



Five sources in one exposure, one basis for every comparison.

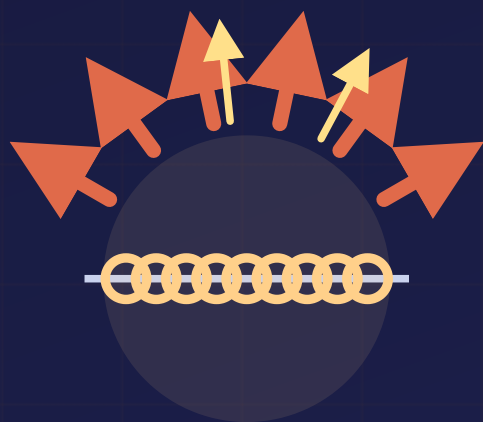
NLC Academy | Episode 17

Everything before LED. And what it still does better.

Four families of lamp ran the world before LED: incandescent, halogen, fluorescent, and the high-intensity discharge family. Each made light a different way. This episode is how each one worked, what actually ended it, and the handful of jobs LED has not taken.

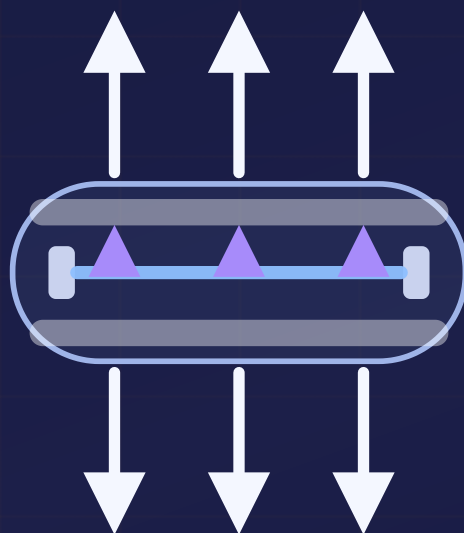
The spine

Three ways to make light, and **only one is new.**



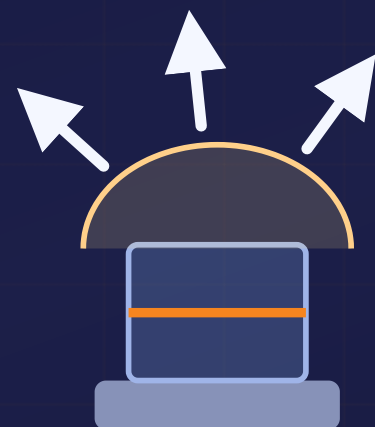
Incandescence

Heat a wire until it glows. Temperature alone fixes the spectrum, so most of the power leaves as infrared. [24]



Gas discharge

Strike an arc through vapour. In a fluorescent lamp the strongest line is invisible, so a phosphor converts it. [15]



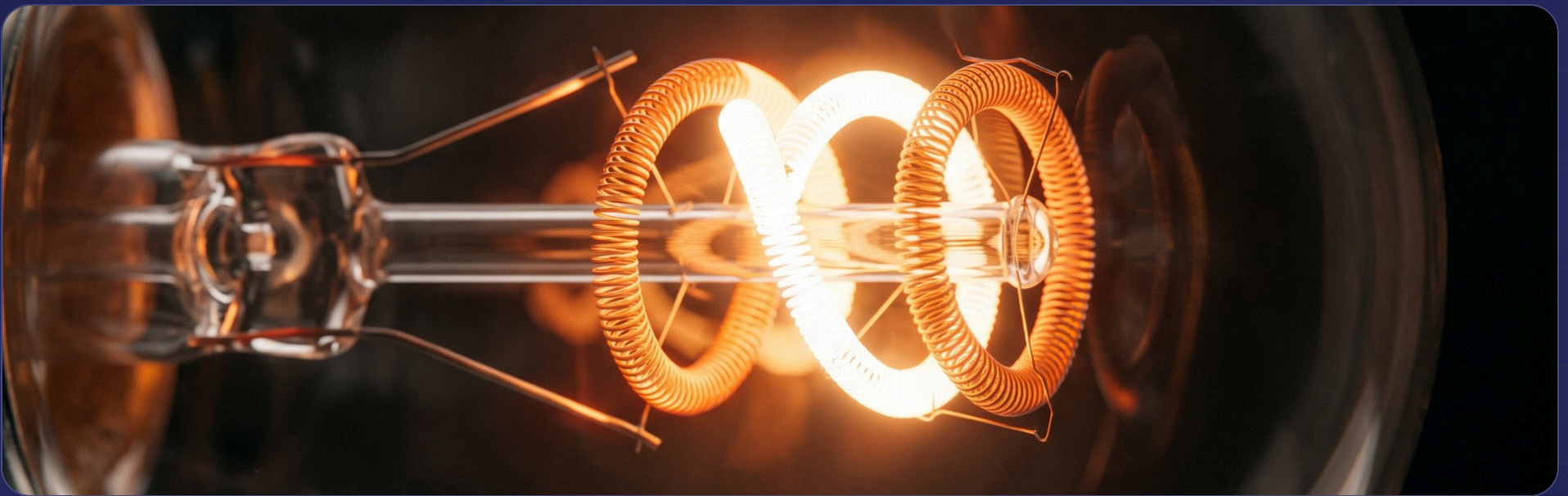
Electroluminescence

Drive current across a semiconductor junction. Photons come out of the recombination itself, so the material sets the spectrum, not a temperature.

Incandescence relies on heat, a discharge excites atoms, an LED makes photons in a semiconductor. **Their spectra and conversion losses set the efficacy.**

The heat tax

A filament is a heater that happens to glow.



A coiled-coil tungsten filament: a helix wound into a second helix, packing length into a small hot volume.

- 1** Tungsten melts at 3422°C (3695 K), but evaporation caps it first: an ordinary filament runs near $2800\text{--}2900\text{ K}$, some 800 K under the melt. Halogen runs hotter, $3000\text{--}3500\text{ K}$, because its cycle returns evaporated tungsten. [24][32]
- 2** Only a tenth of the **radiated** power is visible, and on an **input** basis worse: a halogen lamp sends about 86% to infrared against 7% to light. [25][26]

A tungsten bar at its melting point is quoted at **52 lm/W** : a bare-emitter ceiling, not a system one. The same paper expected infrared-reflective coatings to pass it. [24]

How it gets there

A filament is a resistor. The light is a side effect.

- 1 Joule heating: current through the filament's own resistance dissipates I^2R as heat. The temperature climbs until the power radiated away equals the power going in, and settles there. [24]
- 2 On 230 V that costs very little current. A 60 W lamp draws 0.261 A through 882 Ω hot; 40 W draws 0.174 A and 100 W draws 0.435 A. A filament is pure resistance, so the power factor is 1.
- 3 Cold, that same filament is only about 61 Ω . Tungsten's resistance climbs roughly 14 to 16 times between room temperature and working temperature, so the first instant after switch-on pulls near 3.8 A, not 0.26 A. [24]

Currents are P/V at 230 V, unity power factor. The resistance ratio is measured, 14.4x on a 120 V lamp, and carries over because resistivity is a property of the metal; no 230 V measurement of cold resistance was found. [24]

Which is why a filament lamp almost always fails **at the instant you switch it on**, not while it is running. [24]

The mercury generation

The arc makes ultraviolet. The coating makes the light.



- 1 A low-pressure mercury arc converts about two-thirds of the input power into invisible ultraviolet, mostly the 253.7 nm mercury line. It never leaves the lamp. [15]
- 2 The phosphor re-emits it as visible light, and physics takes a cut: a 253.7 nm photon carries far more energy than the visible one it becomes, capping down-conversion near 45%. [15]
- 3 Which phosphor decides everything. Halophosphate gives Ra 51-72; triphosphor on the same 36 W tube gives more light AND better colour, Ra 82-85. [12]

The flat green-white is the shape of what the coating emits. How green it photographs depends on the tube and the camera's white balance.

Mercury per lamp fell fourfold inside one maker's T8 range, **8.0 mg to 2.0 mg**, and that still did not save it. [5]

The HID family

The discharge happens in **one small tube.**



In a clear lamp the outer bulb only protects and filters. In a phosphor-coated one it also makes light: the coating converts arc ultraviolet into visible red, lifting a 400 W mercury lamp from Ra 22 to Ra 43. [3]

Mercury vapour

The oldest, and the weakest on efficacy, 50-55 lm/W. [3]

Metal halide

Salts in the arc fill the spectrum. Ceramic tubes reach Ra 90-92. [6]

High-pressure sodium

The orange one that lit every street. 91-137 lm/W by wattage. [8]

Low-pressure sodium

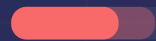
Not an HID lamp at all, and still the most efficacious here. [9][30]

Low-pressure sodium is the odd one out twice over: **not HID, and still the most efficacious lamp here.**

The ladder

Eight sources, **one honest scale.**

Incandescent, 40-100 W Ra 100 2700-2840 K 12.3-16.5 lm/W



Halogen, mains and capsule Ra 100 2700-3000 K 9-21 lm/W



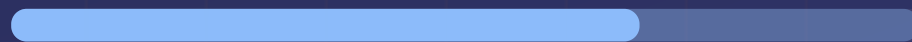
Mercury vapour Ra 39-50 3800-4200 K 50-55 lm/W



Compact fluorescent, pin-based Ra 82-85 4000 K 67 lm/W



Linear fluorescent, T12 to T5 Ra 51-85 2700-6500 K 72-104 lm/W



Metal halide, quartz/ceramic Ra 58-92 3000-4300 K 83-112 lm/W



High-pressure sodium Ra 25 2000 K 91-137 lm/W



Low-pressure sodium Ra -44 1800 K 176 lm/W



Off the ladder: a qualification floor, not a measured lamp; DLC counts the driver [7]

LED replacement lamp, T8 Ra ≥ 80 1800-6500 K 130 lm/W

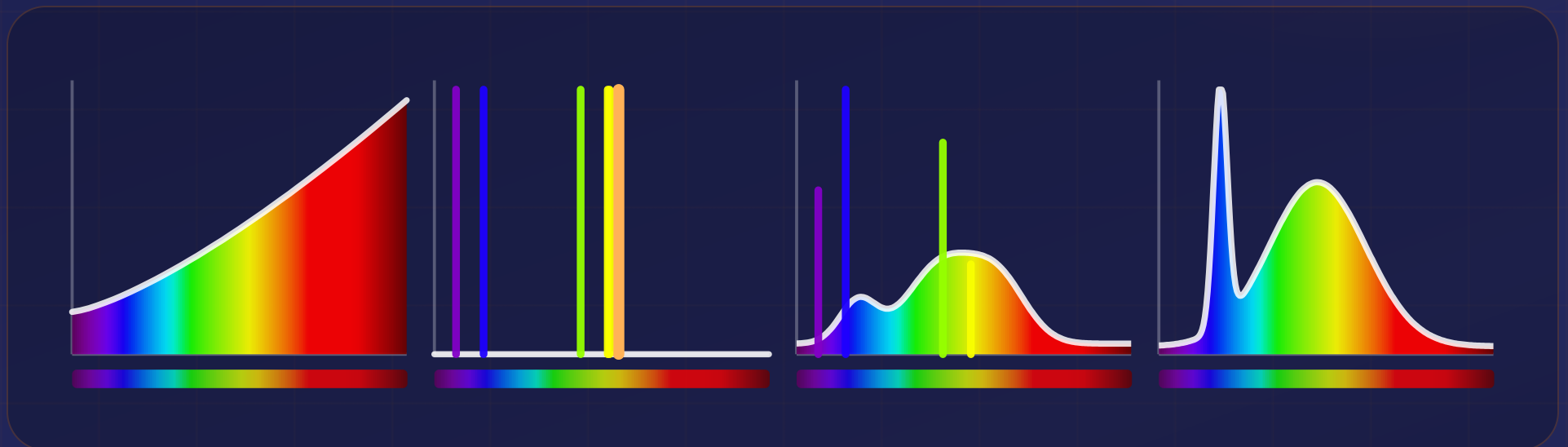


Bare lamp, one basis: lumens over lamp watts, 100 h, 25 °C. Ra per CIE 13.3, CCT per datasheet. Bar length spans the family range. [11]

Read it twice. **The two most efficacious lamps here are the two worst at colour:** high-pressure sodium at Ra 25, low-pressure sodium at Ra -44.

Colour

Four spectrum shapes, and colour follows the shape.



Wavelength (nm), violet to red

380 → 760 nm

Continuous

Incandescent and halogen. Smooth, gapless, no lines.

[11]

Discrete lines

Low-pressure sodium and clear mercury. A low-pressure sodium curve sits at zero between its lines; high-pressure sodium does not.

[9]

Fluorescent

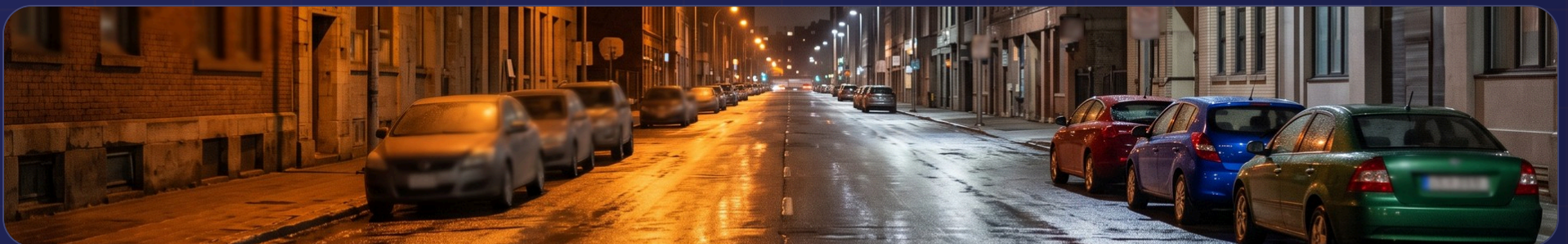
A phosphor continuum with mercury lines on it. The 254 nm line driving it is off the left edge.

[12]

White LED

A blue pump near 450 nm and one broad phosphor band. No mercury lines.

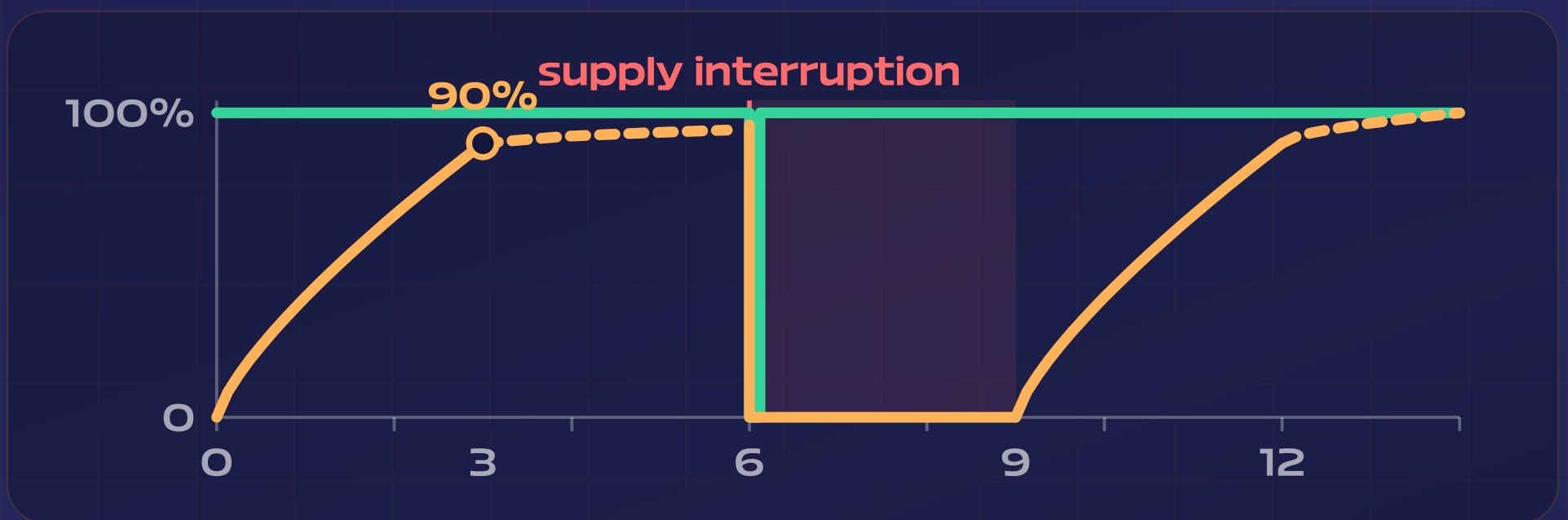
[7]



Line positions above are measured wavelengths; heights are schematic.

The wait

Minutes to start, minutes more to restart.



↑ % of stabilised bare-lamp output

Time (minutes) →

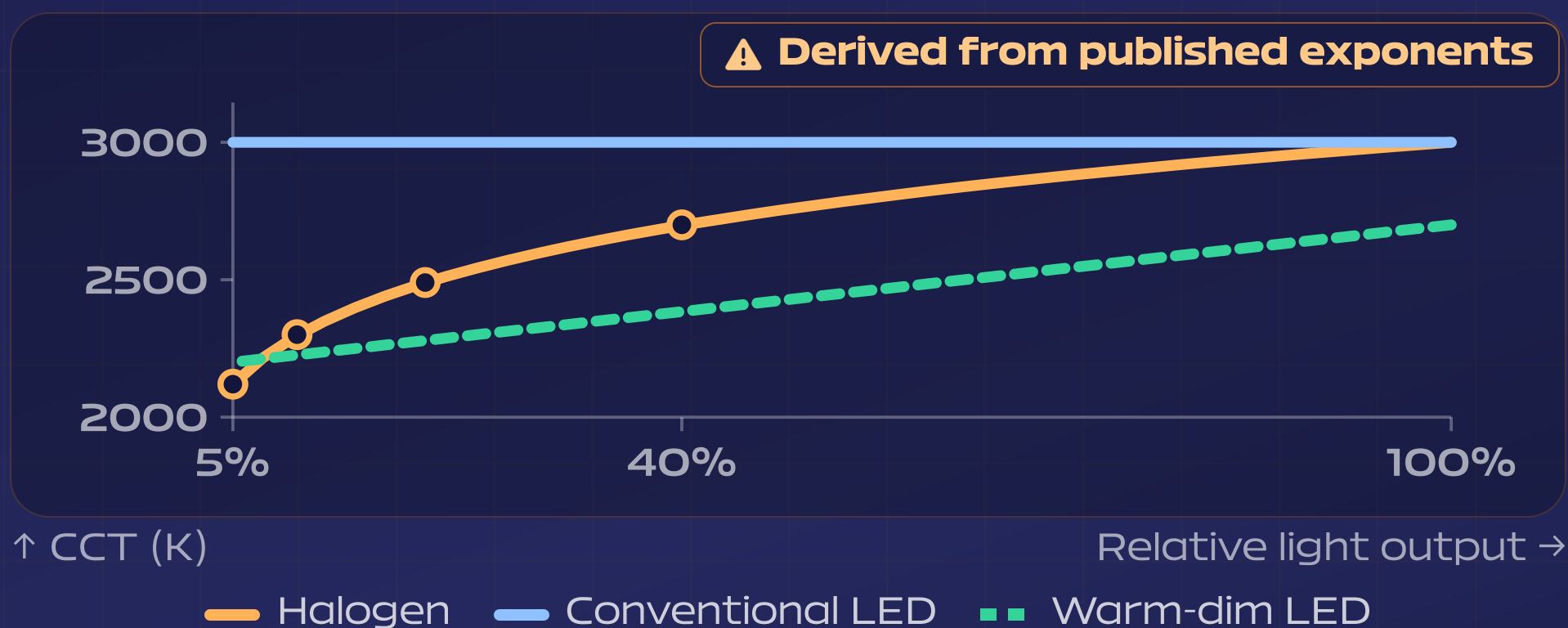
— Metal halide, pulse-start — LED

- 1 A protected pulse-start metal halide lamp takes about 3 minutes to reach 90% brightness, and after a brief supply interruption it will not restrike hot for another 2-4 minutes. [13]
- 2 A standard switch-start lamp is slower in both directions, about 15 minutes to restrike, and a 1500 W stadium lamp needs 10-15 minutes. Fluorescent is not instant either: a linear tube takes 2-3 minutes to settle. [14] [15]

HID works in minutes, not milliseconds. **LED has neither delay:** it lights instantly and recovers immediately after a power dip.

The one thing halogen still does

Dim a filament and the colour follows it down.



- 1 Dimming cools the filament, so its colour temperature falls with it. The lamp maker publishes the exponents: light output follows $(V/V_0)^{3.19}$ and colour temperature $(V/V_0)^{0.37}$, which puts a 3000 K halogen near 2300 K at a tenth of its output. [16]
- 2 A conventional LED holds its colour temperature all the way down. A warm-dim LED is engineered to fall, typically 2700 K to 2200 K, to imitate exactly this curve. [17]

The halogen curve above is not illustrative: it is **computed from the published exponents** and lands within 3 K of the same datasheet's dimming table.

Mercury and the law

What the treaty actually says, and about whom.

Saudi Arabia acceded

Not signature, not ratification: the Kingdom **acceded** on 27 February 2019, in force from 28 May 2019. [18]

And it is bound by the amendments

Saudi Arabia lodged no Article 30(5) declaration, so Annex amendments bind it automatically. The COP-4 Annex A amendments took effect 28 September 2023, the COP-5 amendments 25 April 2025. [18]

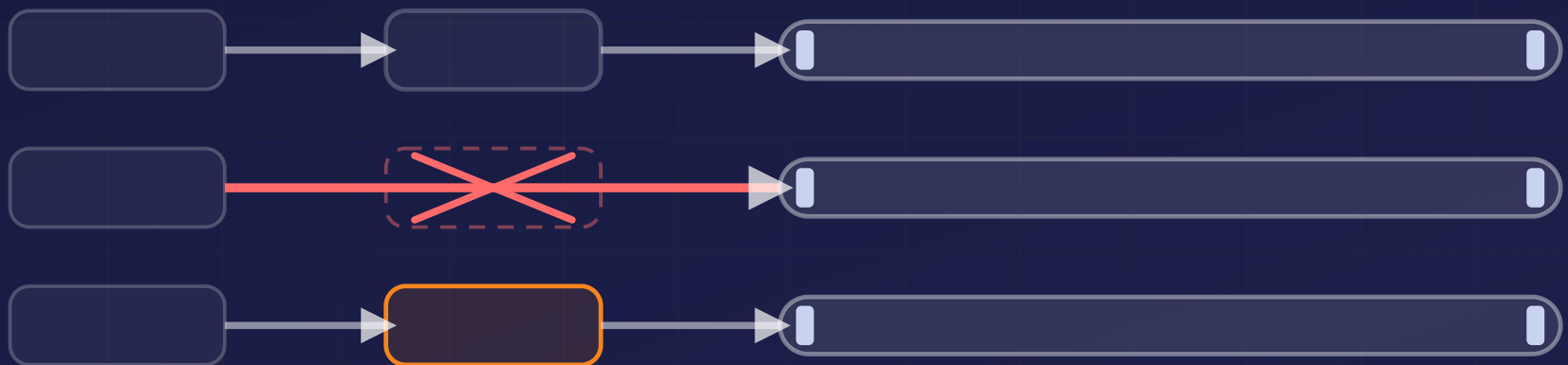
 It restricts **manufacture, import and export** of listed products, not use, subject to an **exclusion** in Annex A or a **registered exemption** under Article 6. Different things. Lamp dates: 2020, 2025, 2026, 2027, never 2021. [18]

 Locally: SASO's General Technical Regulation for Energy Efficiency, Annex 1, SASO 2870, 2902, 2927. [19]

One HID family is in Annex A: **high-pressure mercury vapour, 2020**. Metal halide and sodium lost on economics, not law. [18]

The retrofit trap

One tube, three completely different jobs.



Type A

Direct replacement on a compatible electronic ballast. Least installation work, but compatibility and conversion losses remain. [27]

Type B

Ballast bypass; mains to the lampholders. Needs electrical modification, correct wiring and a permanent retrofit label. GSA's 2024 P100 barred it; that standard was rescinded in 2025, so check your own specification. [27]

Type C

An external LED driver replaces the ballast. Most installation work, but a purpose-designed LED system with no ballast compatibility to solve. [27]

Whichever you pick, the label matters: **the next person to open that fitting has to know what is behind the lampholders.** [27]

Where LED has not caught up

Where old sources still persist, **or still outperform LED.**

Germicidal UV-C

A mercury germicidal tube (Signify TUV) turns about 40% of input power into UV-C. The best SHIPPING 265 nm UV-C LED publishes 6.2% wall-plug efficiency (ams OSRAM SU CULFP1.VC, 127 mW); a 7.5% part is announced but sampling only until October 2026. One 75 W tube takes roughly 220 of them. [20]

Infrared process heating

Heraeus rates its short-wave halogen emitters up to 1 MW per square metre of radiant power density, responding in about a second. That is far above the irradiance an LED array reaches in the same catalogue comparison. [21]

Metrology

NIST disseminates the spectral irradiance scale from 250 to 2400 nm on 1,000 W tungsten-halogen FEL lamps. Tungsten is the transfer standard, not the scale itself. [29]

Product and test basis named on each card.

Where they persist anyway

Still specified, for reasons other than efficacy.

Reptile UV-B

A 2024 survey of 18 UVB-LED lamps found none matched the solar UV spectrum, every one missing the 315 to 335 nm band the authors call essential to vitamin D3 synthesis. Sampled before January 2023, so newer models are not covered. [31]

Horticultural HPS

LED has passed HPS on photon efficacy: about 1.70 $\mu\text{mol/J}$ for double-ended HPS against DLC Horticultural's 2.5 $\mu\text{mol/J}$ threshold. HPS persists on installed base, not performance. [23]

Dark-sky amber

Not a filter over white LED, and not simply a low CCT. Tucson and Pima County's PROPOSED 2025 draft defines it by peak wavelength, 585 to 605 nm, and FWHM under 18 nm. Both still enforce their 2012 code. [22]

Most Annex A lamp entries are qualified "for general lighting purposes", though CCFL and EEFL lamps are listed separately for electronic displays. Specialist lamps outside those categories are out of scope rather than exempted. In the EU their mercury runs on RoHS exemptions listed to 24 February 2027, which is a review date: under Article 5(5) a renewal filed in time keeps an exemption valid until the Commission decides. [18]

From the NLC range

The LED answer to **each legacy source.**



LUXO

Replaces halogen downlights

134 lm/W

2700-5000 K

Recessed COB downlight, four CCT options.



ALLIGATOR

Replaces fluorescent battens

150 lm/W

IP66 · IK08

Weather-proof linear luminaire for wet, dusty rooms.



DIAMOND

Replaces HID high bays

170 lm/W

100-240 W

Instant strike, instant restrike and dimmable: no HID high bay was.



FALCON

Replaces sodium street lighting

199 lm/W @ 3000 K

1800-6500 K

Low CCT is not narrow-band amber: check SPD, peak and FWHM against the local code.

Quoted from each NLC product page. Luminaire figures, not slide 7's bare-lamp basis; FALCON bases its values on 3000 K.

Before you sign

Five lines that keep a retrofit honest.

- ☐ Ask for **the measurement basis** behind every efficacy figure: bare lamp, lamp plus gear, or luminaire. All three can be correct for one product. [7]
- ☐ On a fluorescent retrofit, **name the type**, A, B or C, and survey the existing ballasts first. A dimming ballast with a non-dimming lamp can damage the ballast or lamp. [27]
- ☐ Match **illuminance, distribution and glare on the task plane**, never the old lamp's lumens. A lumen-for-lumen HID swap normally over-lights. [27]
- ☐ Ask how the **rated life** was derived. LM-80 with TM-21 projects the LED *component*; a luminaire-level L70 claim should rest on LM-84 with TM-28. Neither pair projects a lifetime: both extrapolate lumen maintenance only, and an abrupt failure, usually the driver, is outside both. [28]
- ☐ For UV-C, curing, process heat or reptile lighting, **check the spectrum, not the efficacy**. [20][21]

The sources

Every number on these slides, sourced.

- [1] Philips halogen brochure, 120 V baseline
- [2] Osram halogen MR16 and IRC PDS
- [3] Osram HQL, Philips HPL-N PDS
- [4] Philips MASTER PL-C 26W PDS
- [5] Philips linear-fluorescent generation table
- [6] Philips HPI-T Plus, CDM Evolution PDS
- [7] DLC SSL Technical Requirements V6.0
- [8] Signify SON-T PIA Plus, Ceramalux PDS
- [9] Philips SOX low-pressure sodium PDS
- [10] Sylvania Octron 800 XP/SS life data
- [11] CIE 13.3-1995, colour rendering
- [12] Philips MASTER TL-D Super 80 36W/840
- [13] Philips pulse-start metal halide PDS
- [14] Musco 1500 W sports-lighting system
- [15] Signify fluorescent run-up data
- [16] Lamp-maker tungsten dimming exponents

References 1 to 16. Standards are cited in their current active revisions; lamp figures come from the manufacturer's datasheet for a named order code.

The sources

Sources, continued.

- [17] Warm-dim LED product data
- [18] UN Treaty Collection XXVII-17; Minamata
- [19] SASO Gen. Tech. Reg. for Energy Efficiency
- [20] Philips TUV PDS; ams OSRAM UV release
- [21] Heraeus infrared emitters catalogue
- [22] Tucson/Pima County lighting code, 2025
- [23] DLC Horticultural Tech. Req. V4.0
- [24] MacIsaac et al. 1999, Phys Teach 37:520
- [25] Agrawal et al. 1996, Am J Phys 64:649
- [26] Ushio halogen technical specifications
- [27] UL 1993; GSA LED guidance, 2025
- [28] ANSI/IES LM-80, TM-21, LM-84, TM-28
- [29] NIST SP 250-89, spectral irradiance
- [30] IES Lighting Definitions, HID lamp
- [31] Wunderlich et al. 2024, Zoo Biol 43(1):61
- [32] ITIA, tungsten properties (melting point)

Short forms: PDS = product datasheet, DLC = DesignLights Consortium, ITIA = International Tungsten Industry Association. Full citations with URLs and access dates are on the episode page, linked from the next slide.

PRACTICAL LIGHTING ENGINEERING

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Read the full episode article

<https://nlc.com.sa/academy/conventional-lights.html>



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