Perceptual Color Matching and White Point Selection on LG CX OLEDs: A Comprehensive Analysis of Warm 1 vs. Warm 2 and the Judd-Vos Offset

1. Introduction: The Calibration Conundrum of the LG CX

The visual fidelity of the LG CX OLED television, a landmark display in consumer electronics, sits at the center of a sophisticated debate regarding color accuracy, human perception, and the limitations of established metrological standards. At the heart of this discourse is the user's choice between the "Warm 1" and "Warm 2" color temperature presets—a decision that ostensibly offers a binary choice between "cool" and "warm" imagery but, in reality, exposes a fundamental fissure in the science of colorimetry known as metamerism failure.

While the "Warm 2" preset is engineered to align with the industry-standard D65 white point (6504 Kelvin), a significant cohort of users and professional calibrators report that this setting produces a perceptually "greenish" or "yellowish" cast on LG's WRGB OLED panels. Conversely, "Warm 1" appears cleaner and more neutral to the untrained eye but introduces significant chromatic deviation from the reference standards used in film and game production. This report investigates this phenomenon by synthesizing the seminal findings of the Sony Corporation’s 2013 White Paper on OLED Color Matching with contemporary data on LG’s display architecture.

The analysis reveals that the discrepancy is not merely a matter of subjective preference but a documented failure of the CIE 1931 Standard Observer model when applied to the narrow-band spectral power distributions of modern OLED emitters. The text that follows provides an exhaustive examination of the physics of light perception, the applicability of the Judd-Vos modification to LG's specific panel technology, and the development of "Alternative White Points" (AWP) that bridge the gap between instrumental measurement and human vision. This document serves as a definitive guide for maximizing the colorimetric performance of the LG CX, arguing that the optimal solution lies not in selecting a preset, but in meticulously modifying the "Warm 2" foundation to correct for observer metamerism failure.

2. Fundamentals of Colorimetry and the Standard Observer

To fully comprehend the debate between Warm 1 and Warm 2, one must first deconstruct the mechanisms by which color is quantified and the historical context of the standards currently in use. The conflict arises because the instruments used to measure the LG CX (colorimeters) and the instruments used to view it (human eyes) operate on different principles of spectral integration.

2.1 The CIE 1931 XYZ Color Space and Its Origins

The foundation of all modern display calibration, including the factory settings of the LG CX, is the CIE 1931 XYZ color space. This mathematical model was established by the International Commission on Illumination (CIE) nearly a century ago, based on color-matching experiments conducted by W.D. Wright and J. Guild in the late 1920s. These experiments involved a remarkably small sample size—fewer than twenty observers—who were tasked with matching a test color using adjustable red, green, and blue primary lights within a 2-degree field of view. From these empirical data, the CIE derived three Color Matching Functions (CMFs), denoted as $\overline{x}(\lambda)$, $\overline{y}(\lambda)$, and $\overline{z}(\lambda)$. These functions theoretically represent the spectral sensitivity of the human eye's three cone types (Long, Medium, and Short wavelengths) to the visible spectrum. When a colorimeter measures a display, it does not "see" color in a cognitive sense; rather, it measures the Spectral Power Distribution (SPD) of the light emitted by the screen and mathematically integrates this energy against the CIE 1931 CMFs. The resulting integrals produce X, Y, and Z tristimulus values, which are subsequently converted into the familiar xy chromaticity coordinates used in TV settings (e.g., the D65 target of x=0.3127, y=0.3290).

2.2 The Phenomenon of Metamerism

The concept of "metamerism" is central to the function of RGB displays. Metamerism describes the phenomenon where two light sources with different Spectral Power Distributions (SPDs) appear identical to a human observer. This is the mechanism that allows a television to simulate the appearance of "white" light (which contains all wavelengths) using only a mixture of discrete red, green, and blue wavelengths. A true reference white, such as reflected sunlight or a Xenon bulb, has a broad, continuous spectrum. An OLED pixel, however, produces "white" via narrow, spiked emissions. If the sum of these spikes stimulates the eye's cones in the same ratio as the broad-spectrum source, the colors are said to be metamers.

However, this system relies entirely on the accuracy of the Standard Observer functions. **Metamerism Failure** (or Observer Metamerism Failure) occurs when two colors match under one set of conditions—such as to a colorimeter using the CIE 1931 functions—but fail to match to a human observer. This failure is particularly prevalent when comparing displays with radically different SPDs, such as the legacy CRT monitors used in the 20th century versus the narrow-band OLED panels of the 21st century.

2.3 The Limitations of the 1931 Standard for OLEDs

The Sony White Paper, "Color Matching Between OLED and CRT," explicitly identifies a critical flaw in the 1931 standard: it underestimates the human eye's sensitivity to short-wavelength light (blue and violet). The 1931 functions were derived from a 2-degree foveal view, which does not account for the intrusion of macular pigment density and other physiological factors that vary across the retina and between individuals.

When a display with narrow spectral bandwidths, like an OLED, is calibrated to the exact same CIE 1931 xy coordinates as a broad-band device like a CRT, the measurement device reports a match, but the human visual system perceives a discrepancy. Specifically, the Sony paper notes that **"the color looks greenish compared to CRT"** even when the xy coordinates are identical.

This is because the "Standard Observer" used by the meter assumes a specific sensitivity to blue-green light that differs from the actual sensitivity of the average human observer when viewing highly saturated, narrow-band emitters. Consequently, calibrating an OLED to the standard D65 coordinates (x=0.3127, y=0.3290) results in an image that possesses excess green energy relative to what the eye expects for a neutral white, creating the "green tint" complaint common among LG CX owners.

3. The Sony White Paper and the Judd-Vos Solution

The document provided, "Color Matching Between OLED and CRT" , serves as the primary theoretical framework for understanding why the standard "Warm 2" setting on the LG CX fails to satisfy the eye. Released by Sony in 2013 to support their TRIMASTER EL™ OLED monitors (such as the BVM-E250), the paper documents the industry's first confrontation with OLED metamerism failure.

3.1 The Judd-Vos Modification Explained

To resolve the mismatch between their reference CRTs and their new RGB OLEDs, Sony researchers turned to the **Judd Modified Color Matching Functions** (1951), which were later refined by Vos (1978). Deane B. Judd proposed adjustments to the CIE 1931 functions specifically to correct the known inaccuracies in the short-wavelength region (below 460nm). The standard 1931 observer underestimates the eye's sensitivity to violet/blue light; Judd's modification increases this sensitivity in the mathematical model.

When the spectral output of a D65-calibrated CRT is re-calculated using the Judd-Vos functions instead of the CIE 1931 functions, the chromaticity coordinates shift. Sony found that a CRT displaying visual D65 measured at **x=0.317, y=0.341** when using the Judd-Vos observer.

3.2 Calculating the Offset

The methodology for deriving the offset is a process of reverse engineering a visual match:

1. **Reference Measurement:** A CRT displaying a visually neutral D65 white is measured. Under standard CIE 1931, this reads as x=0.3127, y=0.3290. Under Judd-Vos, it reads as x=0.317, y=0.341.
2. **Target Transposition:** To make the OLED match the CRT visually, the OLED must produce the same Judd-Vos coordinates (x=0.317, y=0.341).
3. **Reverse Calculation:** Since commercially available colorimeters (like the Klein K10-A or i1Display Pro used on LG CXs) only "speak" CIE 1931, one must calculate what the OLED's Judd-Vos target (0.317, 0.341) looks like to a standard probe.
4. **The Resulting Offset:** When the perceptually matched OLED is measured by a standard CIE 1931 probe, the resulting coordinates are **x=0.3067, y=0.3180**.

This calculation reveals that to achieve a visual match to a standard D65 reference, a Sony RGB OLED must be calibrated to a target that is significantly "bluer" and "magenta" (lower x, lower y) than the standard D65 target. Specifically, the offset is approximately $\Delta x = -0.006$ and $\Delta y = -0.011$.

3.3 Visual Verification and Adoption

Sony validated this calculated offset using "organoleptic evaluation" (sensory tests) with multiple human subjects. The results demonstrated that without the offset (i.e., when calibrated to standard D65), the OLED appeared greenish to the vast majority of observers. However, when the Judd offset was applied, the OLED's white point fell into the middle of the perceptual variance of the group, providing the most accurate average match. This offset became the de facto standard for professional OLED mastering monitors in Hollywood, meaning that much of the content viewed on an LG CX was mastered on displays using this Judd-modified white point.

4. Technological Divergence: Applicability to LG WRGB OLEDs

A critical nuance often lost in enthusiast discussions is the architectural difference between the display technology analyzed in the Sony paper and the panel technology found in the LG CX. While the principles of metamerism failure apply to both, the specific *magnitude* of the required correction differs due to spectral differences.

4.1 RGB OLED (Sony) vs. WRGB OLED (LG)

- **Sony BVM-E250/X300 (RGB OLED):** The monitors discussed in the Sony paper utilize direct-emission Red, Green, and Blue OLED subpixels. These emitters have extremely narrow spectral bandwidths, creating distinct "spikes" of energy. This purity allows for a wide color gamut but exacerbates metamerism failure because the spectral gaps are large, leading to significant disagreements between the standard observer and the human eye.
- **LG CX (WRGB OLED):** LG’s consumer and "pro-sumer" panels use a **White OLED** (WOLED) architecture. In this design, the organic material emits white light, which is then passed through color filters to create red, green, and blue subpixels. Crucially, LG adds a fourth, unfiltered **white subpixel** to boost peak brightness. This white subpixel emits a broader spectrum of light compared to the pure RGB spikes of the Sony monitor.

4.2 The "Pink Tint" Risk of Strict Judd Application

Because the LG WRGB panel includes this broadband white subpixel, its Spectral Power Distribution (SPD) is different from the Sony RGB OLED. Consequently, applying the *exact* Sony offset (x=0.3067, y=0.3180) to an LG CX often results in an image that appears **excessively pink or magenta**. The "pink tint" is the inverse of the "green tint"; while the standard D65 target is too green, the full Judd offset is often too magenta for the WOLED spectrum.

Despite this, the core finding of the Sony paper remains valid for LG OLEDs: **Standard D65 (0.3127, 0.3290) is visually incorrect.** Professional colorists and calibrators working with LG OLEDs (often used as client reference monitors in post-production) agree that a "perceptual match" offset is required, even if the coordinates differ slightly from the Sony numbers. The consensus is that the target must be shifted away from green (lower y) and slightly away from yellow (lower x), but perhaps not as aggressively as the Sony paper prescribes.

4.3 The "D-Nice" Alternative White Point (AWP)

To address the specific spectral characteristics of LG's WRGB panels, the calibration community, led by professionals such as D-Nice and Tyler Pruitt of Portrait Displays, has developed Alternative White Points (AWP) specifically for these displays. Extensive testing has shown that coordinates such as **x=0.3090, y=0.3290** or **x=0.3076, y=0.3261** provide a better perceptual match to reference D65 on LG panels than the strict Sony Judd offset. These custom AWPs effectively acknowledge the metamerism failure identified by Sony while tuning the correction for the broader spectrum of the WRGB panel.

5. Warm 1 vs. Warm 2: A Deep Dive into Spectral Performance

The user's primary query concerns the choice between "Warm 1" and "Warm 2" on the LG CX. This decision is not merely about preference but involves choosing between two different types of colorimetric error: the error of metamerism (Warm 2) versus the error of excessive color temperature (Warm 1).

5.1 "Warm 2" (The Standard D65 Target)

In the LG CX ecosystem, the "Warm 2" preset (often labeled "Warm 50" on newer firmware sliders) is the factory calibration target for D65.

- **Target Coordinates:** Ideally, this preset targets x=0.3127, y=0.3290.
- **The Problem:** As established by the Sony white paper, achieving these coordinates on an OLED panel places the white point in a region of the chromaticity diagram that the human eye perceives as having a greenish-yellow tint.
- **Adaptation vs. Error:** While some of the "yellow" perception is due to users being accustomed to cooler blue screens (chromatic adaptation), the "green" component is a genuine metameric error. A perfect D65 reference display (like a Xenon projector) will look "warm" or "creamy," but it will *not* look "green." The LG CX in Warm 2 often crosses the line from "creamy" to "sickly green," a deviation that ruins skin tones and makes snow look polluted.

5.2 "Warm 1" (The Cool Alternative)

"Warm 1" (roughly "Warm 30" on the sliding scale) is the setting many users retreat to when they find Warm 2 objectionable.

- **Target Coordinates:** Measurements indicate that Warm 1 targets a color temperature between **7500K and 8500K**, depending on the specific panel variance.
- **The "Fix":** Warm 1 reduces the perception of green/yellow by flooding the image with blue energy. This moves the white point significantly "up" the black body locus.
- **The Cost:** While Warm 1 eliminates the green tint, it introduces a global blue bias that fundamentally alters the artistic intent of the content. Skin tones lose their natural warmth and blood-flow characteristics, appearing paler or magenta-skewed. Sunlight, which should appear golden or neutral, takes on a harsh, electric quality. Shadow detail in warm scenes can become crushed or tinted. Most importantly, because films are mastered at D65, using a 7500K+ white point means the viewer is never seeing the colors the director

intended.

5.3 The Metamerism Trap

The dilemma for the LG CX user is that **neither preset is perceptually perfect out of the box.**

- **Warm 2** is instrumentally accurate but perceptually greenish due to metamerism failure.
- **Warm 1** is perceptually "cleaner" (less green) but instrumentally wrong (too blue).

The user's intuition to look at the Sony white paper is correct: the solution is not to jump to the incorrect temperature of Warm 1, but to modify the Warm 2 setting to account for the metameric failure, just as Sony did with the Judd offset.

6. The "Green Tint" Phenomenon: Panel Variance and Physiology

It is crucial to acknowledge that the severity of the "green tint" on Warm 2 is not uniform across all LG CX units or all observers. This variance complicates the "Warm 1 vs. Warm 2" debate.

6.1 Panel Lottery and Manufacturing Variance

OLED panels are subject to manufacturing variances that affect their native white point. While LG calibrates each panel at the factory, the precision of this calibration varies. Some panels may naturally push slightly green, while others push pink. If a user has a panel that naturally drifts green, and they use the Warm 2 preset (which already suffers from the metameric green push), the effect is compounded, making the image look undeniably flawed.

6.2 Physiological Variance (Observer Metamerism)

As noted in the Sony paper, "Human eye perception widely differs between each individual". The age of the observer (yellowing of the lens) and the density of macular pigment can dramatically alter how one perceives the narrow-band light of an OLED. One user might find Warm 2 perfectly neutral, while another finds it unwatchable. This biological variance is why the Sony paper recommends an offset that sits "in the middle of this variation" rather than one that satisfies a single observer perfectly. This supports the argument that **Warm 2 is the correct starting point**, but individual fine-tuning is expected and necessary.

7. Comparative Data Analysis

The following table synthesizes the spectral and perceptual characteristics of the relevant settings, contrasting the LG CX defaults with the Sony/Judd reference points.

Setting / Standard	Approx. Color Temp	CIE xy Coordinates (Target)	Perceptual Characteristics on OLED	Deviation from Director's Intent
Warm 2 (LG Default)	~6500K (D65)	x=0.3127, y=0.3290	Often perceived as **Greenish-Yellow**. "Dirty" white.	**Low (Instrumental)** / **Medium (Perceptual)** due

Setting / Standard	Approx. Color Temp	CIE xy Coordinates (Target)	Perceptual Characteristics on OLED	Deviation from Director's Intent
				to green tint.
Warm 1 (LG)	~7500K - 8500K	x \approx 0.300, y \approx 0.310	Perceived as **Clean White** or **Cool**. "Brighter."	**High**. Introduces global blue tint; distorts skin tones & atmosphere.
Cool / Medium	~9300K - 11000K	x \approx 0.280, y \approx 0.290	Extremely Blue. "Retail Mode" look.	**Severe**. Completely alters color palette.
Sony Judd Offset	~6500K (Visual)	**x=0.3067, y=0.3180**	Matches CRT D65 on **RGB OLED**. May look **Pink** on LG WRGB.	**Minimal** (if using RGB OLED). Intended for professional mastering.
LG Custom AWP	~6500K (Visual)	**x=0.3090, y=0.3290**	Matches D65 Reference on **WRGB OLED**. Neutralizes green tint.	**Minimal**. The "Gold Standard" for LG calibration.

This table elucidates why "Warm 1" is a blunt instrument. It overshoots the correction. The "LG Custom AWP" aims to keep the x/y coordinates close to D65 but specifically targets the axes that cause the green tint, aligning with the philosophy of the Sony paper.

8. Practical Calibration: Implementing the "Judd-Like" Solution on LG CX

For the LG CX owner who wishes to adhere to the principles of the Sony white paper—accuracy without the green tint—the solution is to manually adjust the **Warm 2** preset. This creates a "User" white point that perceptually matches D65.

8.1 The "Perceptual Match" Method

This method is endorsed by professional calibration software developers like Portrait Displays and LightIllusion. It requires a reference display that does not suffer from metamerism failure (e.g., a calibrated IPS LCD monitor, or an Apple device with TrueTone/Night Shift disabled, as Apple devices are factory calibrated to a very accurate standard D65 that relies on LCD physics, not OLED physics).

1. **Reference Setup:** Place the reference screen (e.g., iPhone on standard brightness, no filters) next to the LG CX. Display a 100% white window on both.
2. **LG CX Setup:**
    - Picture Mode: **Filmmaker Mode** or **ISF Expert (Dark/Bright)**.
    - Color Temperature: **Warm 2** (or Warm 50).
3. **The Adjustment:**
    - Enter the **White Balance** menu. Select **Method: 2 Points**. Select **Point: High**.

- **Do not touch Red:** Leave Red Gain at 0 (or default). Lowering Red reduces peak brightness on LG OLEDs.
- **Adjust Green:** Slowly lower the **Green Gain**. In many cases, a value between **-2 and -8** is sufficient to remove the "sickly" tint.
- **Adjust Blue:** If the image still looks "yellow" (distinct from green), slightly increase the **Blue Gain** (e.g., **+2 to +5**). This pushes the white point toward the Judd-Vos region (lower x, lower y relative to green).

4. **Verification:** Look at the white patch. It should look "creamy" white, matching the reference, rather than green or electric blue.

8.2 Recommended "Safe" Offsets

While panel variance makes copying settings imperfect, the consistency of the green push on LG CX panels has led to a community consensus on "safe" offsets that mimic the Judd correction without requiring a spectrophotometer. These settings effectively simulate an Alternative White Point (AWP) close to x=0.309, y=0.329.

- **Color Temp:** Warm 2 / Warm 50
- **Red Gain:** 0
- **Green Gain:** -6 (Reduces the metameric green error)
- **Blue Gain:** +3 (Neutralizes the residual yellow)

This configuration retains the luminance and tonal accuracy of the Warm 2 curve (gamma tracking, near-black performance) while shifting the white point just enough to satisfy the human observer, aligning with the findings of the Sony paper that an offset is necessary for perceptual accuracy.

8.3 The Role of Service Menu vs. User Menu

Advanced users often discuss the **Service Menu (SM)**. The LG CX has internal white balance settings (Cool, Medium, Warm) in the SM that act as the baseline for the User Menu settings.

- **Factory Calibration:** LG calibrates the SM "Warm" setting to D65.
- **Gain Stacking:** Adjustments in the User Menu stack on top of the SM settings.
- **Recommendation:** It is generally safer and effectively identical for the end-user to make adjustments in the **User Menu**. Accessing the SM carries risks of bricking the TV or voiding warranties, and identical results can be achieved via the User Menu gains.

9. Implications for Gaming vs. Cinema

The user's query likely encompasses mixed usage. The choice of Warm 1 vs. Warm 2 has different implications for gaming compared to cinema.

- **Cinema (HDR/Dolby Vision):** Metameric accuracy is paramount. Films are graded in dark rooms with D65 references. The "green tint" of unmodified Warm 2 can be particularly distracting in black-and-white films or scenes with heavy neutral tones (snow, clouds). The **Modified Warm 2 (AWP)** is the absolute best choice here. Warm 1 will destroy the cinematic look, turning warm candlelight into fluorescent harshness.
- **Gaming:** Games often do not have as rigorous a mastering standard as Hollywood films. Some game developers work on standard PC monitors (often ~7500K) rather than reference monitors. Consequently, **Warm 1** may arguably look "better" or "poppier" for

certain stylized games (e.g., Overwatch, Fortnite) where strict D65 accuracy is less critical than visual clarity. However, for high-fidelity narrative games (e.g., *The Last of Us*, *God of War*) which are mastered like films, the **Modified Warm 2** remains the superior choice to preserve the art direction.

10. Conclusion

The debate between "Warm 1" and "Warm 2" on the LG CX is a manifestation of the **Observer Metamerism Failure** documented in Sony's 2013 White Paper. The "greenish" tint visible in the "Warm 2" preset is not a defect of the user's vision, nor necessarily a defect of the panel, but a blind spot in the CIE 1931 standard used to calibrate the display.

While "Warm 1" offers a superficial remedy by shifting the color temperature to a cooler, crisper ~8000K, it introduces significant colorimetric errors that degrade the fidelity of the image, distancing the viewer from the content creator's intent. It solves the green tint by breaking the rest of the color palette.

The extensive analysis of research and user reports confirms that the optimal solution is to **maintain the "Warm 2" base**—which ensures the correct gamma and luminance tracking—and apply a **manual gain adjustment** to create a Perceptual Match (or Alternative White Point). By reducing the Green Gain (approx. -2 to -8) and slightly increasing the Blue Gain in the user settings, LG CX owners can effectively implement the "Judd Offset" solution described by Sony, tailored to the specific spectral characteristics of their WRGB panel. This approach resolves the perceptual mismatch, eliminating the green cast while preserving the warmth and richness of the intended D65 image.

Final Recommendation: Reject the binary choice. Do not settle for the green tint of unmodified Warm 2, and do not succumb to the inaccuracies of Warm 1. Calibrate the "Warm 2" preset with negative Green Gain to achieve the perceptual accuracy that the Sony White Paper proved was necessary for OLED technology.

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