Mass Flows of Selected Target Materials in LED Products

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Project Introduction – Cycling Resources Embedded in Systems Containing Light-emitting Diodes (CycLED)

Objective

Optimise the flows of resources over all life-cycle phases of LED products

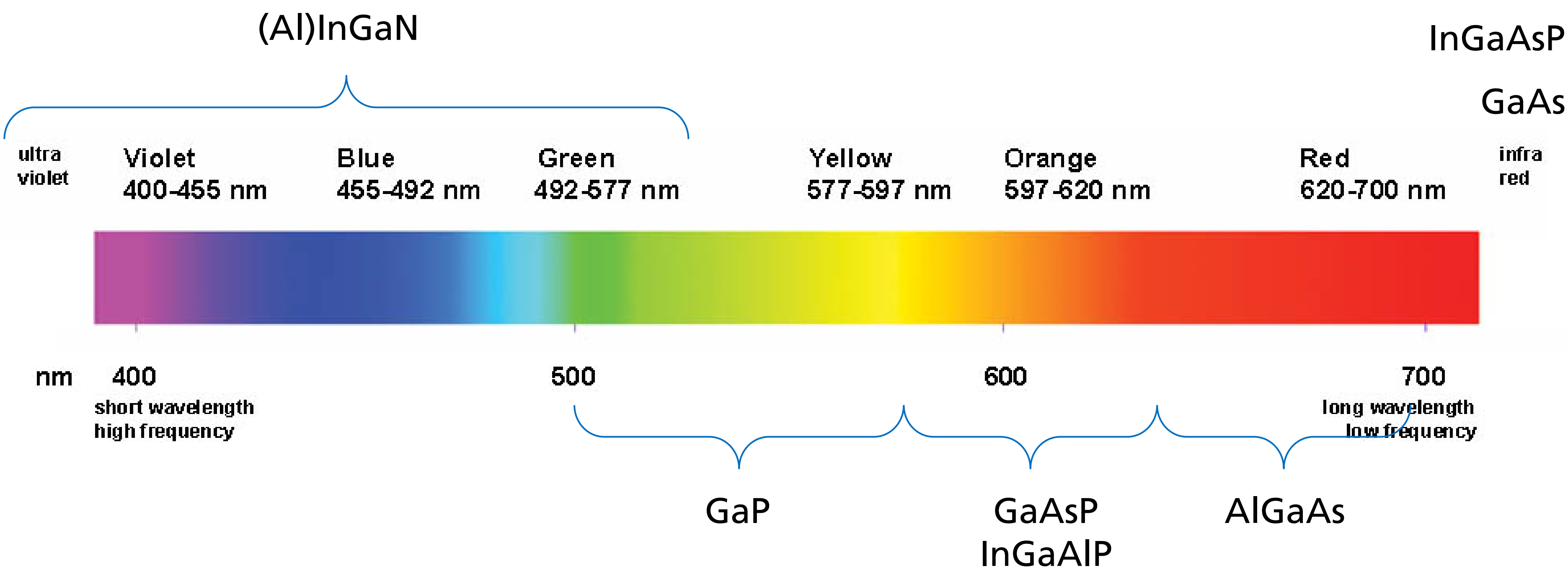
Key research topics

- Increased recycling of scarce target metals in LED production
- Optimised reliability and life time of LED products
- Reduce resource losses in production, use and recycling
- Solutions for eco-innovation

Step 1

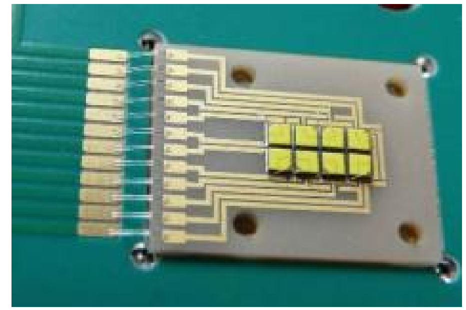
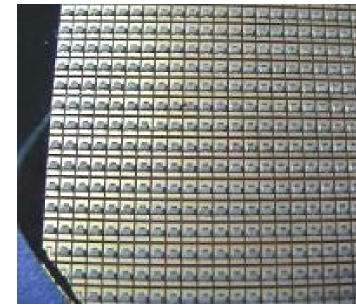
Material Flow Analysis of target materials to identify *hot spots* of resource loss

Resources: LED die



III	Al	Ga	In
V	N	P	As

Resources: LED Packages

Premould	Lead frame	Chip on board	Wafer level
			

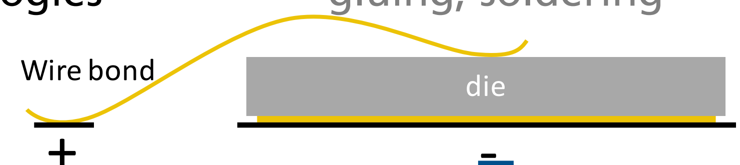
Copper

Copper, aluminium, ceramic (AlN and Al_2O_3)

Si

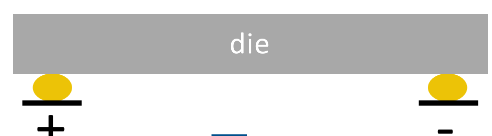
Interconnection technologies

Die and wire bonding gluing, soldering



Au, Sn, Ag

thermo compression (flip chip)



Au

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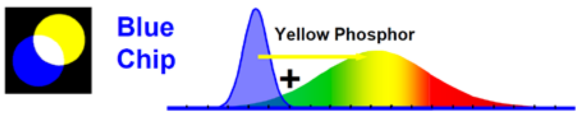
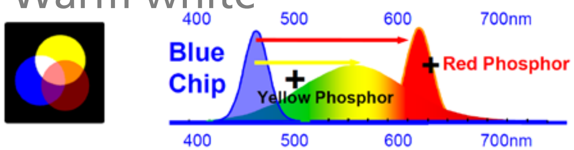
Resources: Phosphor

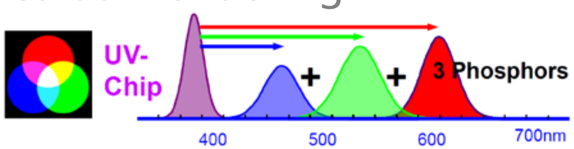
Cold white



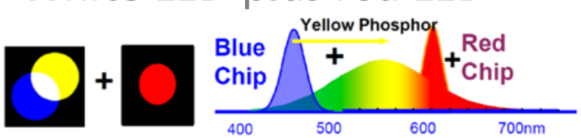
Warm white



Green phosphor: Improvement of colour rendering



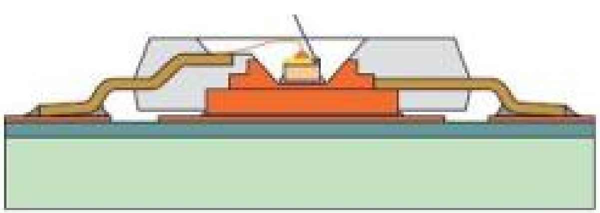
White LED plus red LED



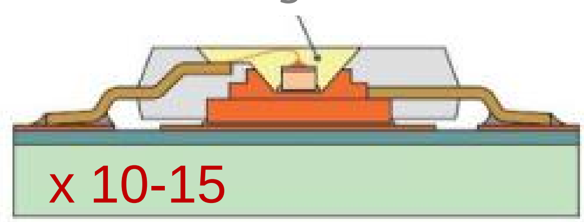
Family	Compound
Garnet	YAG:Ce ($Y_3Al_5O_{12}$:Ce)
	TAG:Ce ($Tb_3Al_5O_{12}$:Ce)
	LuAG
Ortho-silicate	Eu-doped Silicate $(Ca,Sr,Ba)_2SiO_4$:Eu more Ca =>orange more Sr =>yellow more Ba =>green more Eu =>red less Eu =>green

Ce, Er, Y, Tb, Lu

Die level



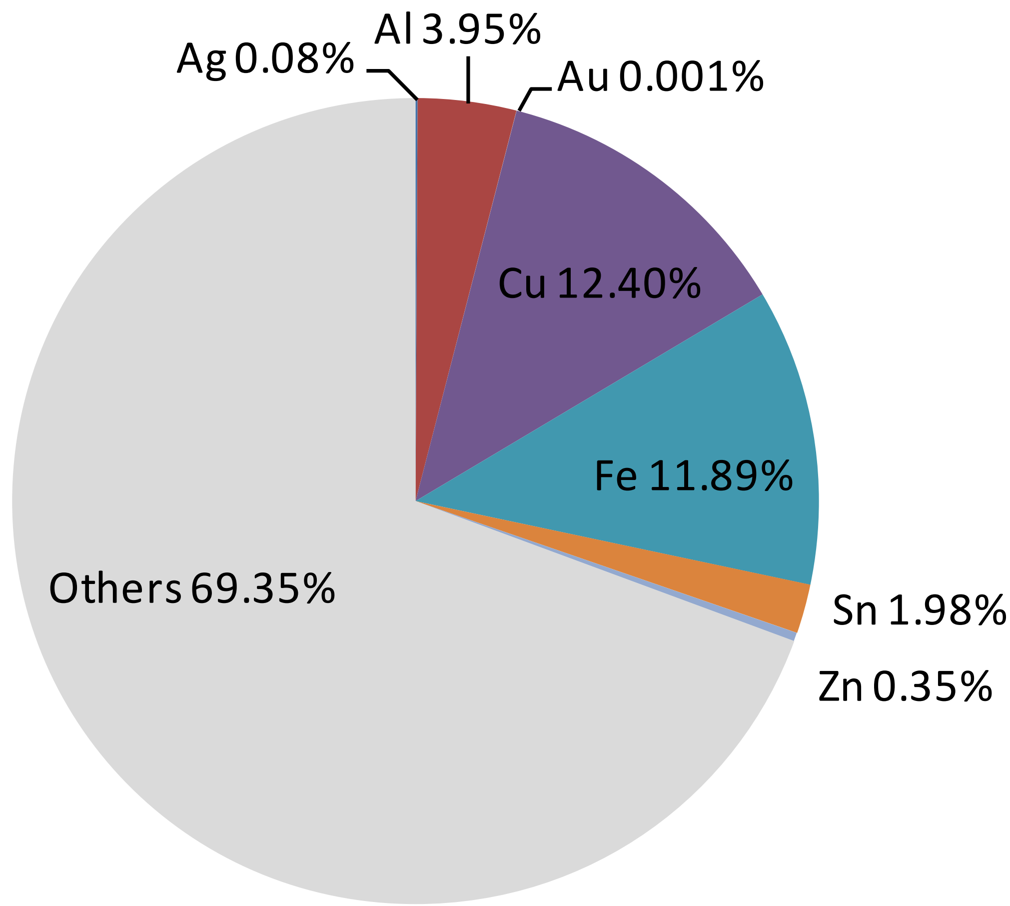
Package level



Lamp level

x 8000

Resources: LED Driver



Own calculations based on dismantling of Toshiba E-Core LED Lamp LEL-AW6L-E27-2/EU (250lm, 5.5W)

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Criticality & economic importance of metals contained in LEDs

	Precious metals		**PGMs**		**RE**												
	Au	Ag	Pt	Pd		Al	As	Be	Cu	Ga	In	Mn	Ni	Sn	Sb	Ta	Zn
Contained in LED	blue	blue			blue	blue	blue		blue	blue	blue			blue			
Criticality	yellow	yellow	red	red	red	green	red	yellow	green	yellow	red	yellow	yellow	red	red	yellow	yellow
Economic importance	red	red	yellow	green	yellow	red	green	green	red	green	green	yellow	yellow	red	green	green	green

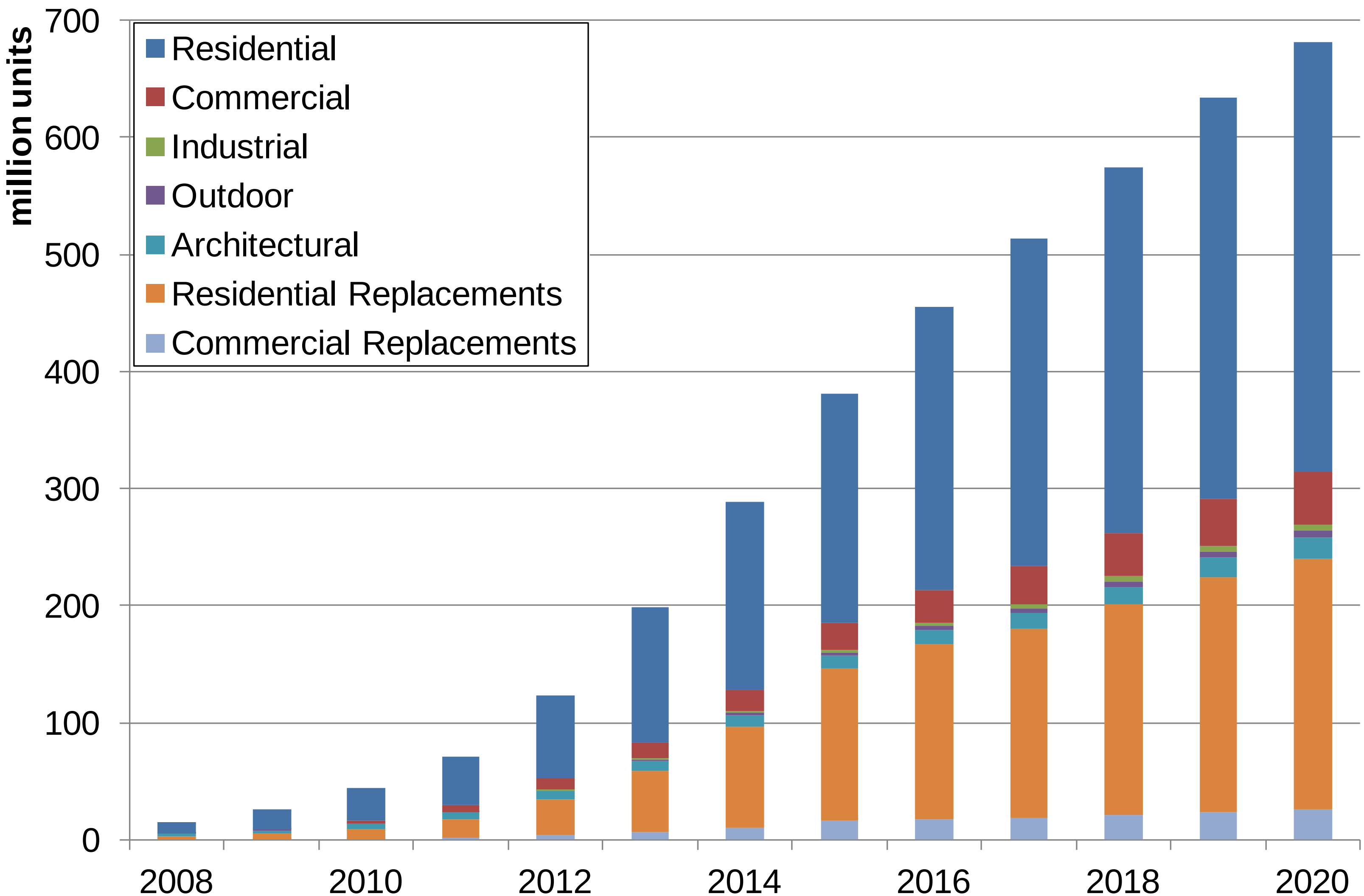
Target metals

- **Rare earth elements** (RE): highly critical, economically important
  Phosphors: Yttrium, Cerium, Terbium, Europium, Lutetium
- **Indium**: highly critical
  LED dies, Indium-Tin-Oxide in LCDs
- **Gallium**: critical & strong demand growth expected
  LED dies, integrated circuits
- **Tin**: highly critical and of high economic importance for the electronic industry
  Interconnection
- **Gold** and **Silver**: critical and of high economic importance for the electronic industry
  Interconnection

Material Flow Analysis: Example Gallium

- Shipments in units of LED products
  - LED lighting products
  - LCDs (LED backlighting units)
- Die area per LED product
- Gallium content per square millimetre die area
  - ➔ Gallium bound in LED products put on European market
- Lifetime of LED products
  - ➔ Gallium bound in LED products at their end of life

Shipments of LED lighting products in Europe



Based on data from McKinsey 2011 Max Marwede

Die area of LED luminaires

$\Phi_{LED}=\Phi_{prod}/(\eta_{opt}\cdot\eta_{th}\cdot d)=(E*A)/(\eta_{opt}\cdot\eta_{th}\cdot d)$

Luminous flux Φ [lm]

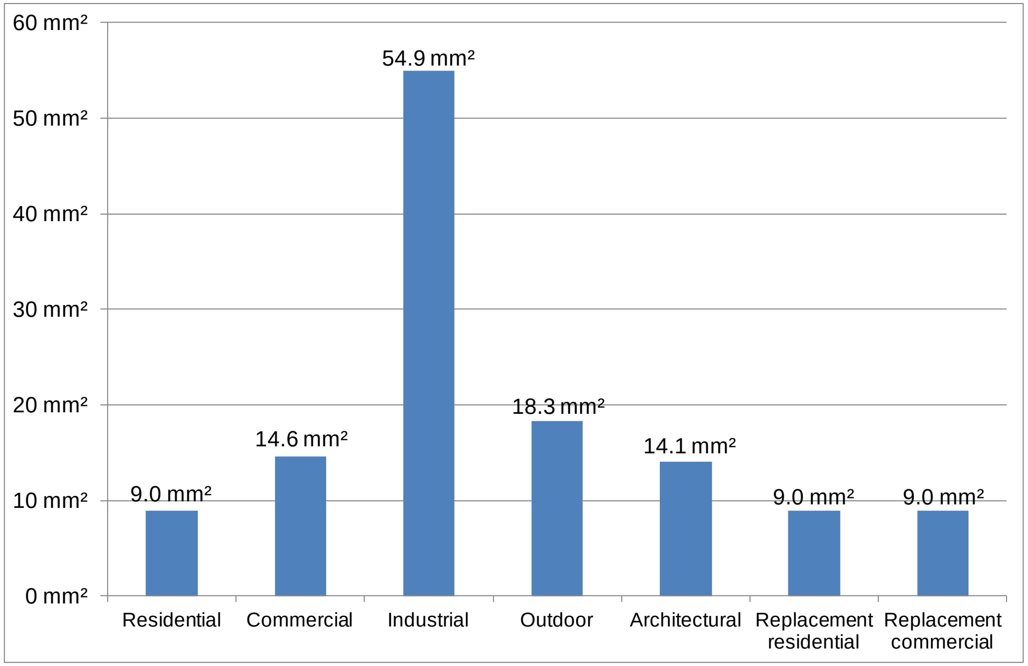
Illuminance E [lm/m²]

Visual task area A [m²]

Optical efficiency η_{opt}

Thermal efficiency η_{th}

Degradation d of luminous flux Φ_{LED} after 50.000 hours



Note! Residential luminaire and replacement lamps equal luminous flux of 60 W incandescent lamp (700 lm)

<u>Die Area</u>

$A=\Phi_{LED}/\varphi*\pi$

luminous efficacy φ: 100 lm/W
power density π: 1 W/mm²

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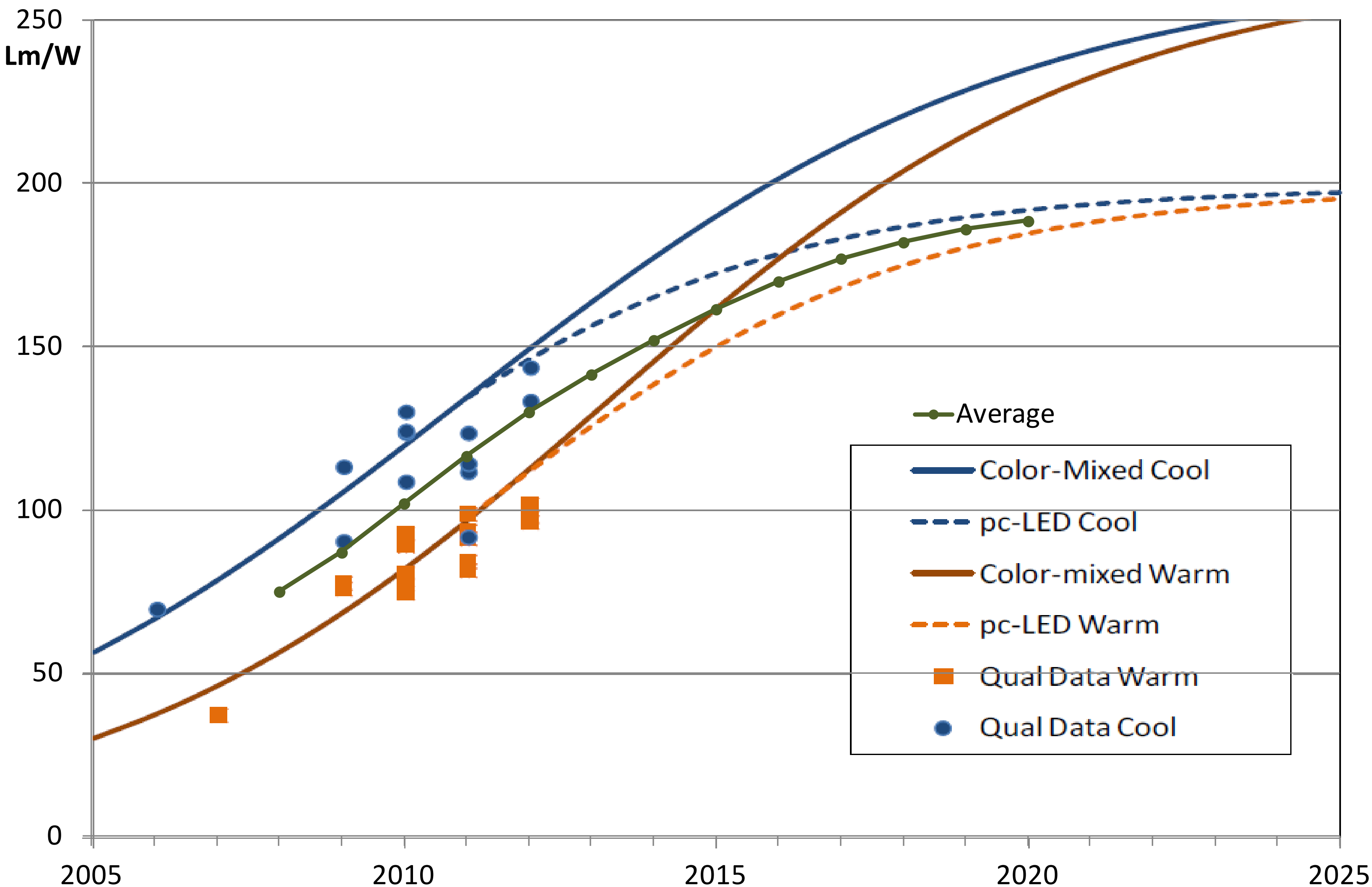
Efficacy Increase



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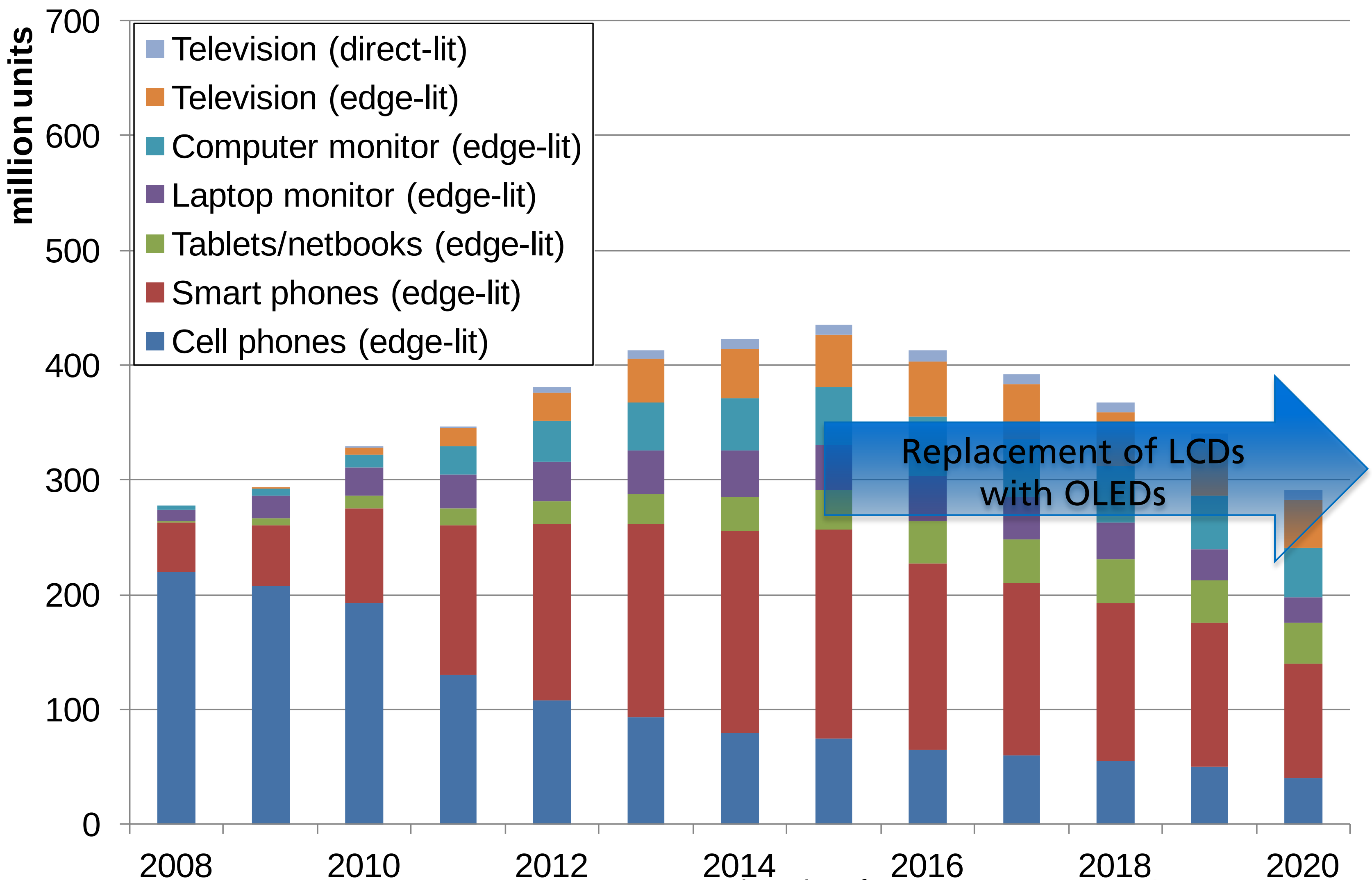
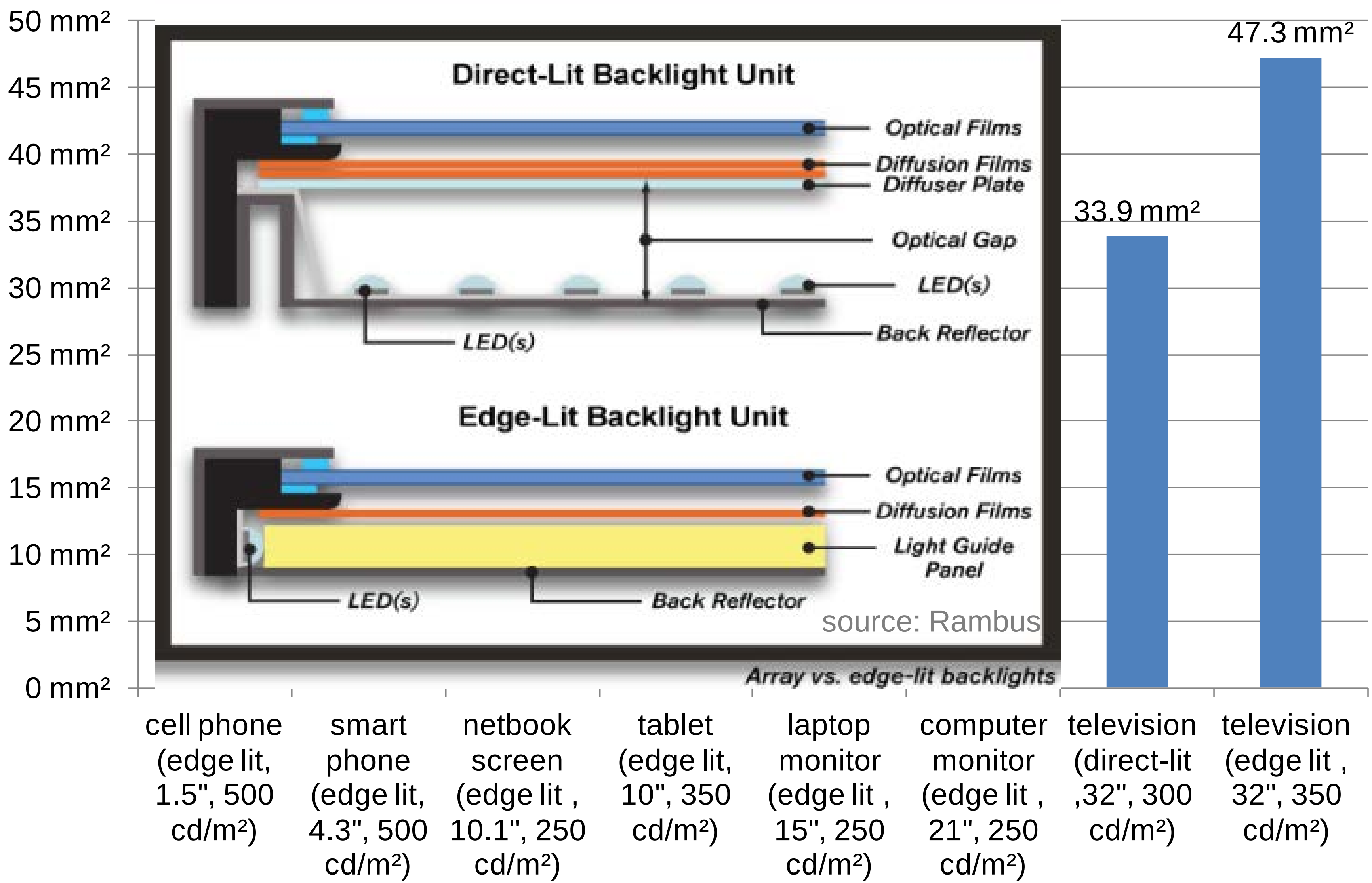
Shipments in Europe of LCDs (Backlight units)

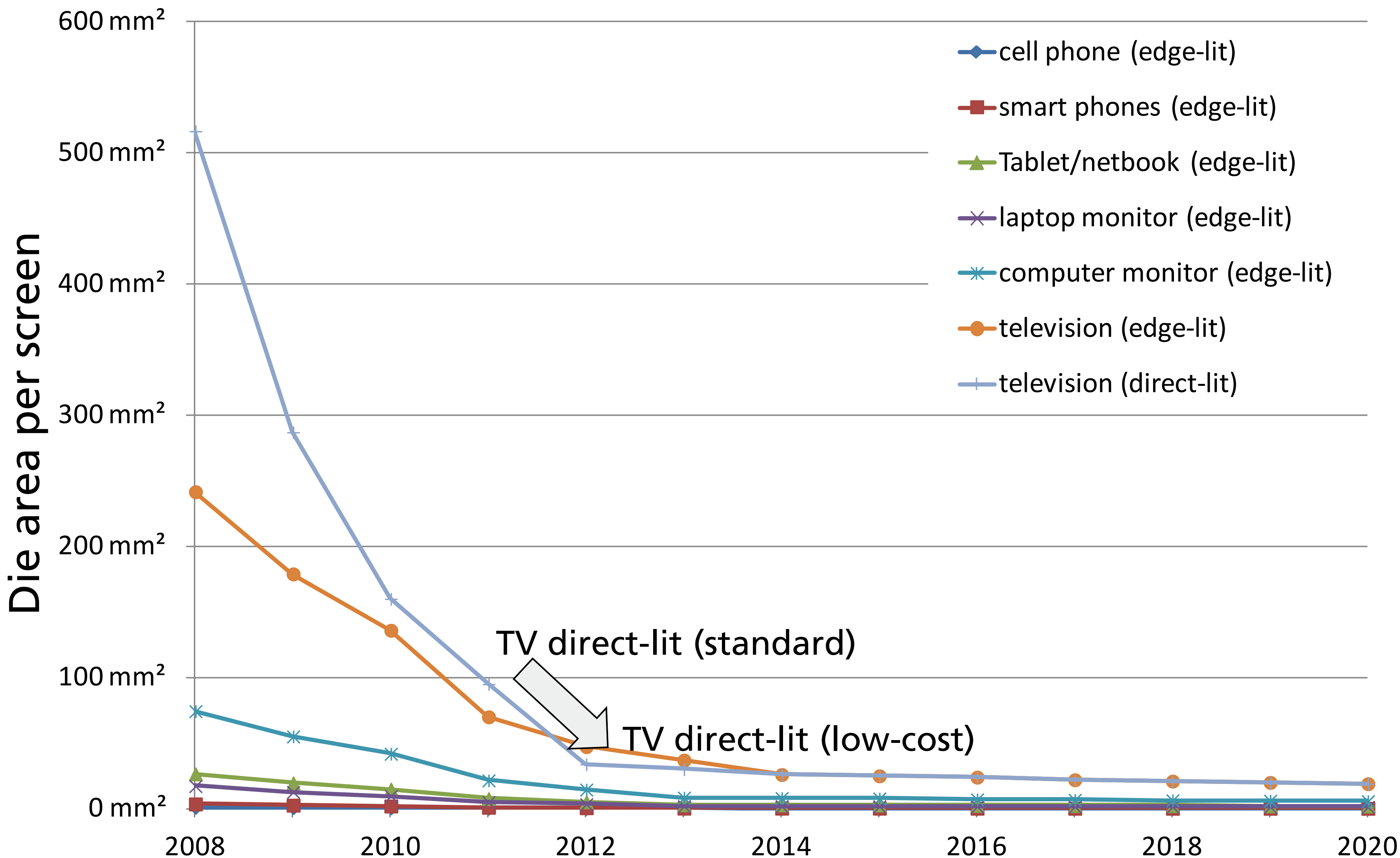


Based on data from Gartner 2012; McKinsey 2011 Max Marwede

Die area in back lighting units



Improvement of LED efficacy and optics



Based on EPIC 2012

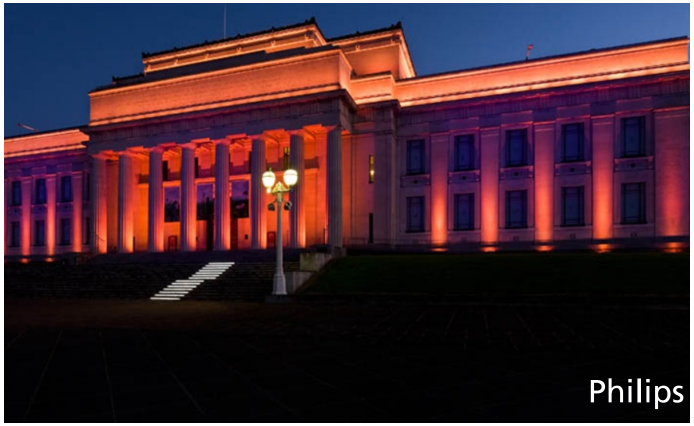
Gallium content

Technology	Elements	Thickness	Mass percentage	Density	µg per 1 mm² die
GaAs (bulk)	Ga	100 µm	50	5.904	295
InGaN (thin-film)	Ga	5 µm	25	5.904	7

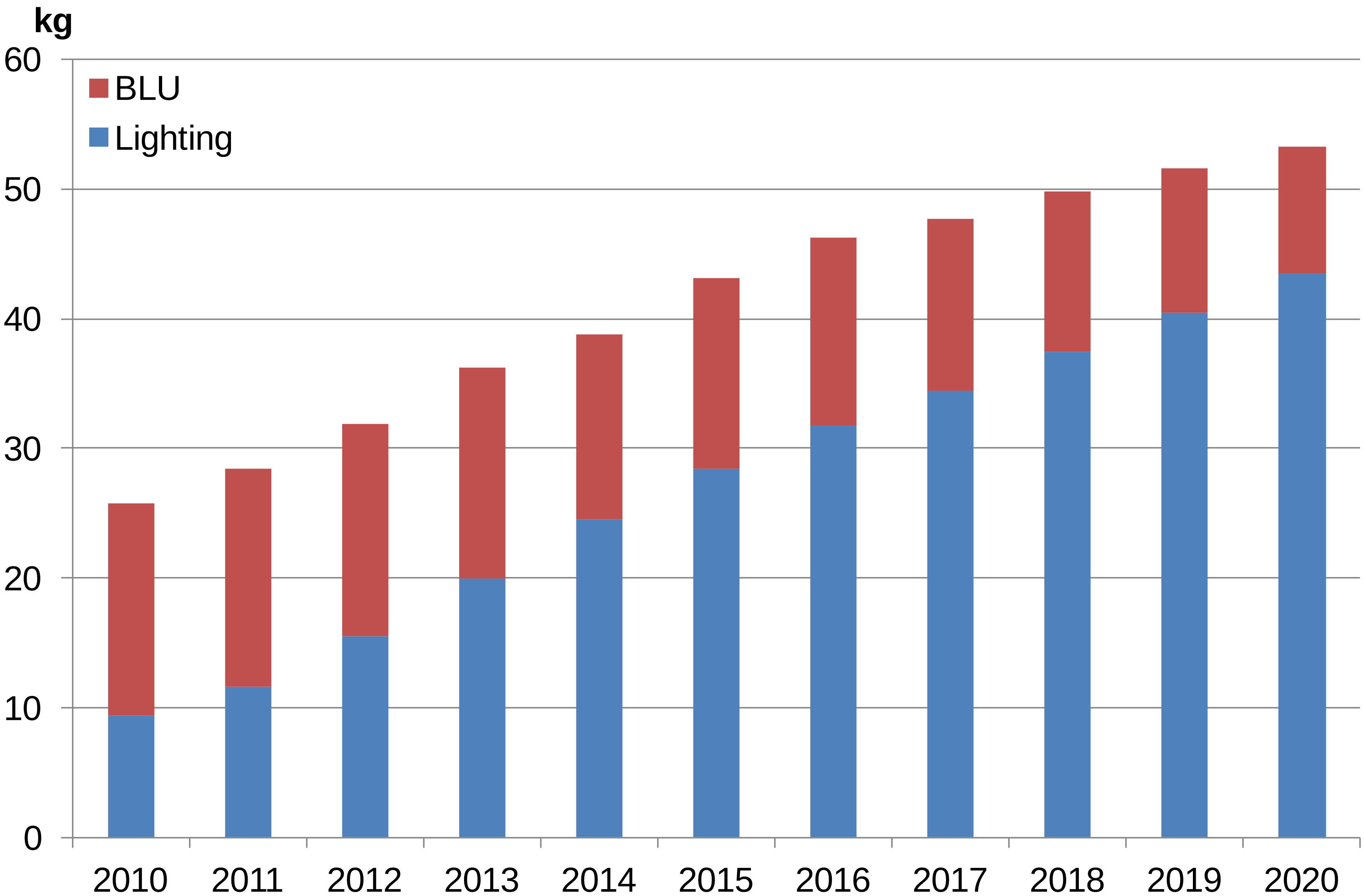
x40

<u>Assumptions</u>

- Architectural Lighting: RGB 2 InGaN LEDs & 1 GaAs
- Commercial Lighting: 10% market share RGB, 90% white
- Residential, Industrial, Outdoor: white LEDs (InGaN)
- Displays: white LEDs (InGaN)



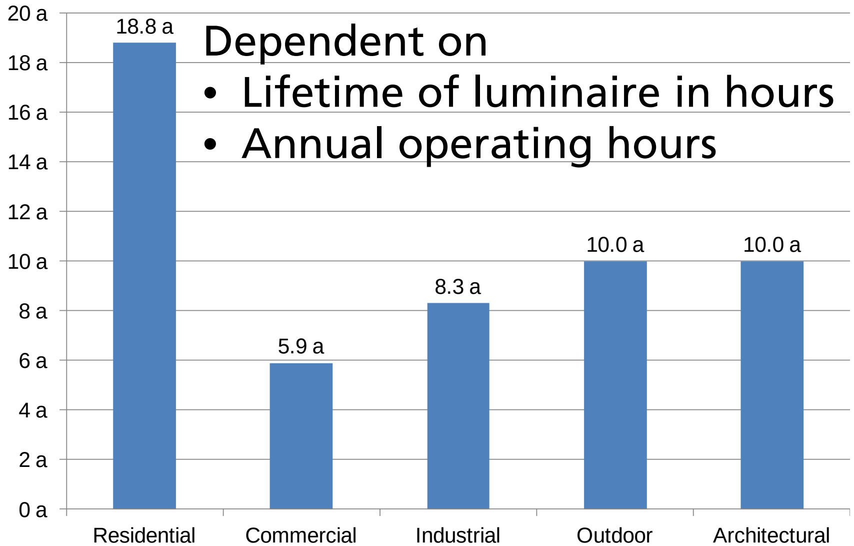
Gallium put on market



Average lifetime of LED products

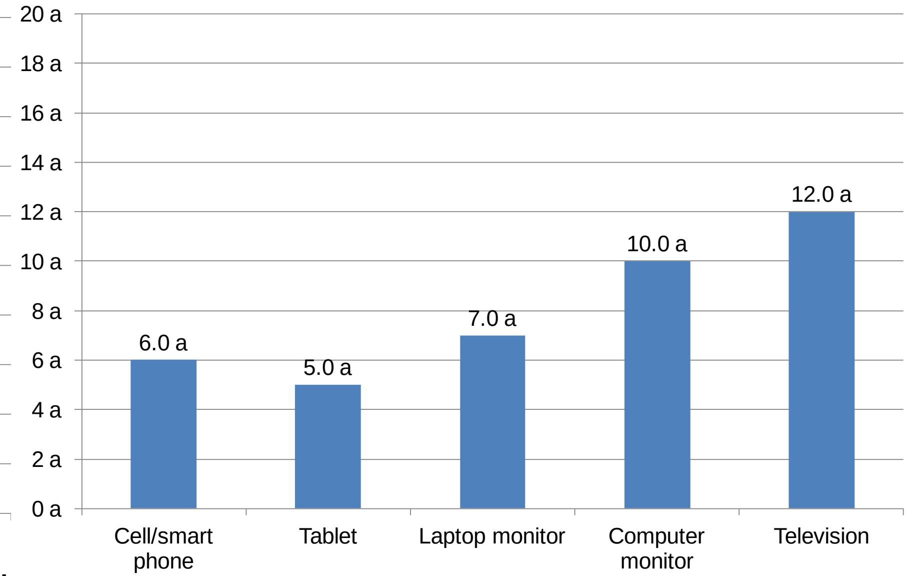
LED Luminaires

Dependent on
- Lifetime of luminaire in hours
- Annual operating hours



CIE 097-2005; EN 15193:2007-09; EN 12665; EN 60598-2-3; Van Tichelen, 2009

Displays



Chancerel 2010

End of Life Flow: $$F^{EoL}(a) = \sum_{t=o}^{a} p_t \bullet F^{in}(a-t)$$

with p_t probability, that a product is discarded after t years $$p_t = \int_t^{t+1} f(\tau)d\tau$$

and normal distribution f(t): standard deviation equals 30% of average lifetime

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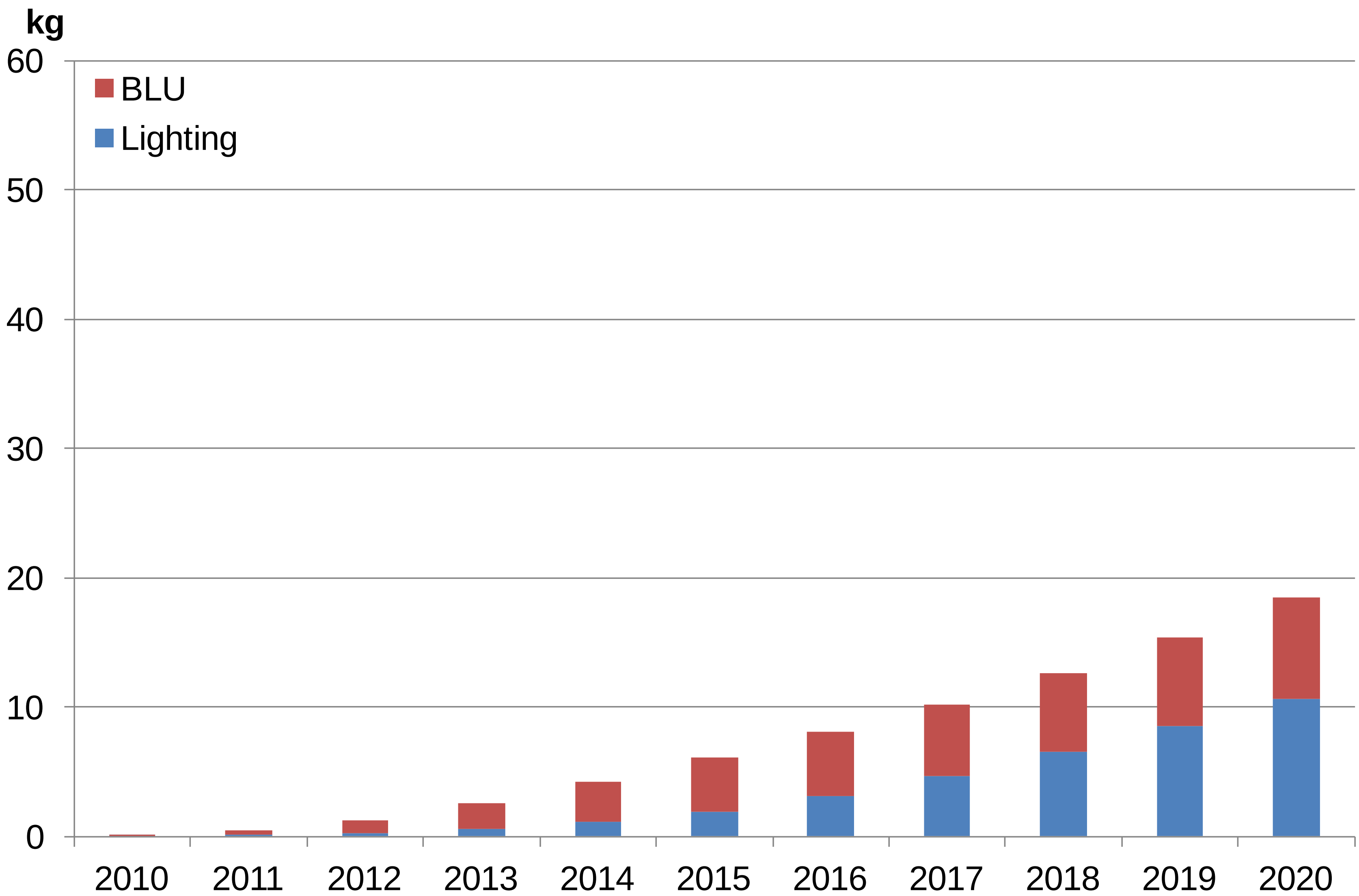
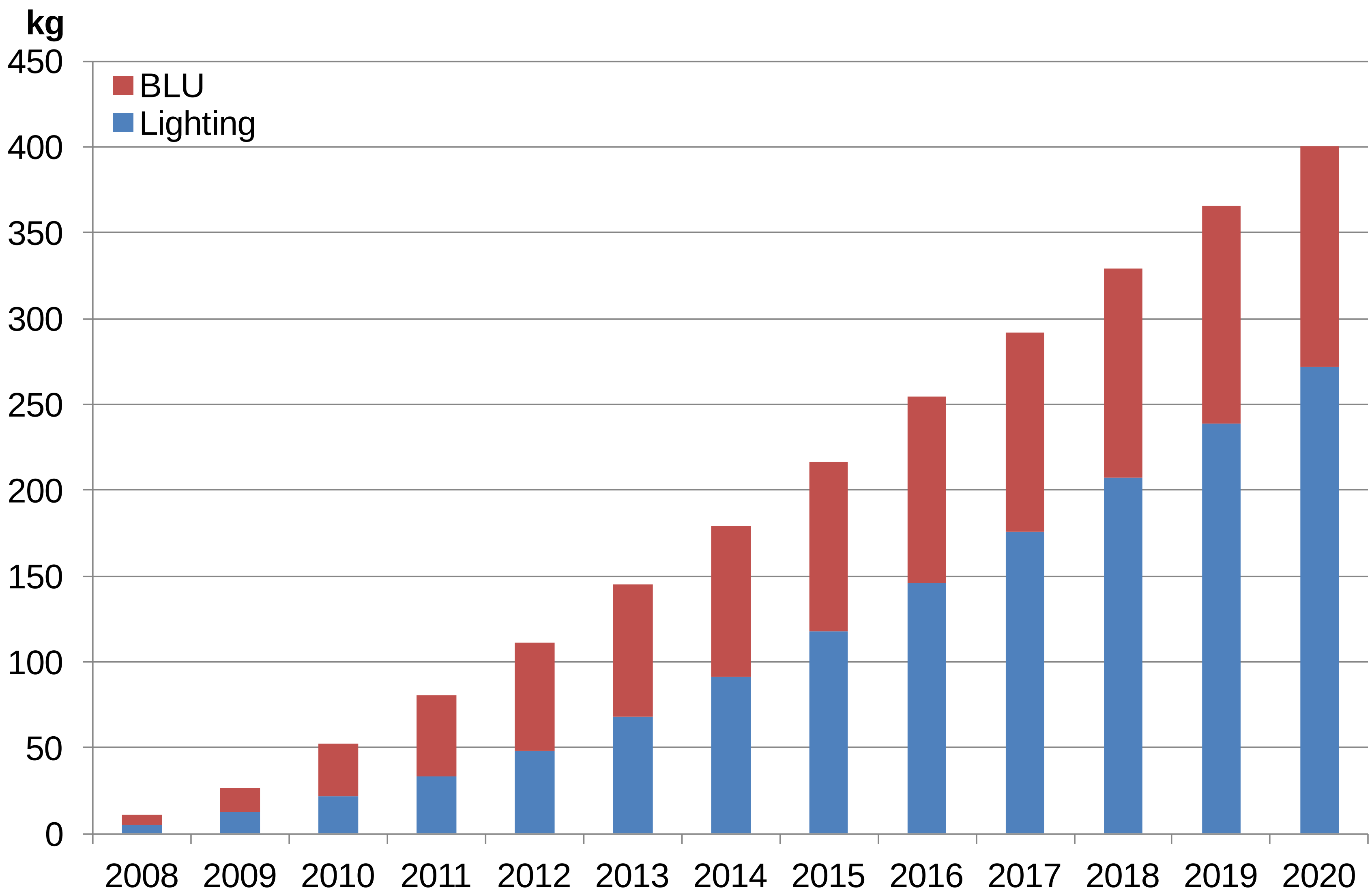
Gallium in end of life products



Gallium in stock



Conclusions

- Long lifetime of LEDs delays end of life waste flows
- Low Gallium content and diffusion of products complicate collection and recycling
- Pre-treatment (separation of LEDs from product) probably necessary
- Better focus on other materials with higher specific material content during recycling

Outlook

- Modelling material flows along the life cycle
  - manufacturing
  - collection, pre-treatment and recycling
- for all target metals
  - Ga, Sn, Ag, rare earths
- Uncertainty and sensitivity analysis

Thank you for your attention!

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Involved SMEs

www.cyc-LED.eu

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