the result of an organised visit to the Light and Building trade fare in Frankfurt 2006 (see also chapter 9 stakeholder consultation). Additional information was collected by consulting manufacturer's catalogues and technical publications. Much research is ongoing and information is not always publicly available, therefore this chapter can never claim to be complete but aims to give a general overview. For commercial reasons brand names are avoided in the text as far as possible.

6.1 BAT State-of the art

6.1.1 Compact fluorescent lamps (CFLi) with enhanced efficacy

The electronic control circuit in the lamp can have a serious impact on the lamp efficacy. These control circuit can be composed of a very simple low cost system up to a circuit based on sophisticated integrated control circuit. The power consumption of this incorporated electronic circuit and the efficiency of the switching semiconductor can influence lamp efficacy.
The base case lamp has an efficacy of 50lm/W (for the bare lamps) while there are lamps that have an efficacy of 55-57lm/W or 10% more.
Price and efficacy data can be found in the following Table 6.1. We assumed that mainly the price has an impact and that the BOM impact is negligible for this product, as could already be concluded from chapter 5.
These data can be used for the improvement options assessment in chapter 7.

Table 6.1: Data for CFLi's with enhanced efficacy.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[1]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	57	6000	5	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra<90	1,05	55	6000	5	FBT-10/27/1B-220/240-E14

6.1.2 Compact fluorescent lamps (CFLi) with enhanced efficacy and long or very long lifetime

The incorporated electronic control circuit in the lamp can also have a serious impact on the lamp life. It is again the sophisticated integrated control circuit and the quality of the components that influences lamp life. Lamp lifes of 10.000, 12.000 and 15.000h are declared by manufacturers.
It is clear that these lamps always have enhanced efficacies. The higher grade ballasts use semiconductors with higher efficacy (e.g. MOSFET half bridge instead of bipolar transistors) and more sophisticated control circuits (e.g. IC).

Price and efficacy data about these lamps are included in Table 6.2 hereafter. These data can also be used for the improvement options assessment in chapter 7. We assumed that mainly the price has an impact and that the BOM impact (printed circuit board assembled) is negligible for this product, as could already be concluded from chapter 5.

Table 6.2: Data for CFLi's with long and very long lifetime.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[2]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	57	10000	9	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra<90	1,05	55	10000	9	FBT-10/27/1B-220/240-E14
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	57	15000	11	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra<90	1,05	55	15000	11	FBT-10/27/1B-220/240-E14

[1] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).
[2] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).

6.1.3 Compact fluorescent lamps (CFLi) with reduced mercury content compared to ROHS directive requirements and use of leachable mercury compounds

The health risks and environmental risks related to the use of mercury were the focus of several studies (RPA (2002))[3] The use of mercury is limited by the RoHS directive (2002/95/EC) and recycling by the WEEE directive (2002/96/EC), see also chapter 1.

Most manufacturers market CFLi's with reduced mercury content compared to the maximum level of 5 mg specified in the ROHS directive.
Currently, there are lamps on the market with mercury content values of less than 1.25 mg.

It is also possible to add substances (e.g. mercury amalgam) to fluorescent lamps that reduce the impact of mercury from disposal of fluorescent lamps that might leach into surface and subsurface water, a method followed by the US as alternative for recycling.
The U.S. Environmental Protection Agency established a maximum concentration level for mercury at 0.2 milligrams of leachable mercury per liter of extract fluid. The concentration level for mercury is generally determined by a standard analysis known as the Toxicity Characteristic Leaching Procedure (TCLP), a well known test procedure implemented in 1990 by the Environmental Protection Agency.

When carrying out the TCLP test, test lamps are pulverized to form lamp waste material similar to that which would result from lamp disposal in land fills or other disposal locations. The ambient conditions in disposal locations may be such as to promote formation of leachable mercury. The TCLP test conditions themselves tend to allow for formation of leachable mercury in amounts greater than the established limit of 0.2 milligrams per liter. During the disposal of the lamp, and in the TCLP test, the glass enclosure of the lamp is broken. Elemental mercury that is contained in the lamp is then exposed to the metal components in an aqueous environment. Elemental mercury, when exposed to both the metal components and the aqueous environment, is oxidized to leachable mercury. The metal components in the lamp provide the source of oxidizable iron and oxidizable copper that promotes the formation of leachable mercury. Several techniques have been developed which prevent the formation of mercury that can leach into the environment. The methods currently used are concerned with a method of delivering a chemical agent or metal upon disposal of a lamp or during the TCLP test. For instance, Fowler et al. (U.S. Pat. No. 5,229,686 and U.S. Pat. No. 5,229,687) describe methods that incorporate chemical agents in the lamp in either a glass capsule or the basing cement. These chemical agents include various salts such as bromide anions, chloride anions, iodide anions, iodate anions, periodate anions, and sulfide anions, to name a few. Other chemical agents include powders such as iron powder, copper powder, tin powder, and titanium powder. In U.S. Pat. No. 5,821,682 Foust et al. describe the addition of a mercury antioxidant for superior TCLP test performance. Mercury antioxidants

[3] RPA (2002): ' Risks to Health and the Environment Related to the Use of Mercury Products', 9 August 2002, Final Report (see http://ec.europa.eu/enterprise/chemicals/studies_en.htm).

include, for example, ascorbic acid, sodium ascorbate, and sodium gluconate. These materials have been found to reduce or prevent the formation of leachable mercurous and mercuric compounds resulting from the oxidation of elemental mercury. Unfortunately, manufacturing processes typically use a separate dispensing step to introduce the mercury antioxidant. In US Patent US20020190646 A1, another method is described which provides in the lamp structure an effective amount of a silver salt, a gold salt or combination thereof.

Price and BOM data about these lamps are included hereafter in Table 6.3 and Table 6.4 and can be used for the improvement options assessment in chapter 7.

Table 6.3: Data for CFLi's with reduced mercury content

Lamp type **Acronym**	**Wattage rated** **[W]**	**Colour Temp** **[K]**	**Colour rend** **Ra**	**LWFt**[4]	**ηlamp @25 °C** **[lm/W]**	**Operational Life time** **[h]**	**Unit price (for end user)** **[€]**	**ILCOS-code**
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra<90	1,05	50	6000	5	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra<90	1,05	50	6000	5	FBT-10/27/1B-220/240-E14

[4] LWFt = Total Lamp Wattage Factor = LWFp x LWFe

Table 6.4: BOM data for CFLi's with reduced mercury content.

MATERIALS Extraction & Production Description of component	Compact fluorescent lamp, bare, E27/B22d - **15W**	Compact fluorescent lamp, bare, E14/B15d - **11W**	Category	Material or Process MEEUP
Glass	25	17,5	7-Misc.	**54-Glass for lamps**
Aluminium for caps	1,5	1	4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps			4-Non-ferro	**30-CU tube/sheet**
Metal Mercury	0,002	0,002		
Plastic housing	25	22		**PBT**[5]
Lamp envelope				**54-Glass for lamps**
Printed circuit board, assembled	20	17		**53-PWB assembly**
Total weight				

6.1.4 Compact fluorescent lamps (CFLi) with long lifetime and reduced mercury content

These lamps combine a more sophisticated control circuit that enhances lifetime (and consequently also efficacy) with the reduced mercury content of lamps from section 6.1.3.

Price and efficacy data about these lamps are included in Table 6.5 hereafter. These data can be used for the improvement options assessment in chapter 7.
The BOM data can also be taken from section 6.1.3.

[5] **PBT** PolyButyleneTerephtalate

Table 6.5: Data for CFLi's with long lifetime and reduced mercury content

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[6]	ηlamp @25 °C [lm/W]	Opera tional Life time [h]	Unit price (for end user) [€]	ILCOS-code
Compact fluorescent lamp, bare, E27/B22d **CFLi**	15	2700	80≤Ra< 90	1,05	57	10000	10	FBT-15/27/1B-220/240-E27
Compact fluorescent lamp, bare, E14/B15d **CFLi**	11	2700	80≤Ra< 90	1,05	55	10000	10	FBT-10/27/1B-220/240-E14

6.1.5 Dimmable compact fluorescent lamps (CFLi) and CFLi compatibility with electronic switches/dimmers

Currently, dimming in domestic lighting is mostly not inspired by energy saving, but, as mentioned in chapter 3, mainly for comfort reasons However, other types of electronic switches are commonly used, which are targeted at energy savings, such as presence detectors or timers.

Common to both dimmers and many electronic switches, is that ordinary CFLi's should not be operated on them. Lamp manufacturers warn against doing so with any CFLi, which is not specifically designed and certified for this use. The reasons for this have been explained in chapter 3.4.5.

The dimmers, which are found in the existing installations, are designed for dimming GLS lamps, MV-HL and LV-HL via iron-core or electronic transformers. Dimmers work by cutting out a part of the mains voltage sine wave, either at the beginning or the end of each half-cycle (respectively "leading edge" and "trailing edge" dimmers). Beside leading and trailing edge phase cut dimmers also 'top sine cutters' exist in the market, commercialised to dim ordinary CFLi's.

More background information on installed dimmers in domestic lighting:
The majority of installed dimmers are based on triac semiconductors and are leading edge phase cut dimmers, which means that they always operate in "leading edge" mode. This kind of dimming technology is not suitable for the type of ballast circuits found in ordinary CFLi's, i.e. a diode bridge input rectifier. This is not due to the dimmer as such, but due to the nature of the ballast circuit, when connected to this type of device. They can operate in a "two-wire" system as explained in chapter 3 and need therefore a small continuous supply current for their internal circuits provided through a certain minimum load, typically minimum a 20 W GLS lamp. Some triac-based dimmers may require even higher minimum loads (>40W), because the triac needs a certain current in order to stay in the conducting mode.
The remaining dimmers are based on transistor technology, for the most part operating in "trailing edge" or "top sine cutting" mode and able to control:

[6] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section 4.3.2).

- Inductive loads, such as magnetic (iron-core) transformers for LV-HL, can be dimmed with leading edge phase-cutting dimmers (if certified for this use).
- Capacitive loads, such as electronic transformers for LV-HL, can be dimmed with trailing edge phase-cutting dimmers.
- Resistive loads, such as GLS lamps and MV-HL, can be dimmed with either of these technologies.

In addition, transistor dimmers have certain advantages, such as electronic protection. Some high-end transistor dimmers automatically detect the type of load, and adjust the operating mode accordingly. Nevertheless a problem occurs in providing supply power to those transistor dimmers. They need a “three-wire” electrical system or a battery, see also chapter 3. A three wire systems means that the neutral wire is present at the switch/dimmer. Unfortunately, the "two-wire" system is the most commonly found system in domestic electrical lighting circuits in the European market. It appears also that many ordinary CFLi’s can be dimmed to a certain extent (30-40%) by three-wire trailing-edge dimmers or "top sine cutters". "Top sine cutters" are beneficial to reduce CFLi peak input currents and loading the CFLi input circuit. However, lamp manufacturers warn against attempting to do so. Paradoxally, certain 'dimmable CFLi's' do not dim on those dimmers.

About dimmable CFLi's:
Dimming fluorescent lamps below 30 % requires special techniques such as injection of a small DC current[7] and selection of the operation frequency, this is not complicated but currently not done in existing CFLi ballast circuits.
In order to overcome these problems, special CFLi’s have been developed for dimming. There are two main types of “dimmable CFLi” in the market:

- Dimmable CFLi’s that can be operated on standard dimmers (and/or other electronic switches).
- CFLi’s with a built-in dimming function, which can be controlled via on ordinary switch (flicking on and off rapidly can be used for selecting one or more steps of dimming level, or for starting a continuous dimming ramp, which can then be stopped at the desired level).

Both types are based on advanced electronic circuits (e.g.: US Patent 5686799 - Ballast circuit for compact fluorescent lamp, ..), which will detect dimmer settings and adjust the light output accordingly. They contain significantly more electronics than ordinary CFLi’s, and are consequently also more expensive to the user.

General remarks:

- Please note that the halogen lamp with integrated transformer can be dimmed on all those dimmers.
- When CFLi's are dimmed the colour temperature increases slightly, the opposite of filament lamps (Halogen, GLS) (see chapter 3).
- Inherent in the sophisticated, integrated control circuit and the quality of the components, the lamps found on the market have also enhanced efficacy and long lifetime.
- “Three-wire” electronic switches (e.g. presence detectors) can use a mechanical relay for switching the lamp, which means that ordinary CFLi’s can be used (although with derating due to inrush currents and peak factor).

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[7] US Patent 5001386 - 'Circuit for dimming gas discharge lamps without introducing striations' (1989)

Price and efficacy data about dimmable CFLi’s is included in Table 6.6 hereafter and can be used in the impact assessment in chapter 8.
The influence on the BOM’s (printed circuit board assembled) is also assumed to be negligible.

Table 6.6: Data for dimmable CFLi’s.

Lamp type **Acronym**	**Wattage rated** **[W]**	**Colour Temp** **[K]**	**Colour rend** **Ra**	**LWFt**[8]	**ηlamp @25 °C** **[lm/W]**	**Operational Life time** **[h]**	**Unit price (for end user)** **[€]**	**ILCOS-code**
Compact fluorescent lamp, bare, dimmable, E27/B22d **CFLi**	20	2700	80≤Ra<90	1,05	61	15000	20	FBT-20/27/1B-220/240-E27

6.1.6 Other compact fluorescent lamp (CFLi) improvements

The following information is included in order to assess the recent technical developments that were made in lamp technology for CFLi. This information is useful to assess whether consumer acceptance barriers indentified in chapter 3 will be justified in future scenarios when evaluating policy options in chapter 8.

6.1.6.1 Amalgam technology

Common fluorescent lamps as well as CFLi's use mercury vapour to generate light. In lamps which are subjected to extreme temperatures (away from the optimum of 25°C), these lamps can loose up to 50% of their nominal lightoutput. This occurs when lamps are used outdoor (e.g. porch lighting) or in indoor luminaires (ambient temp. >> 25°). The latter is particularly a problem for very compact CFLi’s in GLS shapes (enveloped types). Amalgam (a lead/mercury alloy) ensures a high light output, regardless the ambient temperature. The lead/mercury alloy increases the melting point compared to pure mercury, it is not liquid at room temperature.
An additional benefit is that in case of breakage of a cold lamp mercury cannot dissipate in the environment, see also 6.1.3.
The use of solid mercury amalgam compared to liquid mercury is also beneficial in CFLi production because a dripping method is more difficult to control the mercury amount and amalgam is more easy to handle without production losses.
The only drawback of amalgam is that lamps typically need a slightly longer run-up period to reach their maximum light output; possibly the incorporation of better electronic control circuits that boost the lamp at start up can overcome this disadvantage, see also 6.1.6.6.

6.1.6.2 Triphosphor versus halophosphate CFLi’s

First introduced energy saving CFLi’s had low colour rendering and were based on so-called halophosphate technology. By introducing the triphosphor, Ra was ameliorated to values ≥80.

[8] LWFt = Total Lamp Wattage Factor = LWFp x LWFe.

All currently available CFLi’s on the market have that good colour rendering.

6.1.6.3 Multiphosphor lamps

There is an interest on the market for lamps with multiphosphors and correlated Ra≥90. Some manufacturers are already producing them.

6.1.6.4 Lamps with different colour temperature

Most used colour temperature for CFLi’s is 2700 K in Northern Europe, in accordance with the warm light of the replaced incandescent lamps. Nevertheless in Southern Europe, people also like cooler light (4000 K). For this reason, manufacturers are producing lamps with higher colour temperature. This is not possible for GLS or HL lamps unless a couloured outer filter is applied that reduces lamp efficacy even more.

6.1.6.5 Electronic circuit for direct start

Some CFLi’s start with a start delay between 0,5 to 1 second. This delay is introduced for preheating lamp electrodes and increasing the CFLi life time (e.g. in long life lamps 15000 h). This phenomenon can cause inconvenience for some people in comparison with the direct starting incandescent lamp.
Most of the lower cost CFLi on the market have 'direct start' or 'instant start', those CFLi have typically a shorter life time (e.g. 6000 h).

6.1.6.6 Improved electronic circuit for shorter warm-up time

Some CFLi’s have long warm-up times (definition see chapter 1). This phenomenon could causes inconvenience for some people (see chapter 3). Longer warm-up times are mainly caused by the amalgam technology that is necessary for small size CFLi’s because the amalgam needs more time to evaporate (higher temperature required). By improving the integrated electronic circuit warm-up time can be shortened the same way as electronic ballasts do for LFL or CFLni. Most of all a preheating is beneficial, but this needs a start delay (see 6.1.6.5). Data on warm up times is included in chapter 3, the best compact amalgam lamps with preheating easily obtain above 80 % light output in less then a minute (see also chapter 3).

6.1.6.7 CFLi with integrated halogen lamp for direct lighting

There are hybrid CFLi's on the market that are combined with a halogen lamp. The halogen lamp is only switched on during the warm up period of the CFLi and therefore provide full light output immediately after switching on the lamp.

6.1.6.8 Improved electronic input control circuit for power factor control and light output insensitive to line voltage fluctuations

As mentioned in section 4.3.2.1, the low value of the power factor for CFLi’s below 25W causes additional losses in the electrical grid. Typical data for CFLi found on the market is included in chapter 3. The power factor of low power CFLi (<25 W) could be ameliorated by incorporating an electronic input circuit, the same as currently all light sources above 25 W need according to EN 61000-3-2. In this case the power factor is between 0,95 and 0,99. Some smaller CFLi manufacturers brought such CFLi (<25 W) on the market, however they are significantly more expensive(about 20 euro). It should be taken into account that the need of an improved power factor for CFLi is arguable because many loads in the electrical grid are inductive and a capacitive CFLi can provide compensation as discussed in chapter 3. A complementary benefit of this circuit is that the light output does not vary with the line voltage, such as lower cost CFLi and all GLS lamps do.

6.1.7 Cold Cathode Compact Fluorescent lamps with integrated balllast (CCFLi)

Cold cathodes fluorescent lamps (CCFL) are fluorescent lamps that do not employ a cathode heater. Nowadays, miniature CCFLs are extensively used as backlights for computer liquid crystal displays or flatscreen television sets but more recently lamps for general illumination appeared on the market They claim a longer life time, dimmability and improved light distribution with only a slightly lower lamp efficacy compared to usual CFLi's. Please note that these lamps also contain mercury. More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 5 for television sets[9].

Figure 6.1: CCFL reflector lamp.

Stakeholders please provide input. This section will be updated in part 2 of the study with technical data.

6.1.8 Pin based compact fluorescent lamps (CFLni)

It is possible to design new luminaires (e.g. halogen torchieres or uplighters) with CFLni instead of HL-MV or GLS lamps. This is a technical improvement that needs to be done at systems level (luminaire) as defined in this study (see chapter 1). More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 8 on office lighting. This section will be updated in part 2 of the study related to luminaires (system level).

[9] www.ecotelevision.org

6.1.9 Directional or reflector Compact fluorescent lamps (CFLi)

This section will be updated in part 2 of the study.

6.1.10 Mains voltage halogen lamps with xenon

Incandescent lamps have an inert filling gas to reduce the evaporation of the filament (IESNA (1993)). The usual filling gas is a mixture of argon and nitrogen. Argon is slightly less heat conductive than nitrogen and therefore more suitable, however a small amount of nitrogen is often needed to impair formation of destructive electric arcs. Incadescent lamp efficacy is related to life time and line voltage, e.g.: a 100 W-230 VAC (rated life time 1000 h) clear GLS has 1340 lm and a 100 W-120 VAC (rated life time 750 h) has 1710 lm; lower voltage GLS lamps show a higer lamp efficacy (e.g. a 60 W GLS for 24 VAC has a 30 % higher lamp efficacy compared to a 60 W GLS for 230 VAC).
An halogen lamp is a modified incandescent lamp where the filling gas include a halogen gas (iodine, bromide, chlorine, fluorine) in order to induce a tungstenhalide cycle, which impede the lamp envelope blackening and extend the lifetime of the tungsten filament wire. Due to that, the size of the lamp envelope can be considerably reduced, which enables some remarkable improvements . As a result of that, halogen lamps have in general higher efficacies and a longer lifetime compared to incandescent lamps. Of course, all types of halogen lamps can be fully dimmed A further improvement of the halogen lamps performance can be achieved by the reduction of thermal losses. This can be obtained by using a less heat conductive inert filling gas, e.g. krypton or xenon. The highest efficacy can be obtained with xenon filling gas. Actual mains voltage halogen lamps filled with Xenon show an improvement in efficacy up to 20% compared to standard halogen lamps at the same lamp life. Recently not only linear (R7s) and compact (G9) Xenon filled HL-MV lamps were introduced on the market but also replacement lamps for GLS (see Figure 6.2), providing 30% energy saving compared to an IEC 60064 standard GLS (60W, 620 lm, 1000 h). These newly introduced lamps have identical outer measurements and are available as well with clear bulbs (important for decorative types) for easy one-to-one replacement of the incandescent lamps available today on the market.
These lamps have an excellent colour rendering (CRI=100) and can easily be dimmed as long as the wattage is above the minimum wattage of the dimmer.

Figure 6.2: Xenon HL-MV-lamp, form A and form B.

The lamp data can be found in Table 6.7.

Table 6.7: Data for selected xenon filled HL-MV lamps.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt[10]	ηlamp @25 °C [lm/W]	Opera tional Life time [h]	Unit price (for end user) [€]	ILCOS-code
Halogen lamp, clear, 230V, Xenon, form A, E27/B22d **HL-MV**	42	2800	100	1	15	2000	3.6	HSGSA/C/UB-42-230-E27
Halogen lamp, clear, 230V, Xenon, form B, E14/B15d **HL-MV**	28	2800	100	1	12,3	2000	5	HSGSB/C/UB-28-230-E14
Halogen lamp, clear, 230V, Xenon, G9 **HL-MV**	33	2900	100	1	13,9	2000	8,9	HSG/C/UB-33-230-G9-44
Halogen lamp, clear, 230V, Xenon, linear, R7s **HL-MV**	230	2800	100	1	22,0	2000	3,8	HDG-230-230-R7s-114,2

6.1.11 Replacing low voltage halogen lamps (HL-LV) with low voltage halogen lamps with infrared coating and xenon

A further development that has increased halogen lamp efficacy is applying an infrared-reflective coating. The basic infra-red coating technology to increase lamps efficacy[11] is over 30 years old. In lighting it was first commercially used in the early eighties to increase the efficacy of low pressure sodium lamps. The quartz lamp filament envelope is coated with a multi-layered dichroic coating which allows visible light to be emitted while reflecting a portion of the infrared radiation or heat back onto the filament. Therefore the lamp filament wire is heated more efficiently. Such lamps are called halogen-infrared lamps, and they require less power than standard halogen lamps to produce any given light output. The efficiency increase can be as much as 40% when compared to its standard equivalent. This technology is mainly applied to low voltage halogen lamps (see also next point for a solution for mains voltage applications). Several lamp manufacturers have these lamps in their HL-LV product portofolio.
In Table 6.8 the data for the selected lamps are shown.

[10] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section **Error! Reference source not found.**).
[11] United States Patent 4,017,758 (1977) 'Incandescent lamp with infrared filter'

Table 6.8: Data for the selected infrared-coated HL-LV.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt [12]	ηlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Halogen lamp, clear, 12V, infra-red coating GY6,35 **HL-LV**	35	3000	100	1,11	23,2	4000	7	HSGST/UB/IB-35-12-GY6,35
Halogen lamp, clear, 12V, infra-red coating GY6,35 **HL-LV**	20	3000	100	1,11	18,9	4000	7	HSGST/UB/IB-35-12-GY6,35

6.1.12 Mains voltage halogen lamps (HL-MV) with infrared coating and integrated electronic transformer

In Europe where the line voltage is about 230 VAC, halogen main voltage (HL-MV) lamps have relative long filament wires; therefore it is diffucult to focus back the infrared radiation to the filament wire and as a consequence this technology could not succesfully be applied to main voltage halogen lamps (HL-MV). The basic idea[13] to incorporate a transformer for this purpose in the socket is over 20 years old.
A recent development to overcome the problem for applying succesful infrared coating technology in main voltage lamps is to integrate an electronic transformer in the lamp socket (see Figure 6.3) and use a HL-LV bulb with infrared coating. The efficacy of these lamps is almost twice the efficacy of a normal incandescent lamp of the same wattage. So a 30W electronic HL-MV lamp is equivalent to a '53W' GLS-C lamp and a 20W electronic HL-MV lamp to a '37W' GLS-C lamp.

Figure 6.3: Electronic MV halogen lamps

These clear lamps, giving bright, sparkling light, are an energy efficient alternative for clear incandescent lamps where high luminance light bulbs are needed such as in (antique) luminaires with crystal ornaments. These lamps are dimmable with classical, household dimmers. The integrated transformer has to be able to withstand the high temperature generated by the lamp, which currently limit the maximum wattage of lamps available on the market. The data for these lamps are shown in Table 6.9 and can be used for the improvement options assessment in chapter 7. These lamps are also available with a frosted outer bulb to prevent glare. These lamps have also an excellent colour rendering (CRI=100) and can easily

[12] LWFt = Total Lamp Wattage Factor = LWFp x LWFe.
[13] United States Patent 4,998,044 (1985) 'Efficacy incandescent light bulbs'

be dimmed on all dimmers also below the minimum wattage due to a special electronic circuit.

Table 6.9: Data for electronic HL-MV lamps.

Lamp type Acronym	Wattage rated [W]	Colour Temp [K]	Colour rend Ra	LWFt [14]	Hlamp @25 °C [lm/W]	Operational Life time [h]	Unit price (for end user) [€]	ILCOS-code
Halogen lamp, clear, 230V, electronic, form A, E27/B22d **HL-MV** (electronic)	30	2850	100	1	21	3000	9	
Halogen lamp, clear, 230V, electronic, form B, E14/B15d **HL-MV** (electronic)	20	2850	100	1	19	3000	9	

Table 6.10: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production ***Description of component***	Halogen lamp, clear, 230V, electronic, form B, E27/B22d - **30W**	Halogen lamp, clear, 230V, electronic, form B, E14/B15d - **20W**	**Category**	**Material or Process MEEUP**
Glass	22	12	7-Misc.	**54-Glass for lamps**
Aluminium for caps + cover	4	3,5	4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps			4-Non-ferro	**30-CU tube/sheet**
Metal Mercury				
Plastic housing	15	15		**PBT**[15]
Lamp envelope				**54-Glass for lamps**
Printed circuit board, assembled	40	40		**53-PWB assembly**
Total weight				

[14] LWFt = Total Lamp Wattage Factor = LWFp x LWFe .
[15] **PBT** PolyButyleneTerephtalate

6.1.13 Replacing mains voltage halogen lamps by more efficient low voltage halogen lamps by integrating an electronic transformer in the luminaire or furniture (system level)

It should be noted that luminaires designed for use with halogen lamps can obtain higher lamp efficacy if designed for HL-LV compared to HL-MV if this lamps use infrared coating technology, see section 6.1.10. . This is a technical improvement that needs to be done at systems level (luminaire) as defined in this study (see chapter 1).
This section will be updated in part 2 of the study related to luminaires (system level).

6.1.14 Reflector lamps with WLED SSL lamps

This section will be updated in part 2 of the study.
Preliminary data:

Figure 6.4: Typical WLEDcomponent and LED lamp

White-light emitting diode (WLED) solid state lighting (SSL) lamps (see Figure 6.4) are recently becoming available on the market with increasing efficacy (up to 94 lumen/W ((Härle (2007)) and increasing life time as a result of decades of semiconductor research and progress. WLED are p art of ultra-brite (UB) LEDs that include also coloured LEDs. WLEDs are nowadays especially applied where small white light sources are needed, e.g. in display backlighting of portable devices. Also applications where coloured light is required benefit from LED's, e.g. traffic and other signs (applications with a low power density). LED's can be dimmed easily. WLED's are available in a wide range of lamp efficacies (5-80 lumen/W) even from the same manufacturing production line, the LEDs have to be sorted during manufacture by their actual characteristics.
WLED's that are nowadays on the market are mainly Solid State Lighting (SSL) devices, that rely on semiconductor material. For this SSL technology, efficacy and life time rapidly decrease with ambient temperature, therefore no high power densities or compact light sources can be obtained. SSLs are therefore primarily produced as discrete devices they are mainly available in low wattages (typical 1 to 5 Watt) and the main market products nowadays are mobile appliances (48 % in 2006, Steele (2007)). They are also sold as LED replacement lamps for existing reflector lamps(see Figure 6.4).
Dr. Shuji Nakamura of Nichia of Japan is the inventor of the white LED which took a composite YAG phosphor coating on top of a blue LED and converted it to white light. This technique is nowadays nearly used by all WLED manufacturers. A theoretical limit in efficacy can be expected in the range of 135-150 lm/W with lens and without converter (Härle (2007). The spectrum of some white LEDs differs significantly from incandescent light. There

is a strong dependency of maximum efficacy on colour temperature colour coordinate (up to 20% increase) (Härle (2007)). The most efficient WLEDs appear blue (e.g. CT 6000 K) and do not meet the CRI > 80 colour rendering requirement for office lighting (EN 12464-1).
The SSL dependence on solid state semiconductor material could keep the price relatively high for these sources and the environmental impact of the production should be followed up in the near future. LED semi-conductors are crystals comprised of combinations of typically two or tree inorganic elements, such as gallium phosphide (GaP), gallium nitride (GaN), gallium indium nitride (GaInN) or gallium indium phosphide (GaInP). It should be noted that LEDs in general, thus not only WLED, are included in the environmental impact unit indicators in the MEEUP methodology report (table 29 material 48) and herein the production energy requirement or GWP per kg is very high compared to other materials. This can be explained by the high energy (GWP) and environmental impact that is typical for the production of semiconductor material, see also material 47 (ICs SMD) in table 29 in the MEEUP methodology report. The WLEDs in particular make use of the rare raw materials gallium and indium that are used in many other high tech applications (PV panels, monitors, LCD displays with coatings of indium tin oxide) ('Only united are we strong: supply problems await areas other than silicon', Photon International, July 2006). The world annual indium production was estimated(2005) at 455 ton at 650 €/kg with about 6000 ton global reserves only(US Geological Survey, Mineral Commodity Summaries, January 2006). The indium price did rise with a factor 8 from 2002 to 2005. The world annual gallium production is estimated in 2005 at 208 tons at 410 €:kg and the global reserve is more difficult to estimate. Gallium occurs in very small concentrations in ores of other metals and is produced as a byproduct (e.g. bauxite). Based on the world resource of bauxite the reserve exceeds 1 million ton but probably only a small percentage of this metal is economically recoverable (US Geological Survey, Mineral Commodity Summaries, January 2006). The required energy (GWP) and material for the particular high efficacy WLEDs can only be modelled very approximate nowadays because it is unclear how many % of the production reach the high efficacy rating and there are many different and new production processes involved from which no data is made available due to intellectual property concerns. In this study the environmental impact will be modelled with the unit indicator (material 48 'SMD/LED's Avg per kg') from the MEEUP methodology (table 29) (If stakeholders have more accurate information please provide it). It is also clear from the unit indicator in the MEEUP methodology that environmental impact from the production may not be neglected in future assessments.

Material; cost and lamp efficacy data for LED replacement lamp as directional lightsource (DLS):
To be added later (for part 2 of the study)

6.1.15 HID lamps to retrofit HL-MV high wattage lamps

HL-MV high wattage lamps can be replaced by more efficient HID lamp solutions.

The main advantage compared to CFLi is that the HID lamp is a point source that performs better when the light needs to be focused by optics, e.g. in reflector lamps (see 6.1.14) or a luminaire. The HID lamps are mainly available in high lumen output versions (> 1000 lm) and hence users are also forced to use luminaires or reflector lamps to prevent glare and distribute the light. There currently exist HID reflector lamp versions (see 6.1.16) that directly offers cost effective integrated solutions. As a conclusion, it is more likely that the domestic users will move to those HID reflector lamps (see 6.1.16) (part 2 of this study).

No retrofit lamps for HL-MV are available up to date, the main obstacle for a simple retrofit lamp is the need for an HID lamp ballast and igniter. As opposed to CFLi the ballast and igniter has never been integrated so far, probably due to the typical high lamp power. As a consequence the user needs to replace the luminaire, therefore this section will be updated in part 2 of the study.

The lowest lumen output versions have a typical lamp power of 20 Watt with about 1000 lumen after 10000 h operation, hence the lamp efficacy is comparable to CFLi.

Today's commercial HID lamps requiire warm up times in excess of 40 s and restrike times of several minutes. This makes them not very suitable for domestic applications. Instant start and hot restrike HID lamps are demonstrated in car headlights but are not yet available for general lighting applications. Please note also that several HID lamp types such as HPS lamps and car headlights do not have the good colour rendering requirements expected for general indoor lighting.

It is unlikely that much lower lumen output HID lamps will appear on the market in the near future. It is a strong technological challenge. Simply downscaling can compromise life expectancy. Obstacles are the thermal conduction losses from the arc and the electrode losses that become more important for low wattages. Another problem for miniaturization are the required dimensional tolerances -that determine the light colour variation- since they become very hard to control at the small arc tube size needed for sub 20W HID lamps.

Please note that white HID lamps also contain mercury, for more information on HID lamps see the preparatory study on street lighting lot 9 for more information.

6.1.16 HID reflector lamps

This section will be updated in part 2 of the study.

6.1.17 Luminares with improved light output ratio (system level)

This section will be updated in part 2 of the study.

6.2 State-of the art of best existing product technology outside the EU

The EU has premises of leading international companies in the field of lighting with also important R&D related to office lighting within the EU. For the cited BAT above, similar technology exists around the world, mainly in the US and in Asia. Many European companies are also internationally active and it is difficult to allocate their activities and achievements exclusively to the EU. The production of CFL is often located in China.
On the longer term (above 5 years), the proliferation of more advanced electronic lamp technology and solid state lighting such as LEDs could be allocated to technology resulting from Asian technological developments.

6.3 BNAT in applied research

6.3.1 OLED lamps

OLEDs (Organic LED) are a new upcoming technology,and are considered BNAT in the scope of this study concerning general domestic lighting illumination.This technology is intrinsically well suited for indoor area illumination and could appear as 'glowing wall paper' without the need for 'luminaires'. OLEDs (Organic Light-Emitting Diodes) are a flat display technology (see Figure 6.5), made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. OLED’s could tackle in the future the material and cost problem currently encountered in SSL LED’s. The first OLED’s are already on the market for particular, very flat illuminated displays in portable devices. OLED’s based on organic material are still part of current R&D. OLED efficiencies under particular operational conditions have been reported up to 64 lm/W at 1000 Cd/m² (Budde (2007)). The actual OLED’s still have a to prove efficacy in working conditions (e.g. temperature and required life time).

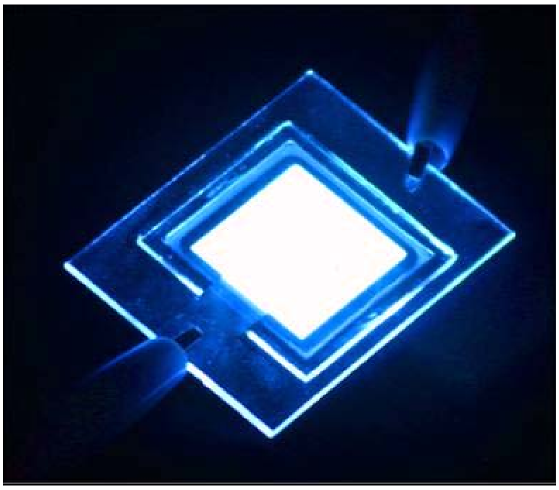

Figure 6.5: OLED prototype (Picture courtesy of OLLA project)

Conclusion:
The reported OLED performance in scientific papers is interesting but the product is not yet on the market for domestic general lighting applications but the technology might appear on the market in future. OLED's are classified therefore BNAT and there will be no case study for OLED's in further chapters.

6.3.2 Incandescent lamps using tungsten photonic lattice

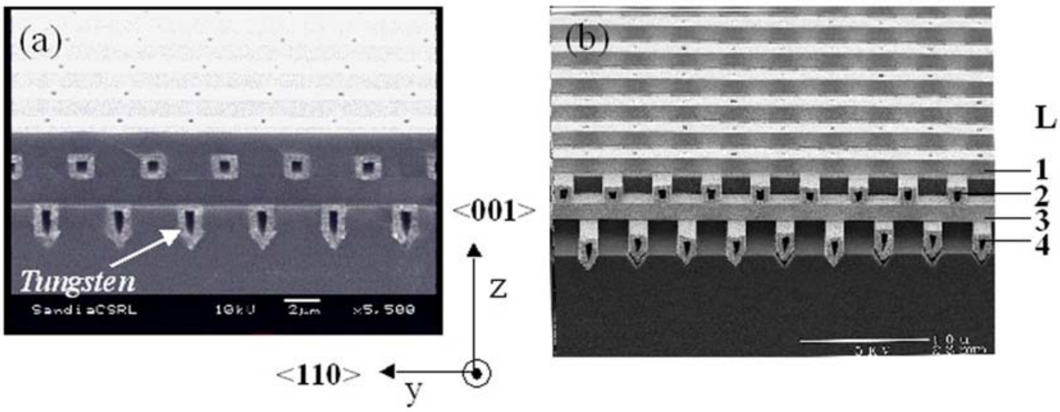

Figure 6.6: Images of a Sandia 3-D tungsten photonic crystal, taken by a scanning electron microscope The dimensional scale is in microns

New microscopic tungsten lattice could contribute to futher efficacy improvements of incadescent lamps These could benefit from a tungsten filament fabricated with an internal crystalline pattern (Figure 6.6) could transmute the majority of wasted infrared energy into the frequencies of visible light[16]. No prototypes were available on the market in 2007.

[16] Sandia (2002): 'A cool tungsten light bulb may be possible 'Tungsten photonic lattice changes heat to light', press release Sandia National Laboratories, May 2002

6.3.3 Mercury free dielectric barrier discharge lamps

DBD or Dielectric Barrier Discharge lamps are mercury free discharge lamps.
These are lamps with an electrical plasma discharge between two electrodes separated by an insulating dielectric barrier. A frequent used filling gas is Xenon and no mercury is needed. A special high voltage inverter is needed. There is no loss of electrode material and lamps can be constructed with high service life. The plasma discharge produces UV radiation that is converted in visible light similar to other fluorescent lamps. The technology is also used in plasma displays. One flat panel lamp is on the market (, the efficacy is about 35 lm/W. Also new lamp constructions are investigated for general illumination (e.g. EP1596420 in 2005).

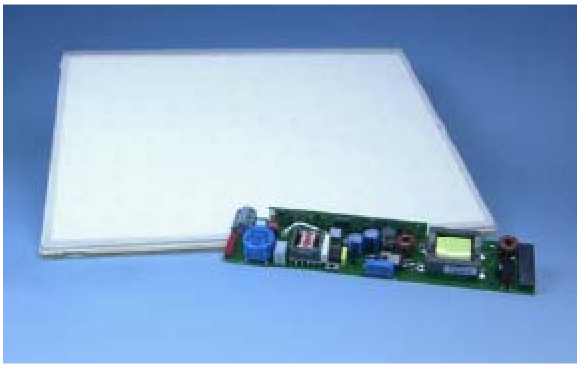

Figure 6.7: Planon (R) DBD lamp

6.3.4 Theoretical maximum lamp efficacy

It is important to note that the lamp efficacy has a physical upper limit, this is when all light is converted into visible electromagnetic radiation.
This maximum lamp efficacy is related to the colour due to the definition of lumen and the relative spectral sensivity of the human eye that was taken into account.
The maximum lamp efficacy for a perfect cool white light source is 348 lm/W and the absolute maximum for monochromatic yellow-green light (555 nm) sources is 683 lm/W (IESNA (1993), p. 204).

7 IMPROVEMENT POTENTIAL

For more info see website www.eup4light.net.

8 SCENARIO- POLICY- IMPACT- AND SENSITIVITY ANALYSIS

For more info see website www.eup4light.net.