

ACES Color Workflow in Unreal Engine 5

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Abstract

ACES [1] is a standardized color management system widely used in the film and visual effects industry to ensure consistent and accurate color reproduction throughout the production pipeline. Integrating ACES into game engines like Unreal Engine [2] could have significant benefits, especially for game developers who want to achieve high-quality, consistent color representation across different platforms and displays.

Game developers can achieve heightened visual fidelity by leveraging ACES in Unreal Engine 5, especially concerning wide color gamuts and high dynamic range (HDR) content. The standardized color management system allows cross-platform development, guaranteeing consistent color reproduction on various devices and display technologies. Moreover, Unreal Engine 5's support for ACES facilitates seamless collaboration with other creative industries that utilize this industry-standard color pipeline.

However, implementing ACES in a real-time engine presents unique challenges regarding performance optimization and ensuring compatibility with other game engines. Artists and developers may need to adapt their workflows to accommodate ACES color transforms, impacting the art pipeline and user-generated content.

This paper uses ACES to investigate color input and output consistency to and from Epic Games Unreal 5 regarding Wide Color Gamut and High Dynamic Range imagery.

Keywords: *Unreal Engine 5, ACES, color management, color pipeline, HDR color space, Wide Color Gamut, Nuke, VFX*

1. Test goal and settings

1.1 Introduction

In current high-end media pipelines, film technologies like visual effects and real-time game engine possibilities strongly tend to be combined. In Virtual Production, large LED volumes are used to display real-time content from game engines. According to Epic Games, more than 300 LED volumes (of late 2022) are installed using the Unreal game engine as the content player [3]. This technology enables filmmakers to change the displayed content interactively in real-time and explore creative possibilities.

Unfortunately, the color workflows in Game engines are primarily based on the limited sRGB/Rec709 color gamut and do not offer HDR capabilities at first sight. So, in this paper, we

investigate the possibilities and color fidelity when we apply the film industry's ACES color workflow to Unreal 5 exports.

1.2 Test Goal

The goal is to investigate the behavior of Epic Games Unreal renders in ACES workflow. ACES color management is the central element in film productions. It, therefore, also plays a significant role in color workflows for virtual production, cinematics, and other film-related technologies that use game engines.

Under default conditions, research is conducted into how renders in the ACEScG color space behave compared to sRGB renders. The individual sections examine the influence of the directional light with and without the Sky System on rendering a card object with different luminance values of the base color. The post-processing system is manually set to an exposure correction that correctly renders a 0.18 luminance of the base color. The rendering of primary valences and color temperatures is compared in the following section.

An important aspect is the reproduction of high dynamic range light values. These are luminance values in the render color space larger than the range of 0 to 1 used for displays. Increased values for directional light and high emission values of textures are examined here. An HDR gradient as a texture is applied to the test plate to analyze the behavior of different render options.

As the content used in Unreal depends to a not inconsiderable extent on the Megascan Library [4], a comparison is made of how the textures applied with the Bridge import [5] behave with the same texture inserted manually. In addition, the X-Rite ColorChecker24 is inserted as a texture, and the color fidelity for sRGB and ACEScG renders is examined.

Finally, the renders of primary valences and the Megascan textures in the ACEScG working space are compared with the values in the sRGB/Rec709 color space.

1.3. Test Settings in Unreal 5

For our testing, we use as many default settings as possible to refer to the out-of-the-box conditions that appear to the user at the start

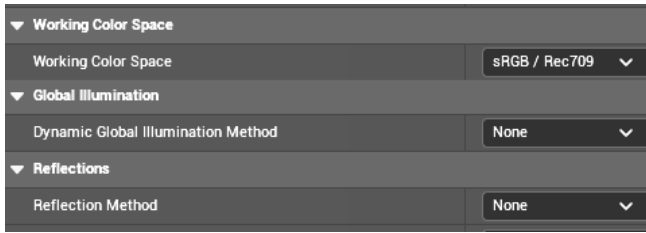


Figure 1. Global Illumination Settings in Unreal

Also, we want to avoid performance optimization settings. We are using the Bake Lighting System in its default condition. To achieve this, Global Illumination and Global Reflection are set to *none* (Fig. 1).

We use the default Directional Light as the only light generally without the Sky System. We do not change the rotation because this would change the *Time Of Day* and, for this, the color temperature.

The test object serves as a geometry plate in the stage center, rotated 45° in the x-direction (Fig. 2). We are also using the default *Floor* because most users start with this object as well. For the tests, the Postprocessing Exposure is set to match the renders to the 0.18 Base Color Luminance of the plate material.

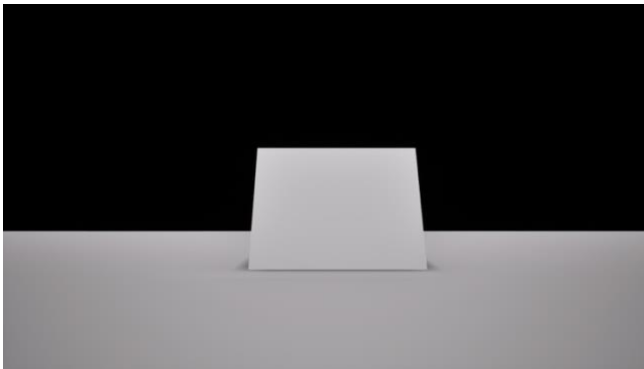


Figure 2. Test Plate

The Working Color Space is *sRGB/Rec709* (see Fig. 1). Section 4 switches to Working Color space *ACEScg* to test the texture behavior in this Wide Gamut color space.

Four files with different output color settings are rendered throughout the analysis process. Most often, only the first and fourth options appear in the tables. The color conversion in Unreal 5 is performed using *OpenColorIO 2.1* with the *ACES2.1* configuration [6] (Fig. 3).

- *sRGB_JPEG* (the default color settings in Unreal 5.3.2 without further color conversion with the Tone Curve and the Transfer Function (gamma correction) applied).
- *sRGB_JPEG_woTC* (the Tone Curve is turned off but with the Transfer function applied).
- *sRGB_EXR* (linear *sRGB* OpenEXR files without Transfer Function but with Tone Curve applied).

- *ACEScg_EXR* (linear *ACEScg* - API OpenEXR files) without Tone Curve and no Transfer Function applied)

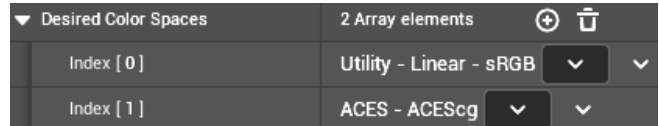


Figure 3. OpenColorIO – Export settings in Unreal

1.4 Test Settings in Nuke

The analysis of the Unreal renders is taking place in *The Foundry Nuke 15.0v1* [7]. The Working Color Space is *ACEScg*. The renders are converted into this color space using the *OpenColorIO 2.1* and the *ACES 2.1* configuration, which is shipped with Nuke. The following color conversions were applied:

- *sRGB_JPEG* (matte paint) – removes the Transfer Function (gamma), converts from *sRGB(D65)* to *ACEScg* (6000K), keeps the Tone Curve. Rendered out as Jpeg-files.
- *sRGB_JPEG_woTC* (matte paint) – removes the Transfer Function (gamma), converts from *sRGB(D65)* to *ACEScg* (6000K), Tone Curve has been removed at render time. Rendered out as Jpeg-files.
- *sRGB_EXR* (Utility – Linear – *sRGB*) – converts from *sRGB(D65)* to *ACEScg* (6000K), keeps the Tone Curve, the Transfer Function has been removed at render time. Rendered out as OpenEXR half-float files.
- *ACEScg_EXR* (scene – linear) – No color conversion is taking place. Rendered out as OpenEXR half-float files.

Additional conversions must be applied because the analysis is taking place in the *CIE Yxy* color space. All rendered images are converted from *ACEScg (6000K)* to *CIE XYZ (D65)* using the *Bradford Matrix* [8] to maintain the color appearance for the final analysis. The conversion is done with the *OCIOColorSpace* – Node. Then, the Nuke *ColorSpace* node was converted from *CIE Yxy* (Fig. 4).

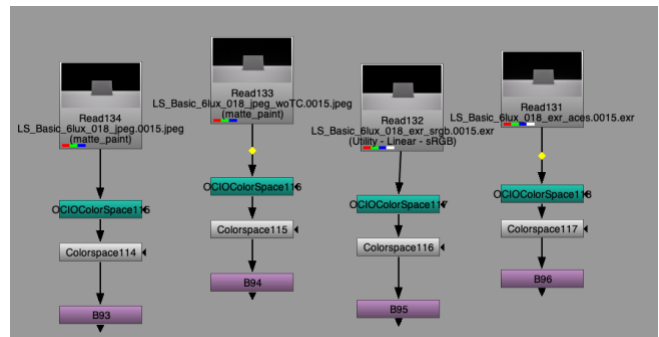


Figure 4. Input and Color conversion in Nuke

The plate in the rendered images is cropped to the same area for all images to avoid different conditions during measuring.

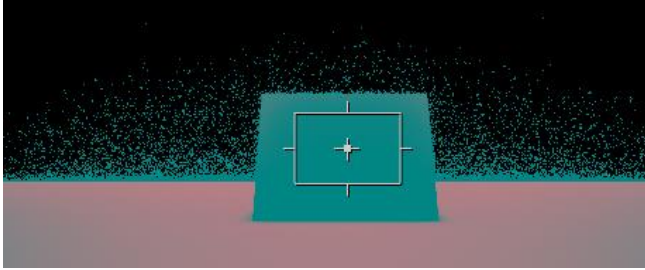


Figure 5. Cropped Image Region

2. Testing Standard Dynamic Range Content

2.1. Default Directional Light

Settings

- sRGB/Rec709 Color Space
- Directional Light default (6 lux)
- No Sky System
- No Post Processing
- Plate with different Base Color Luminance values (0.18, 1.0, 10).

Test goal and procedure

This section aims to find the values for the default Directional Light. Three plates with different materials are tested to determine if an increased (>1.0) luminance value in the material's Base Color will be returned.

Results

CIE Yxy (D65)	Default Directional Light (6 lux)		
File	Y	x	y
	Plate 0.18 base color luminance		
Basic_srgb_jpeg	0.1290	0.3132	0.3218
Basic_srgb_woTC	0.1420	0.3136	0.3240
Basic_srgb_exr	0.1290	0.3135	0.3221
Basic_aces_exr	0.1420	0.3141	0.3237
	Plate 1.00 base color luminance		
Basic_srgb_jpeg	0.4955	0.3128	0.3260
Basic_srgb_woTC	0.4750	0.3136	0.3235
Basic_srgb_exr	0.4959	0.3133	0.3258
Basic_aces_exr	0.4745	0.3136	0.3237
	Plate 10.00 base color luminance		
Basic_srgb_jpeg	0.4956	0.3128	0.3260
Basic_srgb_woTC	0.4750	0.3135	0.3235
Basic_srgb_exr	0.4959	0.3133	0.3258
Basic_aces_exr	0.4745	0.3136	0.3237

Table 1. Different Plate luminance values with default Directional Light

Evaluation

- sRGB_JPEG and sRGB_EXR deliver the same values due to the influence of the Tone Curve.
- sRGB_JPEG_woTC and ACEScg_EXR deliver the same values because no Tone Curve is applied.
- The Color Temperature is close to D65 [0.3127, 0.3290] with a slight offset in y-direction.
- The results for the higher base color luminance (10) do not differ from the material with the 1.00 value. This behavior is due to the energy conversion law. The outgoing energy cannot be larger than the incoming energy.

2.2. Default Directional Light with Sky System

Settings

- sRGB/Rec709 Color Space
- Directional Light default (6 lux)
- With Sky System
- No Post Processing
- Plate with different Base Color Luminance values (0.18, 1.0)

Test goal and procedure

The Unreal Sky System consists of several components that simulate a physical sky with atmosphere, clouds, and fog [9](Fig. 6). this test aims to determine how the Sky System changes the lighting concerning luminance and color temperature.

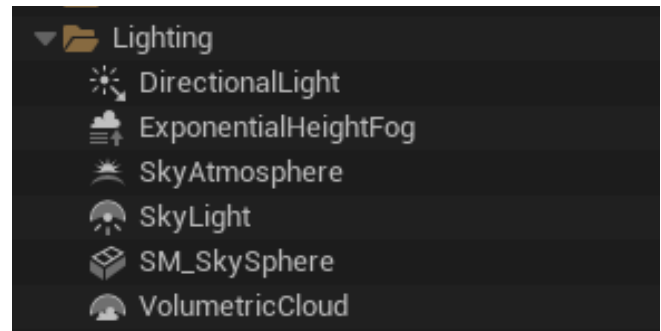


Figure 6. Unreal Sky System

CIE Yxy (D65)	Differences with/without sky		
File	Y	x	y
	Plate 0.18 with sky		
Basic_sky_srgb_jpeg	0.3211	0.3246	0.3340
Basic_sky_aces_exr	0.2900	0.3267	0.3342
Difference_srgb_jpeg	0.1921	0.0114	0.0122
Difference_aces_exr	0.1480	0.0126	0.0105
	Plate 1.00 with sky		
Basic_sky_srgb_jpeg	0.7229	0.3175	0.3318
Basic_sky_aces_exr	1.0130	0.3287	0.3368
Difference_srgb_jpeg	0.2274	0.0047	0.0058
Difference_aces_exr	0.5385	0.0151	0.0131

Table 2. Differences between with and without Unreal Sky System

Evaluation

- The Sky System contributes considerably to the rendered plate’s luminance values, nearly doubling the values.
- The influence of the Sky System shifts the color temperature from D65 to around 6000 K (Fig. 7).
- For the sRGB-JPEG renders of the plate with 1.00 luminance, the influence of the tone curve shifts the color temperature back to D65 (at least in the x-direction), whereas the plate with 0.18 luminance keeps the color values around 6000 K.

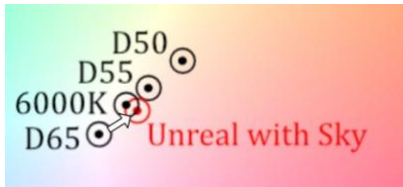


Figure 7. Color temperature shift with applied Sky System

2.3. Directional Light – increased intensity

Settings

- sRGB/Rec709 Color Space
- Directional Light default (6 lux, 10 lux, 20 lux)
- No Sky System, no Post Processing
- Plate with Base Color Luminance value 1.0

Test goal and procedure

This section aims to find out if increased intensity values in the Directional Light will drive the response of the plate material beyond the usual display-referred value of 1.0. Three Directional Light intensities are applied: 6 lux, 10 lux, and 20 lux. All intensities are measured for the plate material with the 1.00 base color luminance.

Results

CIE Yxy (D65)	Different Directional Light values		
File	Y	x	y
Plate 1.00 6 lux			
Basic_srgb_jpeg	0.4955	0.3128	0.3260
Basic_aces_exr	0.4745	0.3136	0.3237
Plate 1.00 10 lux			
Basic_srgb_jpeg	0.4930	0.3126	0.3257
Basic_aces_exr	0.4714	0.3135	0.3235
Difference: 10 lux – 6 lux			
Difference_srgb_jpeg	-0.0025	-0.0002	-0.0003
Difference_aces_exr	-0.0031	-0.0001	-0.0002
Plate 1.00 20 lux			
Basic_srgb_jpeg	0.5205	0.3128	0.3261
Basic_aces_exr	0.5087	0.3135	0.3243
Difference: 20 lux – 6 lux			
Difference_srgb_jpeg	0.0250	0.0000	0.0001
Difference_aces_exr	0.0342	-0.0001	0.0006

Table 3. Plate values and differences for Directional Light values of 6 lux, 10 lux and 20 lux

Evaluation

- Values are only slightly increased between 6, 10 and 20 lux.
- No HDR values are generated.
- Automated Exposure Correction prevents higher luminances than 1.00.
- In the Unreal manual, the process is described as the following:

The Post Process Volume provides controls for setting up Exposure (more commonly called eye adaptation), which automatically adjusts how bright or darker the scene looks [10].

2.4. Finding a matched 0.18 luminance value for the Post Processing Exposure Correction

Settings

- sRGB/Rec709 Color Space
- Directional Light default (6 lux)
- No Sky System
- Post Processing with different Exposure Correction values
- Plate with Base Color Luminance value 0.18

Results

CIE Yxy (D65)	Post Processing Exposure Correction (EC)		
File	Y	x	y
Automated EC			
Post_aces_exr	0.1423	0.3140	0.3236
Manual EC 8.00			
Post_aces_exr	0.1964	0.3141	0.3242
Manual EC 7.80			
Post_aces_exr	0.1764	0.3139	0.3245
Manual EC 7.90			
Post_aces_exr	0.1859	0.3139	0.3245
Manual EC 7.84			
Post_aces_exr	0.1799	0.3139	0.3245
Post_srgb_jpeg	0.1802	0.3135	0.3235
Post_srgb_woTC	0.1798	0.3133	0.3250
Post_srgb_exr	0.1801	0.3138	0.3236

Table 4. Matches of 0.18 luminance values

Evaluation

- With a reverse engineering approach, we found a match with the exposure control of 7.84.
- All renders are colors to the reference value of 0.18.

2.5. RGB Primaries

Settings

- sRGB/Rec709 Color Space
- Basic Light Setting (6 lux, EC 7.84, no Sky System)
- Plates with primary colors (red, green, blue)

Test goal and procedure

With the reference of 0.18 base color luminance in the renders, this section aims to test the primaries' color fidelity in the sRGB color space. We test at what positions in the CIE Yxy color space the sRGB primary renders appear.

CIE x,y (D65)	Specified Primary Positions		
sRGB-Primaries	Y	x	y
Red	0.2126	0.6400	0.3300
Green	0.7152	0.3000	0.6000
Blue	0.0722	0.1500	0.0600
White Point	1.0000	0.3127	0.3290

Table 5. Positions of the sRGB primaries in the sRGB specification [12]

Results

CIE Yxy (D65)	RGB Primary differences specification measured		
File	Y	x	y
Red Primary			
Prim_red_srgb_jpeg	0.1686	0.6367	0.3286
Prim_red_aces_exr	0.2049	0.6400	0.3300
Difference srgb_jpeg	0.0440	0.0033	0.0014
Difference aces_exr	0.0077	0.0000	0.0000
Green Primary			
Prim_green_srgb_jpeg	0.5503	0.3000	0.6000
Prim_green_aces_exr	0.6723	0.3000	0.6000
Difference srgb_jpeg	0.1649	0.0000	0.0000
Difference aces_exr	0.0429	0.0000	0.0000
Blue Primary			
Prim_blue_srgb_jpeg	0.0547	0.1515	0.0642
Prim_blue_aces_exr	0.0666	0.1503	0.0608
Difference srgb_jpeg	0.0175	-0.0015	-0.0042
Difference aces_exr	0.0056	-0.0003	-0.0008

Table 6. Measured positions of the sRGB primaries

Evaluation

- All renders of the sRGB primaries are close to the original specification.
- The Green primary delivers the best results.
- ACEScg_EXR renders deliver slightly better results.

2.6. Color Temperature values

Settings

- sRGB/Rec709 Color Space
- Basic Post Light Setting (EC 7.84, no Sky System)
- Directional Light (6 lux, 20 lux, 100 lux)
- Plates with Different Color temperatures

Test goal and procedure

This section tests Unreal's ability to convey the white points of the most essential CIE Illuminants (Table 7).

CIE x,y (D65)	White Point Specified Positions		
CIE-Illuminants	Kelvin	x	y
Illuminant A	2856	0.44757	0.40745
F3	3450	0.40910	0.39430
D50	5003	0.34567	0.35850
D55	5503	0.33242	0.34743
6000K	6000	0.32168	0.33767
D65	6504	0.31271	0.32902
D75	7504	0.29902	0.31485
D93	9305	0.28315	0.29711

Table 7. CIE-Illuminants in CIE Yxy

Results

CIE x,y (D65)	Differences white points: specification measured	
File	x	y
Illuminant A (2856 K)		
Temp_A_srgb_jpeg	0,0021	0,0513
Temp_A_aces_exr	0,0059	-0,0243
Illuminant F3 (3450 K)		
Temp_F3_srgb_jpeg	0,0455	0,0213
Temp_F3_aces_exr	-0,0121	0,0081
Illuminant D50 (5003 K)		
Temp_D50_srgb_jpeg	0,0190	0,0172
Temp_D50_aces_exr	-0,0018	0,0053
Illuminant D55 (5503 K)		
Temp_D55_srgb_jpeg	0,0110	0,0116
Temp_D55_aces_exr	-0,0013	0,0050
6000 K		
Temp_6000K_srgb_jpeg	0,0047	0,0071
Temp_6000K_aces_exr	-0,0010	0,0050
Illuminant D65 (6504 K)		
Temp_D65_srgb_jpeg	0,0000	0,0023
Temp_D65_aces_exr	-0,0008	0,0051
Illuminant D75 (7504 K)		
Temp_D75_srgb_jpeg	-0,0090	-0,0069
Temp_D75_aces_exr	0,0001	0,0059
Illuminant D93 (9305 K)		
Temp_D93_srgb_jpeg	-0,0179	-0,0182
Temp_D93_aces_exr	0,0029	0,0081

Table 8. Measured position of essential white points

Evaluation

- All renders are close to the values in the CIE specifications.
- Values around D65 are generally better than Illuminants with lower (A) or higher temperature (D93).
- *ACEScg_EXR* delivers much better results than *sRGB_JPEG* but to a degree off in the y-direction.

2.7. XRite ColorChecker24

Settings

- sRGB/Rec709 Color Space
- Basic Light Setting (6 lux, EC 7.84, no Sky System)
- Plate with XRite ColorChecker24 texture

Test goal and procedure

In this section, we apply an *XRite ColorChecker24* texture to the plate. To achieve a more even result according to the angle of the light, the plate is rotated to the right angle to the floor. The ColorChecker24 values are retrieved from the source [13] and converted from D50 to D65.

Results

CIE x,y (D65)	Differences: original measured			
	XRite_srgb_jpeg		XRite_aces_exr	
Patch	x	y	x	y
dark skin	0.0335	0.0069	0.0029	-0.0007
light skin	-0.0012	0.0016	0.0045	-0.0034
blue sky	-0.0157	-0.0206	-0.0014	-0.0046
foliage	0.0046	0.0252	-0.0003	-0.0045
blue flower	-0.0030	-0.0108	0.0002	-0.0025
bluish green	-0.0032	-0.0067	-0.0047	-0.0060
orange	-0.0819	0.0057	-0.0799	-0.0044
purplish blue	-0.0246	-0.0442	0.0010	0.0001
moderate red	0.0288	-0.0028	0.0035	-0.0012
purple	-0.0099	-0.0411	0.0014	0.0023
yellow green	0.0071	0.0108	0.0031	0.0029
orange yellow	0.0003	0.0088	0.0122	-0.0026
blue	-0.0298	-0.0613	0.0028	0.0021
green	-0.0109	0.0380	-0.0010	-0.0037
red	0.0426	-0.0044	-0.0013	-0.0003
yellow	0.0000	0.0053	0.0120	-0.0012
magenta	0.0168	-0.0166	0.0035	0.0008
cyan	-0.0049	-0.0176	-0.0011	-0.0037

Table 9. Positions of XRite ColorChecker24 patches in CIE xy-chromaticity-diagram

Evaluation

- *ACEScg_EXR* renders are very close to the original values.
- *ACEScg_EXR* renders deliver better color fidelity than *sRGB_JPEG*.
- An exception is the Orange patch, which is always a difficult color to deal with [14], [15].

3. Testing High Dynamic Range Content

In the following sections, we test Unreal’s ability to convey HDR content. This topic is significant because the sRGB color space in its original definition is limited in luminance. If it is possible to render out HDR luminance values larger than 1.00, then the Working Color Space in Unreal is not an original sRGB color space, but an in the Y-direction unlimited color space with sRGB/Rec709 primaries as its gamut, and with D65 as the white point.

3.1. Directional Light HDR values

Settings:

- sRGB/Rec709 Color Space
- Basic Post Light Setting (EC 7.84, no Sky System)
- Directional Light (6 lux, 20 lux, 100 lux)
- Plates with base color luminance of 0.18 and 1.0

Test goal and procedure

With the Auto Exposure in the Post Processing set to manual, the exposure is fixed and will not be automatically adjusted when changes in lighting are applied. We increase the intensity of the Directional Light from 6 lux to 20 lux and 60 lux.

Results

CIE Yxy (D65)	Directional Light intensities	
	Y	Y
File	Directional Light 6 lux	
	Plate 0.18	Plate 1.00
DL_6lux_srgb_jpeg	0.1802	0.6346
DL_6lux_srgb_woTC	0.1798	0.7301
DL_6lux_srgb_exr	0.1801	0.6316
DL_6lux_aces_exr	0.1798	0.7299
	Directional Light 20 lux	
DL_20lux_srgb_jpeg	0.4999	0.8541
DL_20lux_srgb_woTC	0.4810	1.0000
DL_20lux_srgb_exr	0.5002	0.8547
DL_20lux_aces_exr	0.4805	1.9416
	Directional Light 100 lux	
DL_100lux_srgb_jpeg	0.8390	0.9821
DL_100luxsrgb_woTC	1.0000	1.0000
DL_100lux_srgb_exr	0.8403	0.9827
DL_100lux_aces_exr	1.7844	7.0787

Table 10. Plate response to different Directional Light intensities

Evaluation

- *ACEScg_EXR* conveys the HDR content (fields highlighted in blue).
- *sRGB_JPEG_woTC* is clipped at 1.000 (fields in orange).
- *sRGB_JPEG* and *sRGB_EXR* are treated by the Tone Curve and only reach luminance values of 0.8 to 0.98 with room for brighter content (fields highlighted in yellow).

3.2 HDR Gradient

Settings

- sRGB/Rec709 Color Space
- Basic Post Light Setting (EC 7.84, no Sky System)
- Directional light (100 lux)
- Plate with Grayscale Gradient

Test goal and procedure

This section tests the render response to the HDR lighting. To understand the luminance distribution, we apply a grayscale gradient from black to white in the x-direction. The intensity of the Directional Light is set to 100 lux. To analyze the gradient, we use the Sample Node in Nuke and crop down the sample region of the image to a strip of 500 pixels by 20 pixels (Fig. 8).



Figure 8. Sample strip of the grayscale render

Please note that the values in the x-direction refer to the length of the image strip and, therefore, to the light luminance secondarily. The numbers are not a direct representation of physical light values.

Results

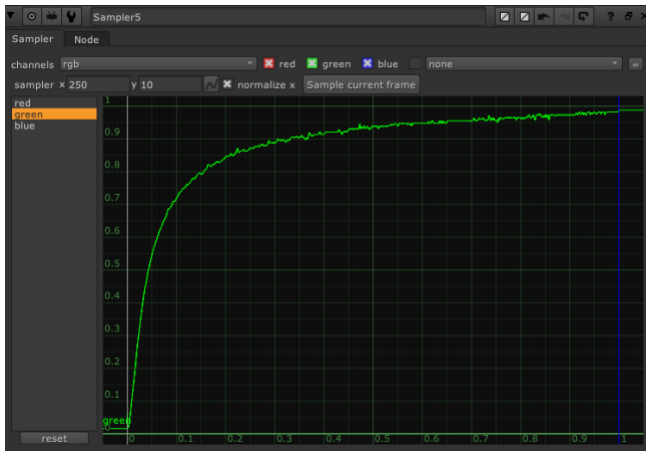


Figure 9. Gradient for sRGB_JPEG render

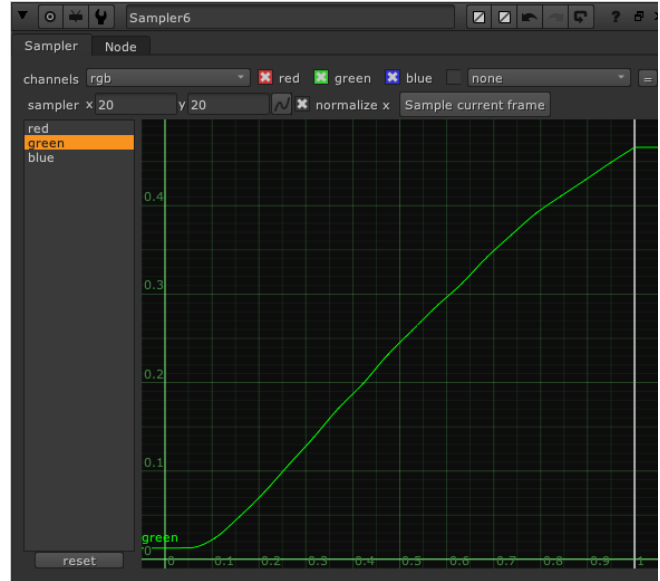


Figure 10. Gradient for sRGB_JPEG render (detail)

The sample region in Figure 10 is heavily cropped in the x-direction to display the lower part of the Tone Curve in Unreal. The dimensions of this strip are 20 by 20 pixels.

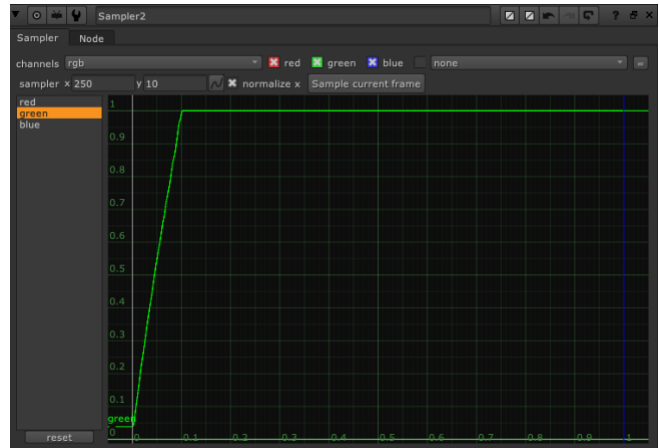


Figure 11. Gradient for sRGB_JPEG without Tone Curve render

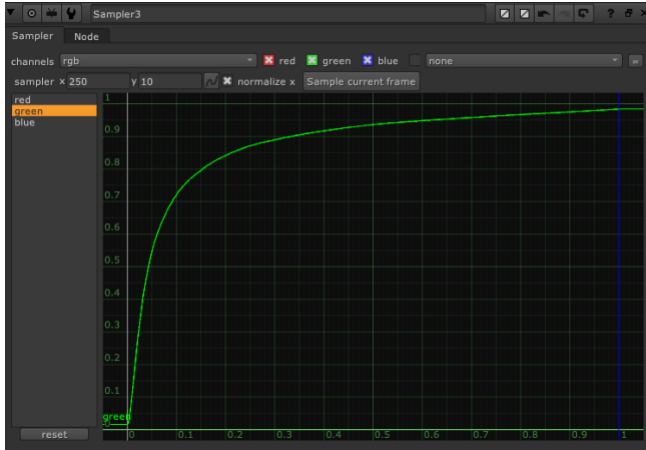


Figure 12. Gradient for sRGB_EXR

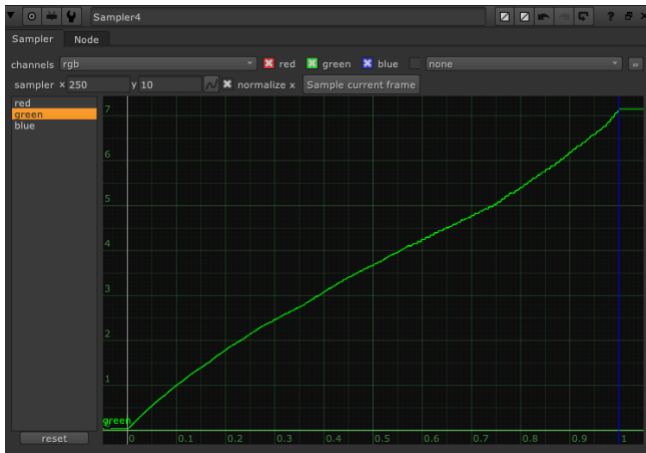


Figure 13. Gradient for ACEScg_EXR render

Evaluation

- sRGB_JPEG and sRGB_EXR show the influence of the Tone Curve.
- Both make space for HDR content above 0.7.
- The response curve in sRGB_EXR is much cleaner and not so fuzzy as in the sRGB_JPEG render because of the larger image depth resolution (16-bit float).
- sRGB_JPEG_woTC is clearly clipped.
- All of the sRGB renders do not convey HDR content.
- The ACEScg_EXR renders transfer the HDR content. The gradient is rendered more or less linearly.

Recommendation

- Use ACES_EXR for HDR-content.
- Use sRGB_EXR for better image depth resolution.
- Do not turn off Tone Curve for sRGB renders.

3.3 Emission

Settings

- sRGB/Rec709 Color Space
- Basic Light Setting (DL 6 lux, EC 7.84, no Sky System)
- Plates with Emission (yellow color 1 lux, 20 lux, 100 lux)

Test goal and procedure

In this section, we apply an Emissive material with a yellow color to the plate. Three different intensities for the emission are used: 1, 20, and 100. We partially leave the Directional Light in its default state to investigate the interactions with the emissive material. The position of the applied yellow emissive color in the CIE Yxy color space is depicted in Table 11.

CIE x,y (D65)	Primaries' Position specified		
sRGB-Primaries	Y	x	y
Yellow secondary color	0.9420	0.4542	0.5482

Table 11. Position of the yellow emissive test color in CIE Yxy

Results

Table 12 displays the measured luminance value (Y) of the renders and the influence of the directional light. The ACEScg_EXR renders transfer the HDR content (fields highlighted in blue). For the sRGB_JPEG renders, the difference with minus without Directional Light decreases when the emissive intensity increases (fields highlighted in light green). For the ACEScg-EXR renders, the difference increases because of the very high returned values (fields highlighted in dark green), which means that the influence of the Directional Light decreases.

CIE Yxy (D65)	Emissive values (Y)		
File	1	20	100
Emis_srgb_jpeg	0.4754	0.9546	0.9847
Emis_woDL_srgb_jpeg	0.4805	0.9548	0.9848
Difference DL woDL	-0.0051	-0.0002	-0.0001
Emis_aces_exr	0.4461	5.0947	18.7732
Emis_woDL_aces_exr	0.4516	5.1444	18.9272
Difference DL woDL	-0.0055	-0.0497	-0.1540

Table 12. Emission with and without Directional Light

CIE x,y (D65)	Differences Emissive Intensity	
File	x	y
Emis_srgb_jpeg Intensity 1	0.4181	0.5061
Emis_srgb_jpeg Intensity 20	0.3607	0.4096
Emis_srgb_jpeg Intensity 100	0.3269	0.3524
Difference 20 1	-0.0574	-0.0965
Difference 100 1	-0.0912	-0.1537
Emis_aces_exr Intensity 1	0.4195	0.5051
Emis_aces_exr Intensity 20	0.4204	0.5044
Emis_aces_exr Intensity 100	0.4204	0.5043
Difference 20 1	0.0009	-0.0007
Difference 100 1	0.0009	-0.0008

Table 13. Position of the emissive color depending on the intensity

Table 13 shows the color deviation due to the different emissive values. The influence of the Tone Curve is visible in the *sRGB_JPEG* renders. With increased emissive values the yellow color is shifted towards white (fields highlighted in light blue). The *ACEScg_EXR* renders maintain the color, independent of the emissive intensities (fields highlighted in dark blue).

Evaluation

- *ACEScg_EXR* renders convey HDR content.
- *sRGB_JPEG* renders shift the overall color to white with increased values.
- *ACEScg_EXR* renders maintain the yellow color.
- In the *sRGB_JPEG* renders, the more the emission is increased, the less influence the directional light.

4. ACEScg Workspace

Now, we set the Working Color Space to ACEScg. It is a Wide Gamut color space and is comprised of significantly more colors than sRGB/Rec709. The problem in color theory is that the numbers for the same color are lower in a wider gamut because the primaries are further away than in a gamut with a smaller area (standard gamut). If we change the color space, all colors in an Unreal level must be converted from the original color space to the new one. Applying a color transform is problematic because the original color space is often unknown.

4.1 Primaries

Settings:

- ACEScg Color Space
- Basic Light Setting (6 lux, EC 7.84, no Sky System)
- Plates with primary colors (red, green, blue)

Test goal and procedure

The Working Color Space in Unreal 5 is set to ACEScg (Fig.14). This section tests the render response to the ACEScg color space primaries. Table 14 lists the position of the sRGB primaries in CIE Yxy, whereas Table 15 lists the position of the ACEScg primaries in CIE Yxy as a reference.

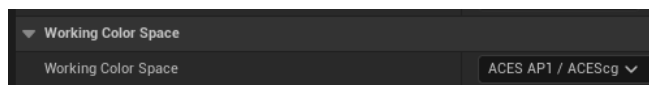


Figure 14. ACEScg as Working Color Space

CIE x,y (D65)	sRGB Primaries		
	Y	x	y
Red	0.2126	0.6400	0.3300
Green	0.7152	0.3000	0.6000
Blue	0.0722	0.1500	0.0600
White Point	1.0000	0.3127	0.3290

Table 14. sRGB primaries in CIE Yxy

CIE x,y (D65)	ACEScg-Primaries (AP1)	
	x	y
Red	0.7130	0.2930
Green	0.1650	0.8200
Blue	0.1280	0.0440
White Point	0.32168	0.33767

Table 15. ACEScg primaries in CIE Yxy

Results

CIE x,y (D65)	Measured Color Space Primaries			
	sRGB/Rec709		ACEScg	
File	x	y	x	y
Red Primary				
Red_jpeg_srgb	0.6367	0.3286	0.6400	0.3300
Red_aces_exr	0.6400	0.3300	0.7119	0.2922
Green Primary				
Green_jpeg_srgb	0.3000	0.6000	0.3000	0.5998
Green_aces_exr	0.3000	0.6000	0.1595	0.8388
Blue Primary				
Blue_jpeg_srgb	0.1515	0.0642	0.1500	0.0600
Blue_aces_exr	0.1503	0.0608	0.1303	0.0466

Table 16. Position of primaries in renders from ACEScg Working Color Space

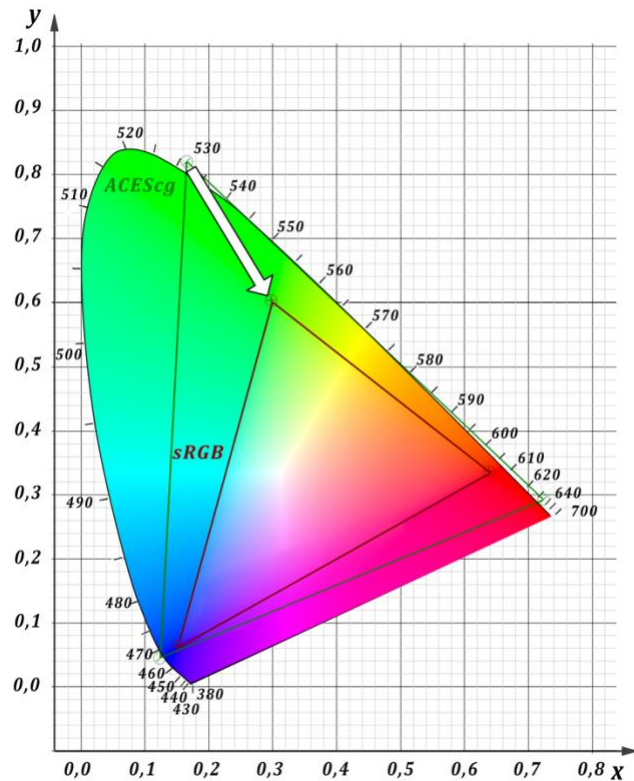


Figure 15. Position of ACEScg and sRGB primaries in CIE Yxy

Evaluation

- *sRGB_JPEG* renders transmit sRGB primaries.
- *sRGB_JPEG* shifts the primaries from the ACEScsg position back into the limited sRGB gamut (Fig. 15).
- *ACEScsg_EXR* renders transmit the ACEScsg primaries
- This behavior may lead to confusing results.

Recommendation

- It is recommended to decide in advance in which color space the renders should be exported.
- Changing the Working Color Space should be done only if necessary.

4.2. Megascan sRGB Textures – Bridge-Import vs. manually applied

Settings

- sRGB/Rec709 Color Space
- Basic Light Setting (DL 6 lux, EC 7.84, no Sky System)
- Plates with textures of different colors – bridge import and manually applied

Test goal and procedure

In this section, we return to the sRGB/Rec709 color space and test if a color difference appears between the same texture one imported and the other manually applied. We use the Bridge Plug-in [5] to the Megascan library for the first import. We import three metal sheets of Surface Materials of different colors (Fig. 16 – 18). For comparison, we change the Albedo textures of the imported materials manually. We apply the corresponding textures directly from the stand-alone Quixel Megascan Library. The textures imported by Bridge are of *High-Quality Import*, and the manually applied textures are 4K-JPEG files.

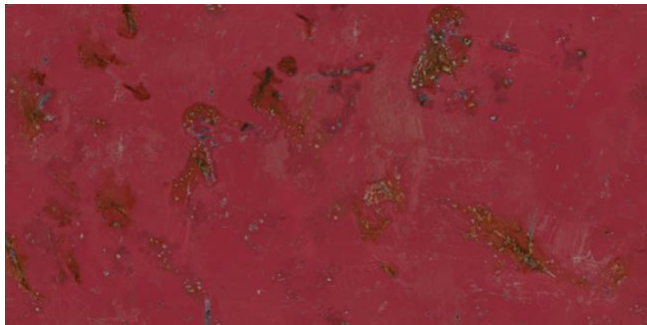


Figure 16. Reddish texture – metal_sheet_xhtnbhlg

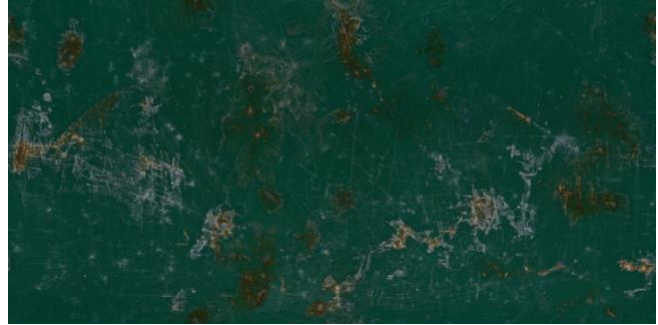


Figure 17. Greenish texture – metal_sheet_vbmiceq



Figure 18. Bluish texture – metal_painted_vbzkear

Results

CIE Yxy (D65)	Texture color differences		
	bridge manually		
File	Y	x	y
Reddish texture			
Difference srgb_ jpeg	0.0015	-0.0022	-0.0016
Difference acs_exr	0.0014	-0.0017	-0.0017
Greenish texture			
Difference srgb_ jpeg	0.0004	-0.0009	-0.0097
Difference acs_exr	0.0003	0.0006	-0.0068
Bluish texture			
Difference srgb_ jpeg	0.0015	0.0011	-0.0020
Difference acs_exr	0.0011	0.0008	-0.0017

Table 17. Color differences between import by Bridge and from stand-alone Megascan Library

Evaluation

- For *sRGB_JPEG* and *ACEScsg_EXR* renders, the measured color values for both textures are nearly the same.
- There is a slight offset in the y-direction for the renders most prominent in the greenish texture.
- With these results, it is possible to perform a reliable test with the textures in the ACEScsg color space.
- In section 4.4, we will compare manually applied sRGB textures with the same textures converted to ACEScsg also manually applied.

4.3. Megascan sRGB Textures in sRGB/Rec709 Working Color Space

Settings:

- sRGB/Rec709 Color Space
- Basic Light Setting (6 lux, EC 7.84, no Sky System)
- Plates with textures of different colors – bridge import and manually applied, sRGB vs. ACEScsg

Test goal and procedure

For this test, we stay in the sRGB/Rec709 color space and investigate how the color appearance of the rendered textures differs from the original texture colors. In *Table 19*, the original averaged color of the reddish and greenish are shown in the fields highlighted in orange.

Results

CIE x,y (D65)	Manually Applied Textures			
	Reddish Texture		Greenish Texture	
File	x	y	x	y
	Original sRGB texture in Nuke (reference)			
Ref_srgb_jpg	0.4994	0.3184	0.2607	0.3848
	sRGB Textures in sRGB/Rec709			
T_srgb_jpg	0.5403	0.3180	0.2583	0.4061
T_srgb_woTC	0.4947	0.3187	0.2658	0.3809
T_aces_exr	0.4966	0.3206	0.2661	0.3812

Table 19. Color deviation for textures in sRGB/Rec709

Conclusion

- The *sRGB_JPEG* renders show a significant color deviation (fields highlighted in blue).
- This deviation is caused by the Tone Curve, then with the Tone Curve removed, the original colors are maintained (fields highlighted in light green).
- *ACEScsg_EXR* renders maintain the original colors (fields highlighted in dark green).

4.4. Megascan Textures in ACEScsg Color Space

Settings:

- ACEScsg Color Space
- Basic Light Setting (6 lux, EC 7.84, no Sky System)
- Plates with textures of different colors – bridge import and manually applied, sRGB vs. ACEScsg

Test goal and procedure

In this test, we compare the behavior of manually applied sRGB and ACEScsg textures in the ACEScsg color space. For this purpose, we convert the original textures from sRGB to ACEScsg.

Results

CIE x,y (D65)	Manually Applied Textures			
	Reddish Texture		Greenish Texture	
File	x	y	x	y
	Original sRGB texture in Nuke (reference)			
Ref_srgb_jpg	0.4994	0.3184	0.2607	0.3848
	sRGB Textures in ACEScsg			
T_srgb_jpg	0.5588	0.2966	0.2488	0.3983
T_aces_exr	0.5605	0.2941	0.1967	0.4029
	ACEScsg Textures in ACEScsg			
T_aces_exr	0.4849	0.3134	0.2605	0.3647

Table 20. Comparison of sRGB and ACEScsg textures in ACEScsg Working Color Space

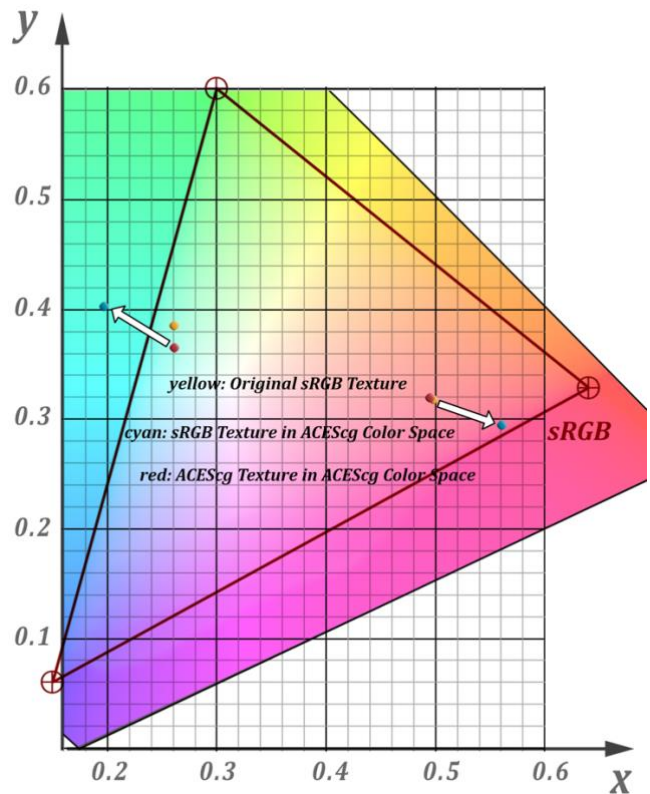


Figure 19. sRGB and ACEScsg textures in ACEScsg color space

The colors are oversaturated when an sRGB texture is used in the ACEScsg colorspace. Because no conversion occurs, the sRGB values are interpreted as belonging to the ACEScsg color space. In *Figure 19*, the problem is depicted. The sRGB color positions (yellow) in CIE Yxy are close to the boundary of the sRGB gamut. Setting the Working Color Space to ACEScsg gamut, the colors keep their positions close to the boundary. But they are shifted because the ACEScsg gamut is more expansive (cyan in *Fig. 19*). Technically, the numbers do not change but are interpreted as belonging to another color space. Moving the color positions out of the sRGB gamut is also possible. This may cause problems like negative color values [16] when converted back to sRGB. The ACEScsg renders show the shifting (*Table 20*: fields highlighted in

dark green). The sRGB renders are restricted to the sRGB color space and stay inside the gamut (fields highlighted in light green).

Converting the texture from sRGB to ACEScg solves the problem, and the ACEScg renders show the correct original color (red in Fig. 19).

Recommendation

- When working in ACEScg color space, make sure that all sRGB color inputs are converted to ACEScg.
- Otherwise, they appear oversaturated.

5. Conclusions and recommendations

To summarize the test, rendering content out of Unreal 5 using the ACEScg color space is strongly recommended. It not only transmits the HDR values but maintains the color fidelity. This approach avoids the influence of Unreal's Tone Curve. It makes it easier to combine Unreal renders with images from other sources in compositing. It also lets you choose which rendering intent you want to apply at the final stage.

Here are the conclusions and recommendations when working with ACEScg render workflow in Unreal 5:

- Always use ACEScg renders for cinematic scene-referred color.
 1. Transmits HDR-Luminance values
 2. Better color fidelity (no Tone Curve/Render Intent)
 3. Better image resolution (16Bit half-float)
- Do not turn off the Tone Curve for sRGB renders.
- Better image resolution for sRGB renders with OpenEXR renders.
- Use ACEScg Working Color Space in Unreal only if you have a sophisticated Texture Management.

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