http://forpub.s3.amazonaws.com/SMW_W1-download.zip
Download all code and test files except LCEVC (Windows-only)

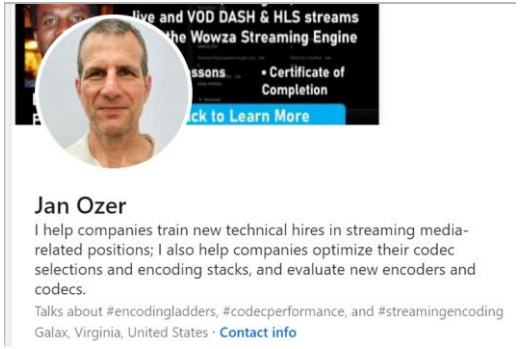
Download presentation: bit.ly/W1_SMW_2022

W1: ADVANCED CODEC IMPLEMENTATION & PRODUCTION

Streaming Media West
Jan Ozer
janozer@gmail.com
www.streaminglearningcenter.com
Courses.streaminglearningcenter.com

Introduction

https://www.linkedin.com/in/jan-ozer/



- Jan
  - Contributing editor Streaming Media Magazine
  - Author Video Encoding by the Numbers
  - Blogs at Streaming Learning Center/OTTVerse
  - Courses at courses.streaminglearningcenter.com

Agenda

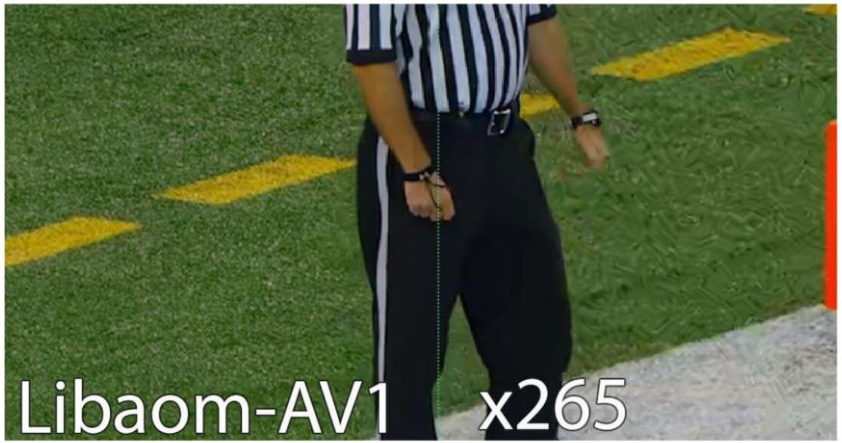
- Introduction
- Overall quality
- H.264
- VP9
- HEVC
- AV1
- VVC
- LCEVC
- EVC

Quality

Should be 9:05

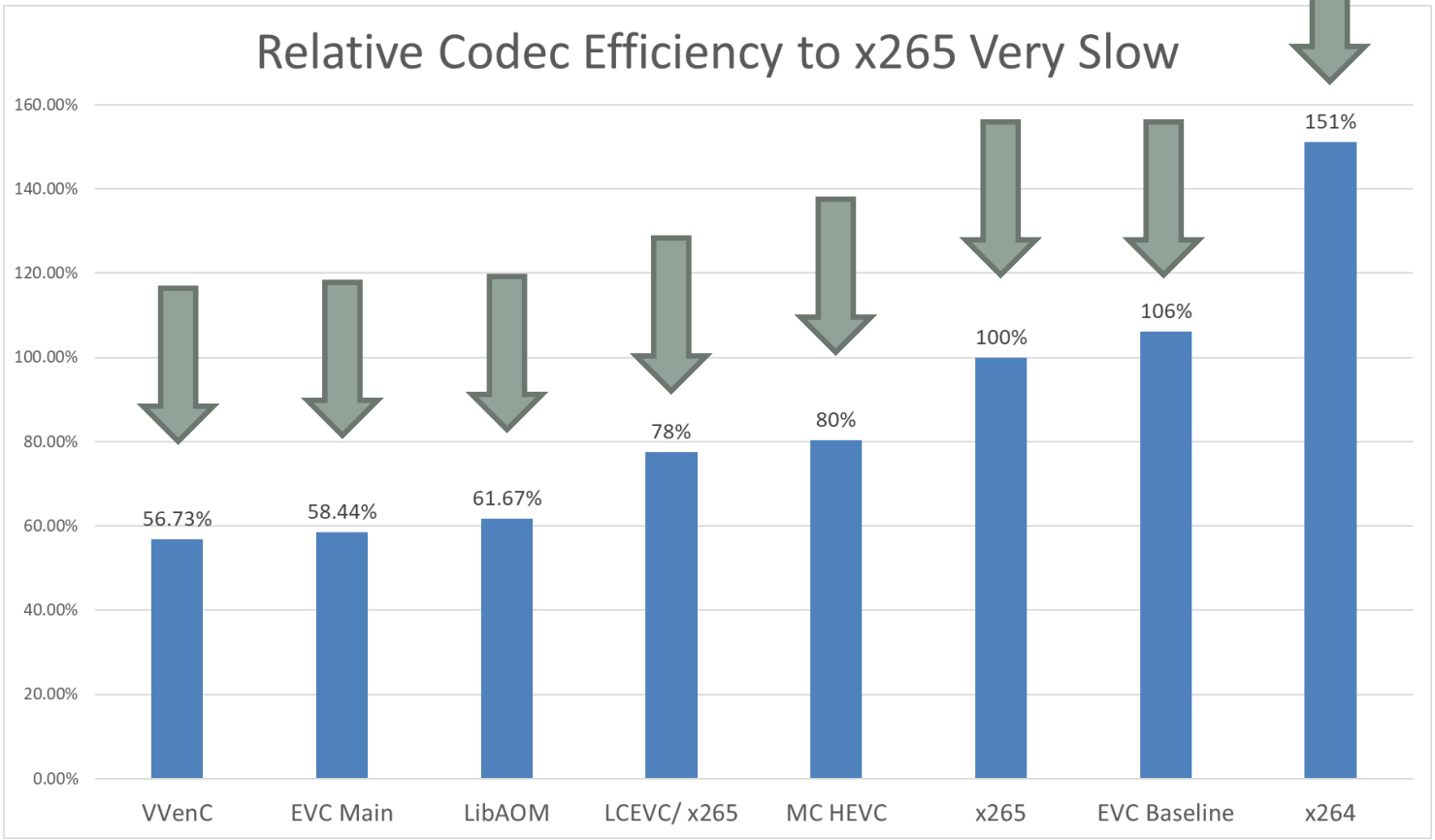
- Streaming Media
- MSU
- Key takeaways

Testing EVC, VVC, and LCEVC: How Do the Latest MPEG Codecs Stack Up?

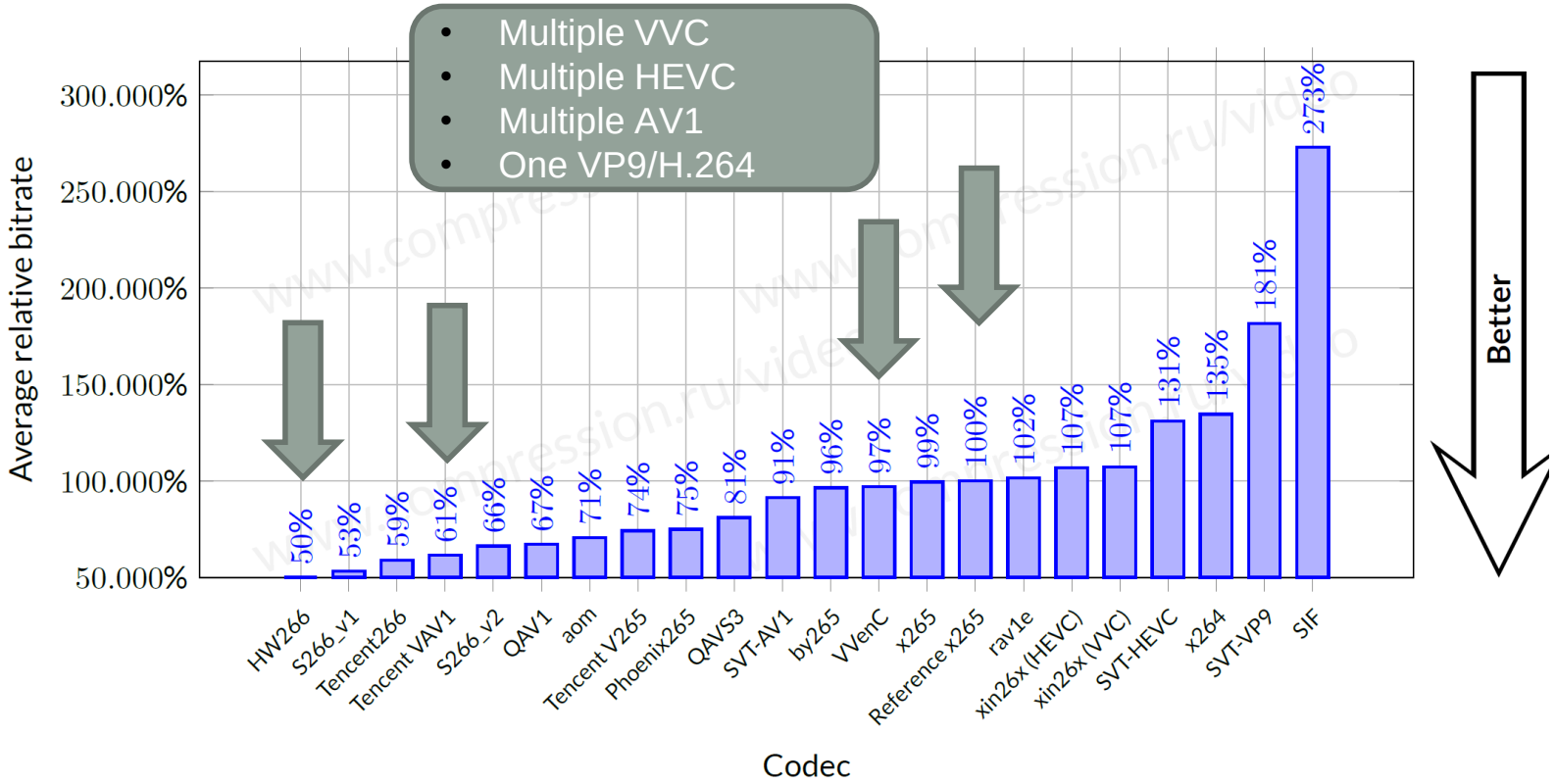


https://bit.ly/codec_soup

Streaming Media Magazine



Moscow State University



http://bit.ly/MSU_codec_2021

Common Data Points – vs. x265

	Best VVC	EVC Main	Best AV1	LCEVC/ x265	Other HEVC	EVC Baseline	x264
Streaming Media	~43%	~42%	~38%	~22%	~20%	+~6%	+~51%
MSU	~50%	NA	~39%	NA	~26%	NA	+~35%

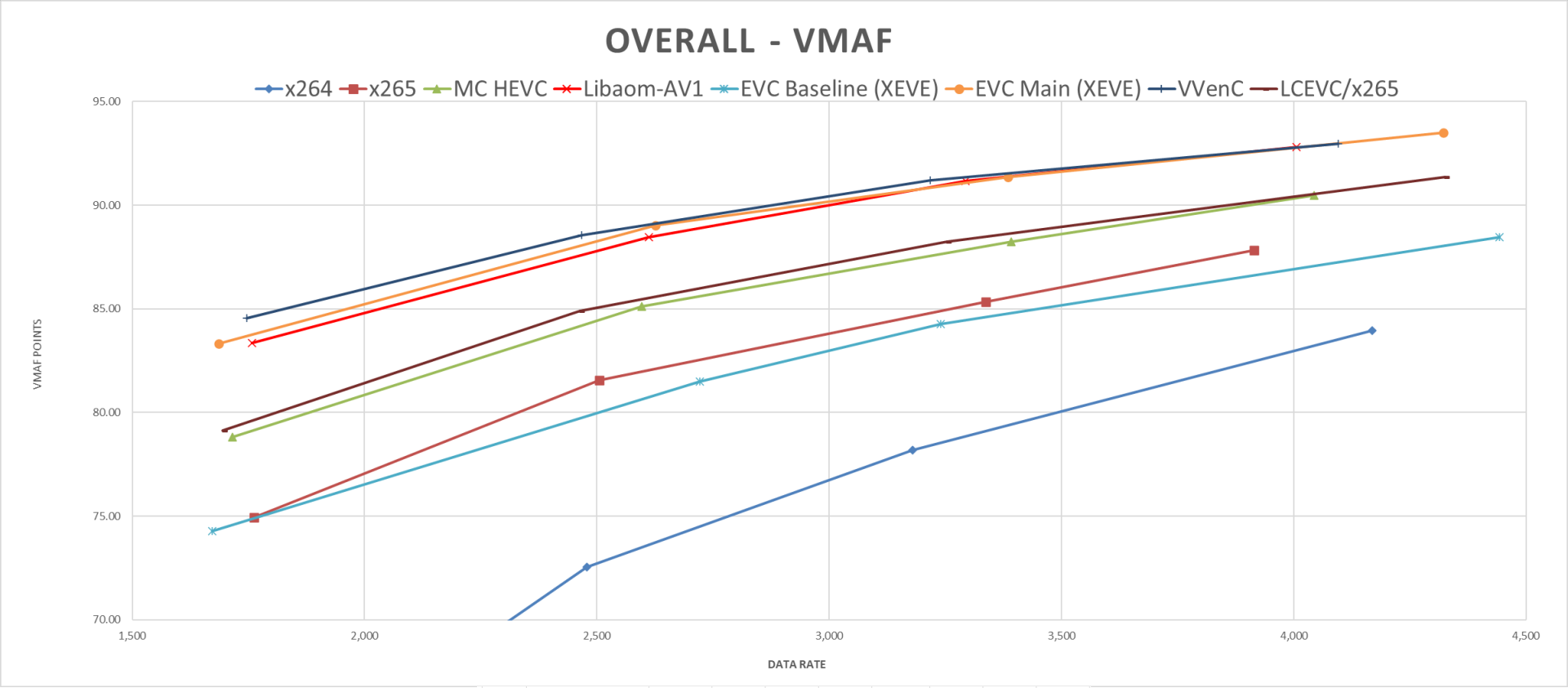
- Common takeaways (Streaming Media ***and*** MSU):
  - VVC – between 43 – 50% more efficient than x265
  - AV1 – around 38% more efficient than x265
  - Other HEVC implementations – up to 26% more efficient than x265
  - x265 between 35 – 51% more efficient than x264
- Other takeaways (Streaming Media only):
  - EVC Main – very efficient in early open-source version - ~42% more efficient than x265
  - LCEVC/x265 as base layer – 22% more efficient than x265
  - EVC Baseline - ~45% more efficient than x264

Caveat

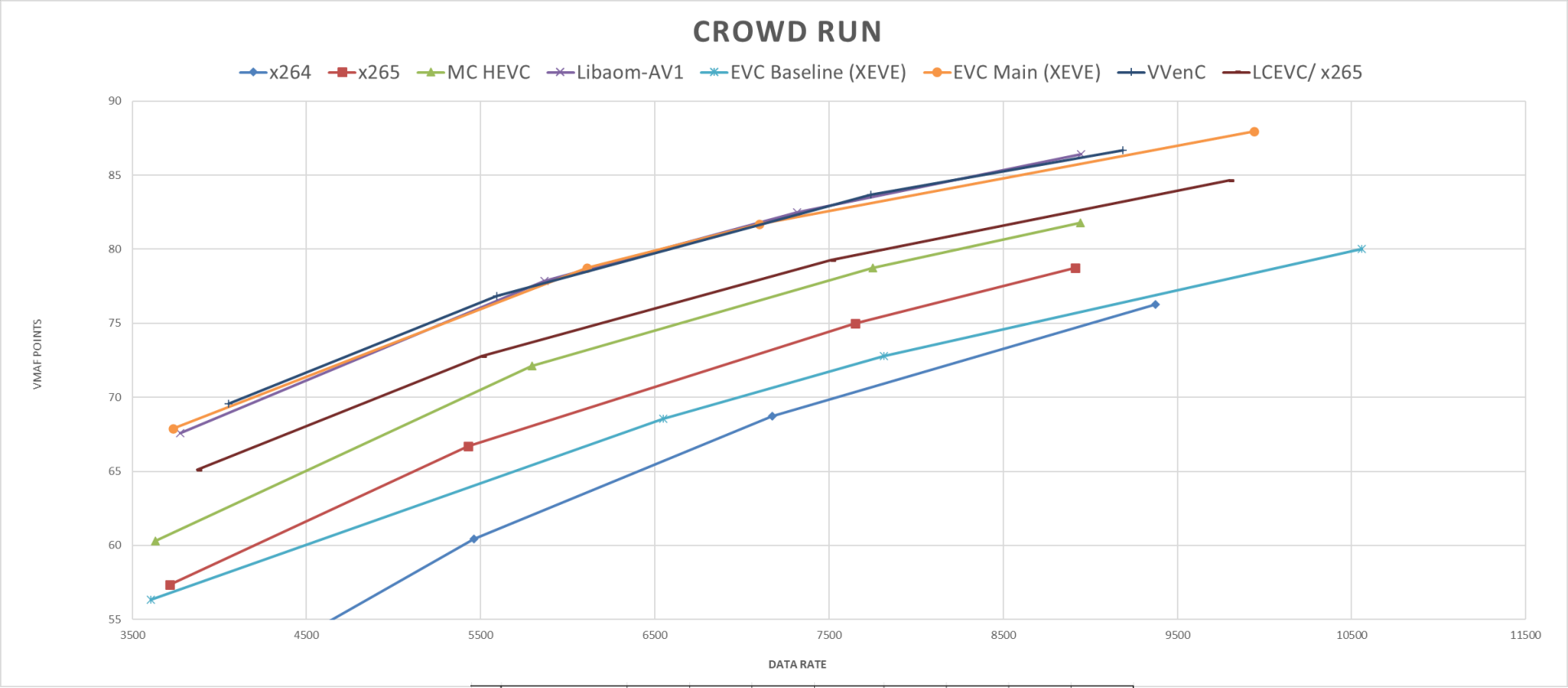
- Streaming Media/MSU tests are BD-Rate computations based upon ***four 1080p files***
  - You don’t distribute four 1080p files
- To compute true impact on your bandwidth/QoE
  - Full encoding ladder
  - Accurate rung usage rate

Rate Distortion Curves and BD-Rate Charts

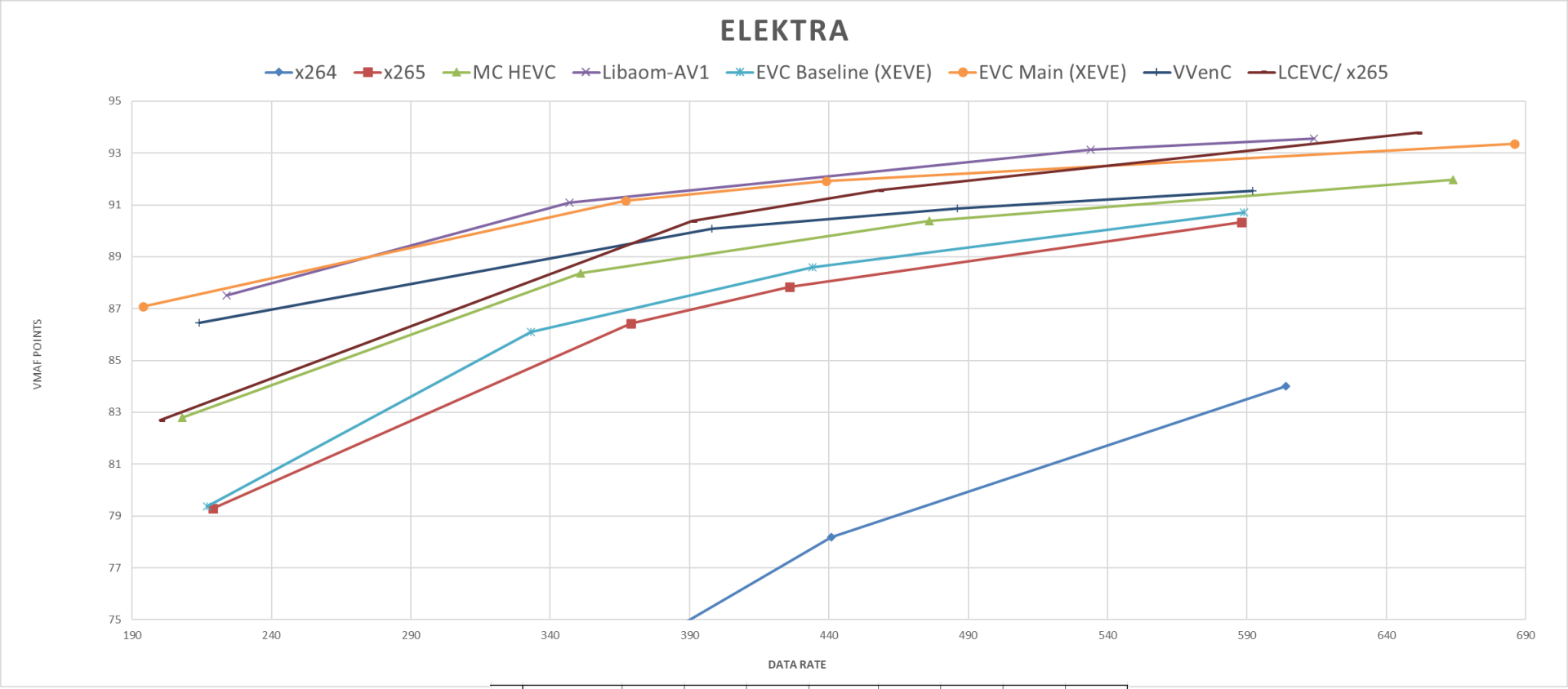
- Summary
- Crowd Run
- Elektra
- EuroTruckSimulator 2
- Football
- Sintel



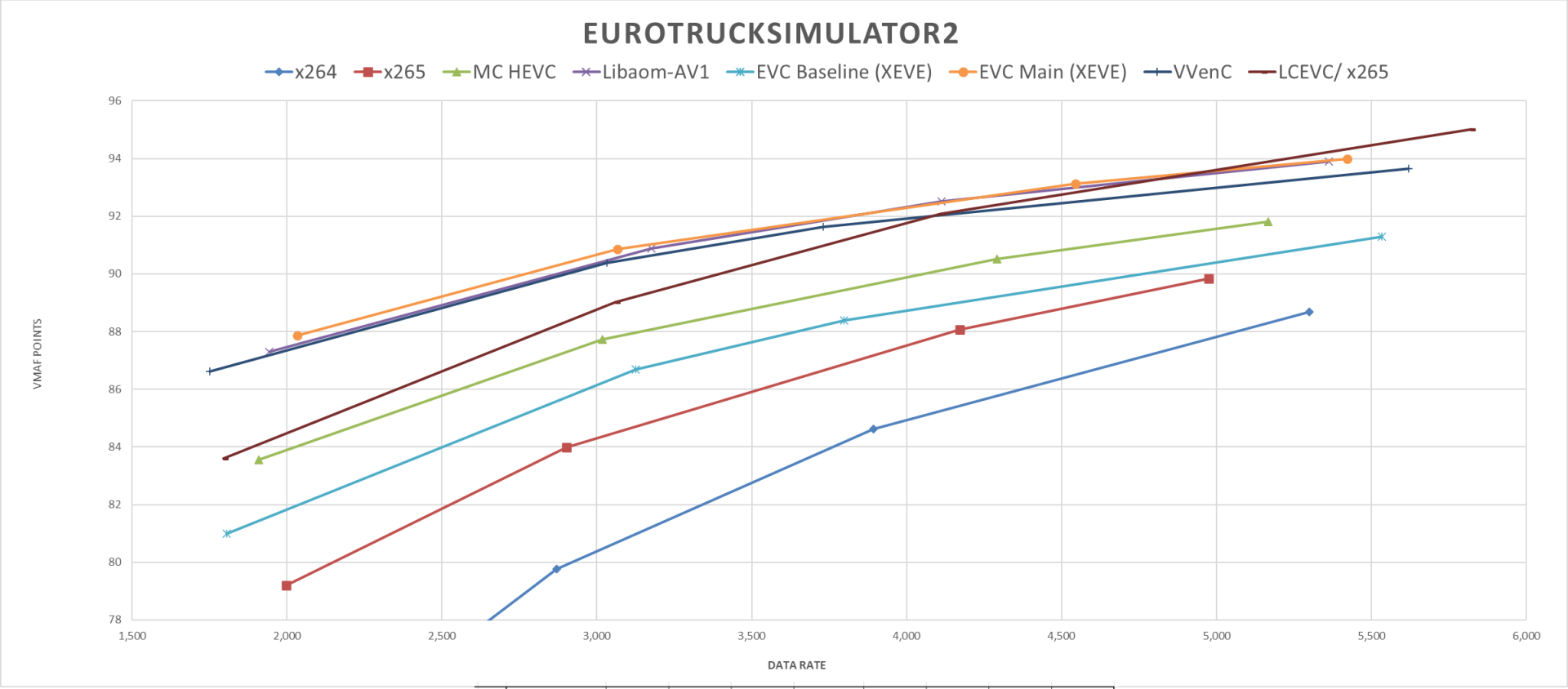
Rank	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	51.19%	84.22%	128.89%	43.26%	139.23%	149.89%	89.96%
6	x265	-33.86%	X	24.44%	62.14%	-5.71%	71.11%	76.29%	28.98%
5	MC HEVC	-45.72%	-19.64%	X	30.81%	-24.72%	37.06%	40.93%	3.56%
3	Libaom-AV1	-56.31%	-38.33%	-23.55%	X	-41.57%	3.52%	5.87%	-20.91%
7	EVC Baseline (XEVE)	-30.20%	6.05%	32.83%	71.14%	X	80.48%	85.48%	37.69%
2	EVC Main (XEVE)	-58.20%	-41.56%	-27.04%	-3.40%	-44.59%	X	2.42%	-24.12%
1	VVenC	-59.98%	-43.27%	-29.04%	-5.55%	-46.08%	-2.36%	X	-26.18%
4	LCEVC/ x265	-47.36%	-22.47%	-3.44%	26.44%	-27.37%	31.79%	35.47%	X



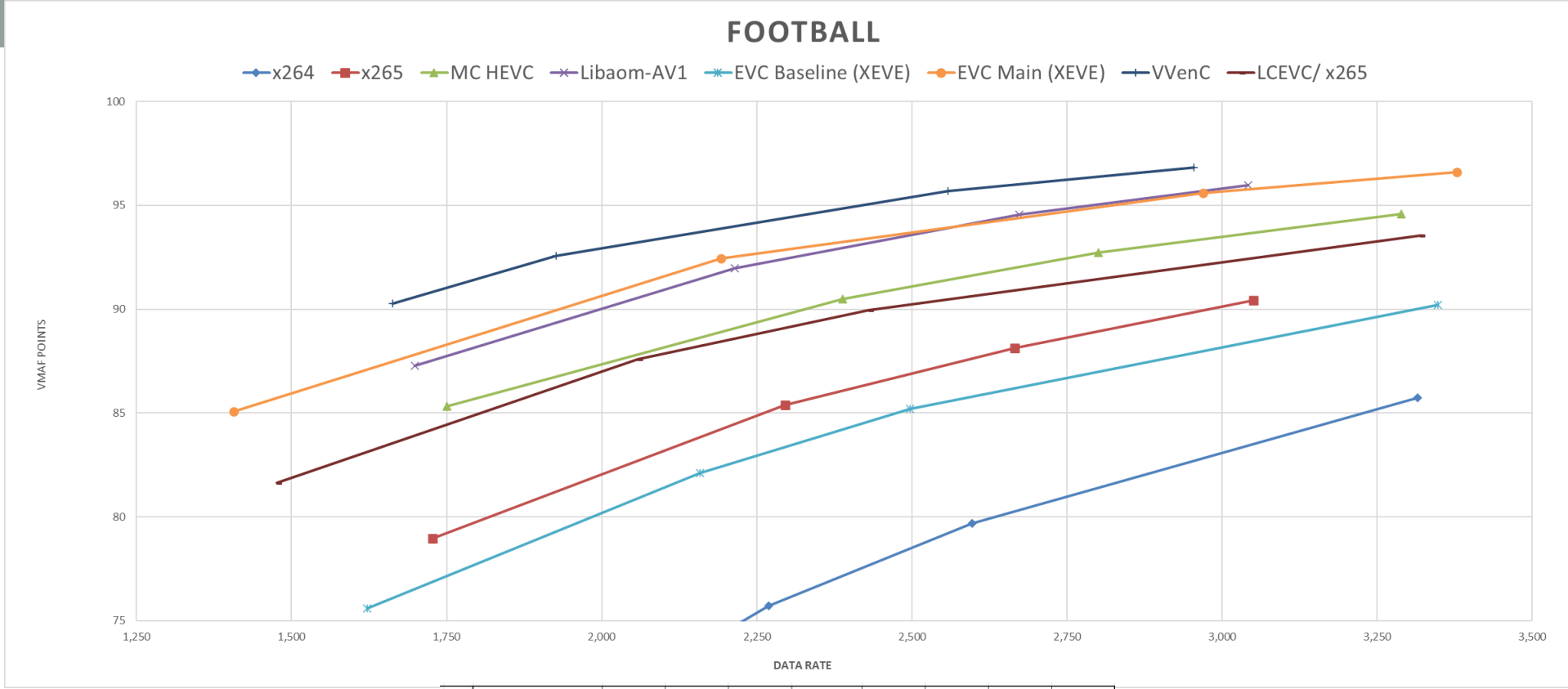
	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	EVC Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	23.64%	42.62%	77.38%	13.74%	79.87%	77.12%	53.82%
6	x265	-19.12%	X	16.55%	48.45%	-8.96%	50.25%	48.96%	27.13%
5	MC HEVC	-29.89%	-14.20%	X	27.09%	-22.54%	28.17%	27.60%	8.29%
3	Libaom-AV1	-43.62%	-32.64%	-21.31%	X	-39.73%	0.27%	0.38%	-15.52%
7	EVC Baseline (XEVE)	-12.08%	9.84%	29.10%	65.93%	X	67.71%	66.52%	41.55%
2	EVC Main (XEVE)	-44.40%	-33.44%	-21.98%	-0.27%	-40.37%	X	0.29%	-15.97%
1	VVenC	-43.54%	-32.87%	-21.63%	-0.38%	-39.95%	-0.29%	X	-16.21%
4	LCEVC/ x265	-34.99%	-21.34%	-7.65%	18.38%	-29.35%	19.01%	19.34%	X



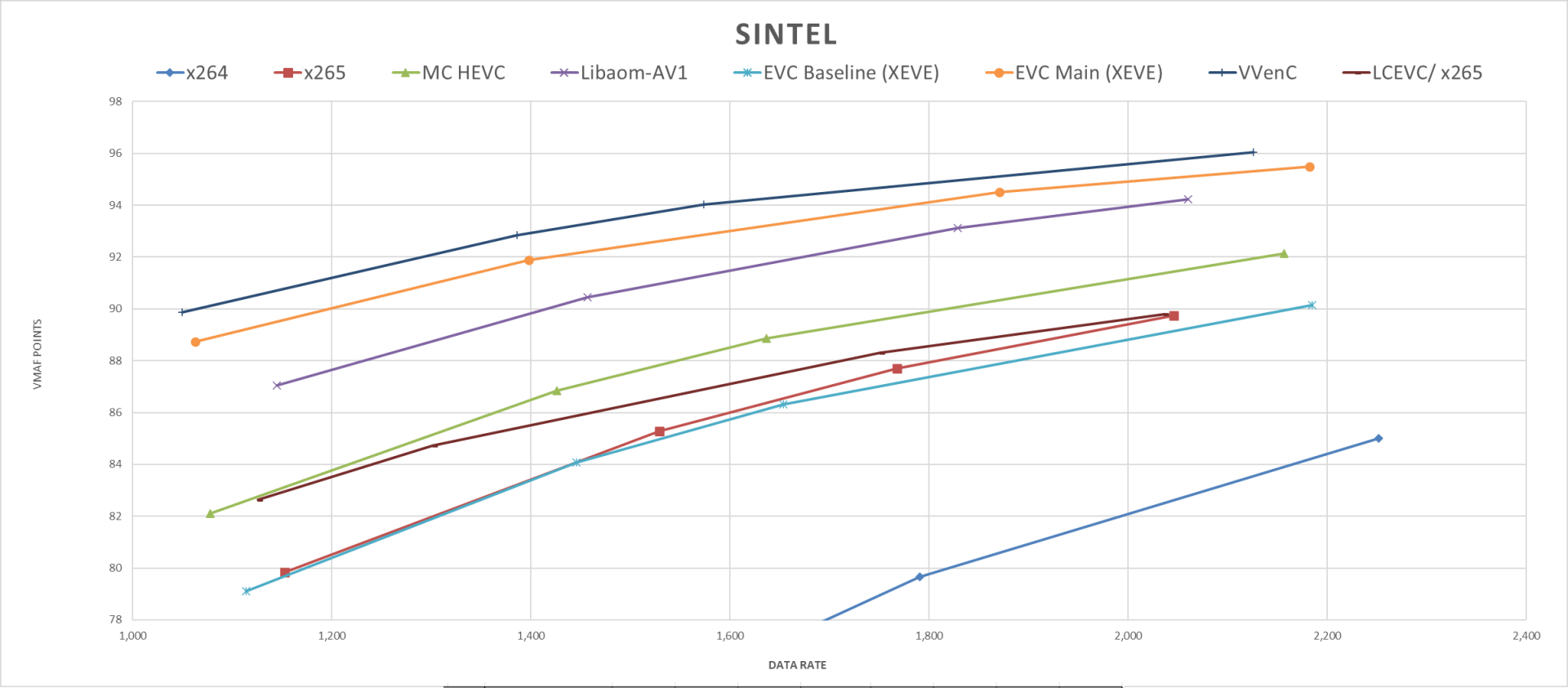
	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	EVC Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	107.87%	169.93%	100.00%	116.90%	100.00%	100.00%	180.43%
7	x265	-51.89%	X	30.76%	88.80%	5.96%	97.83%	57.88%	42.59%
5	MC HEVC	-62.95%	-23.52%	X	51.28%	-18.02%	53.07%	18.79%	12.33%
1	Libaom-AV1	-100.00%	-47.03%	-33.90%	X	-43.48%	-2.45%	-22.87%	-18.61%
6	EVC Baseline (XE	-53.90%	-5.63%	21.98%	76.94%	X	83.95%	45.65%	33.81%
2	EVC Main (XEVE)	-100.00%	-49.45%	-34.67%	2.51%	-45.64%	X	-23.63%	-17.99%
3	VVenC	-100.00%	-36.66%	-15.82%	29.65%	-31.34%	30.95%	X	-2.47%
4	LCEVC/ x265	-64.34%	-29.87%	-10.98%	22.87%	-25.27%	21.94%	2.53%	X



	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	EVC Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	28.81%	72.71%	136.28%	53.07%	140.00%	142.11%	89.10%
7	x265	-22.37%	X	36.99%	91.34%	19.29%	95.66%	93.67%	51.73%
5	MC HEVC	-42.10%	-27.00%	X	44.28%	-14.47%	48.35%	42.94%	13.80%
2	Libaom-AV1	-57.68%	-47.74%	-30.69%	X	-40.51%	2.44%	-3.44%	-13.23%
6	EVC Baseline (XE	-34.67%	-16.17%	16.92%	68.09%	X	73.02%	67.26%	31.97%
1	EVC Main (XEVE)	-58.33%	-48.89%	-32.59%	-2.38%	-42.20%	X	-6.23%	-13.97%
3	VVenC	-58.70%	-48.37%	-30.04%	3.56%	-40.21%	6.64%	X	-12.51%
4	LCEVC/ x265	-47.12%	-34.09%	-12.13%	15.25%	-24.22%	16.24%	14.29%	X



	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	EVC Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	44.57%	85.88%	100.00%	33.74%	129.47%	100.00%	85.72%
6	x265	-30.83%	X	29.84%	51.14%	-8.97%	62.83%	81.66%	26.86%
4	MC HEVC	-46.20%	-22.98%	X	18.70%	-30.25%	25.17%	43.24%	-6.34%
3	Libaom-AV1	-100.00%	-33.84%	-15.75%	X	-40.16%	4.61%	18.57%	-20.93%
7	EVC Baseline (XEVE)	-25.23%	9.86%	43.37%	67.10%	X	79.71%	100.00%	39.83%
2	EVC Main (XEVE)	-56.42%	-38.59%	-20.11%	-4.41%	-44.36%	X	15.28%	-22.96%
1	VVenC	-100.00%	-44.95%	-30.19%	-15.66%	-100.00%	-13.26%	X	-7.80%
5	LCEVC/ x265	-46.16%	-21.17%	6.77%	26.47%	-28.48%	29.79%	8.46%	X



	Overall	x264	x265	MC HEVC	Libaom-AV1	Baseline (XEVE)	EVC Main (XEVE)	VVenC	LCEVC/ x265
8	x264	X	53.16%	80.62%	100.00%	52.53%	100.00%	100.00%	74.75%
6	x265	-34.71%	X	18.01%	48.00%	-1.60%	78.18%	100.00%	9.90%
4	MC HEVC	-44.63%	-15.26%	X	27.23%	-16.91%	51.77%	67.96%	-6.82%
3	Libaom-AV1	-100.00%	-32.43%	-21.40%	X	-34.49%	17.49%	29.82%	-29.30%
7	EVC Baseline (XEVE)	-34.44%	1.63%	20.35%	52.65%	X	84.07%	103.69%	12.12%
2	EVC Main (XEVE)	-100.00%	-43.88%	-34.11%	-14.88%	-45.67%	X	11.37%	-42.54%
1	VVenC	-100.00%	-100.00%	-40.46%	-22.97%	-50.90%	-10.21%	X	-100.00%
5	LCEVC/ x265	-42.77%	-9.01%	7.32%	41.45%	-10.81%	74.04%	100.00%	X

H.264 – 2022 Perspective

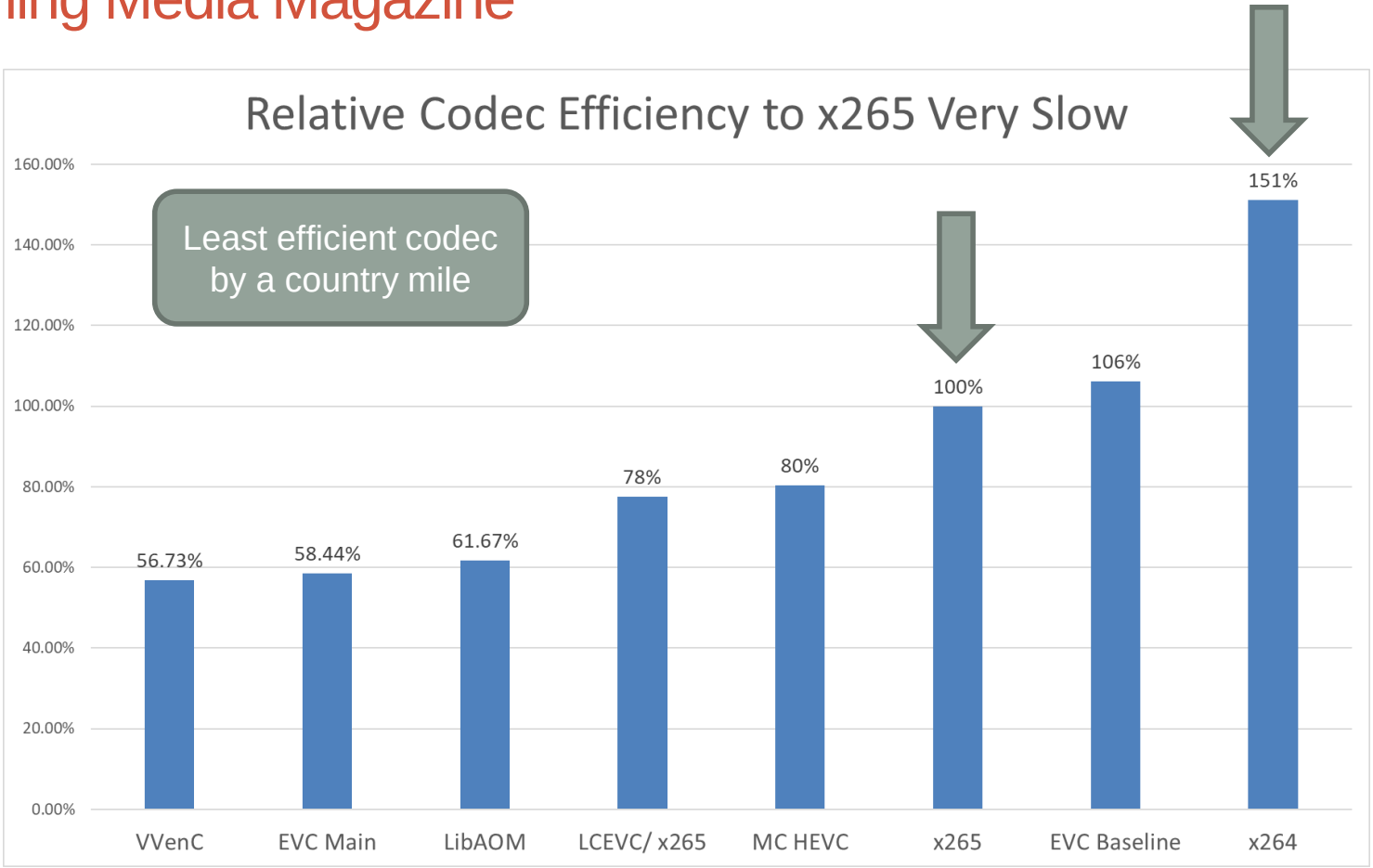
Should be 9:15

- About H.264
- Video quality
- Known royalty costs
- Unique selling proposition
- Rich parents (key stakeholders)
- Producibility
- Playability

About H.264

- Standards-based codec from MPEG/ITU
  - MPEG – AVC (Advanced Video Coding)
  - ITU – H.264
- Published – August 17, 2004
- Standards-based successor to MPEG-2

Streaming Media Magazine



Known Royalty Cost

- Royalties are an accepted cost of video codecs
  - Vast bulk paid by hardware and software implementors; not content producers
  - H.264 does have content fees

- **Products sold to end users and OEM for PC but not part of OS (decoder, encoder or product consisting of one decoder and one encoder = "unit")**
  - **0 - 100,000 units/year = no royalty (available to one legal entity in an affiliated group)**
  - **US $0.20 per unit after first 100,000 units/year**
  - **Above 5 million units/year, royalty = US $0.10 per unit**
  - **Enterprise cap: $3.5M per year 2005-2006, $4.25M per year 2007-08, $5M per year 2009-10, $6.5Mper year 2011-2015; $8.125M in 2016 and $9.75M per year in 2017 through 2025**

- 0-100K - $0.00
- 100K – 5M - $0.20
- 5 M+ = $0.10
- Cap: Currently $9.75

bit.ly/MPEG_LA_H264

Known Royalty Cost - Content

- **Where End User pays for AVC Video**
  - **Subscription (not limited by title) – 100,000 or fewer subscribers/yr = no royalty; > 100,000 to 250,000 subscribers/yr = $25,000; >250,000 to 500,000 subscribers/yr = $50,000; >500,000 to 1M subscribers/yr = $75,000; >1M subscribers/yr = $100,000**
  - **Title-by-Title - 12 minutes or less = no royalty; >12 minutes in length = lower of (a) 2% or (b) $0.02 per title**
- **Where remuneration is from other sources**
  - **Free Television - (a) one-time $2,500 per transmission encoder or (b) annual fee starting at $2,500 for > 100,000 HH rising to maximum $10,000 for >1,000,000 HH**
  - **Internet Broadcast AVC Video (not title-by-title, not subscription) – no royalty for life of the AVC Patent Portfolio License**

Subscriber: $100K cap

Per-title: lower of 2% or $0.02

Free TV: $10K cap

Free Internet video – No royalty

bit.ly/MPEG_LA_H264

Codec Unique Selling Proposition

- Cheap to encode
- Plays everywhere

Rich Parents – H.264 Stakeholder

- Virtually all companies in the broadcast or streaming media ecosystem

- Publisher, product, or service provider
- All support H.264

Producibility

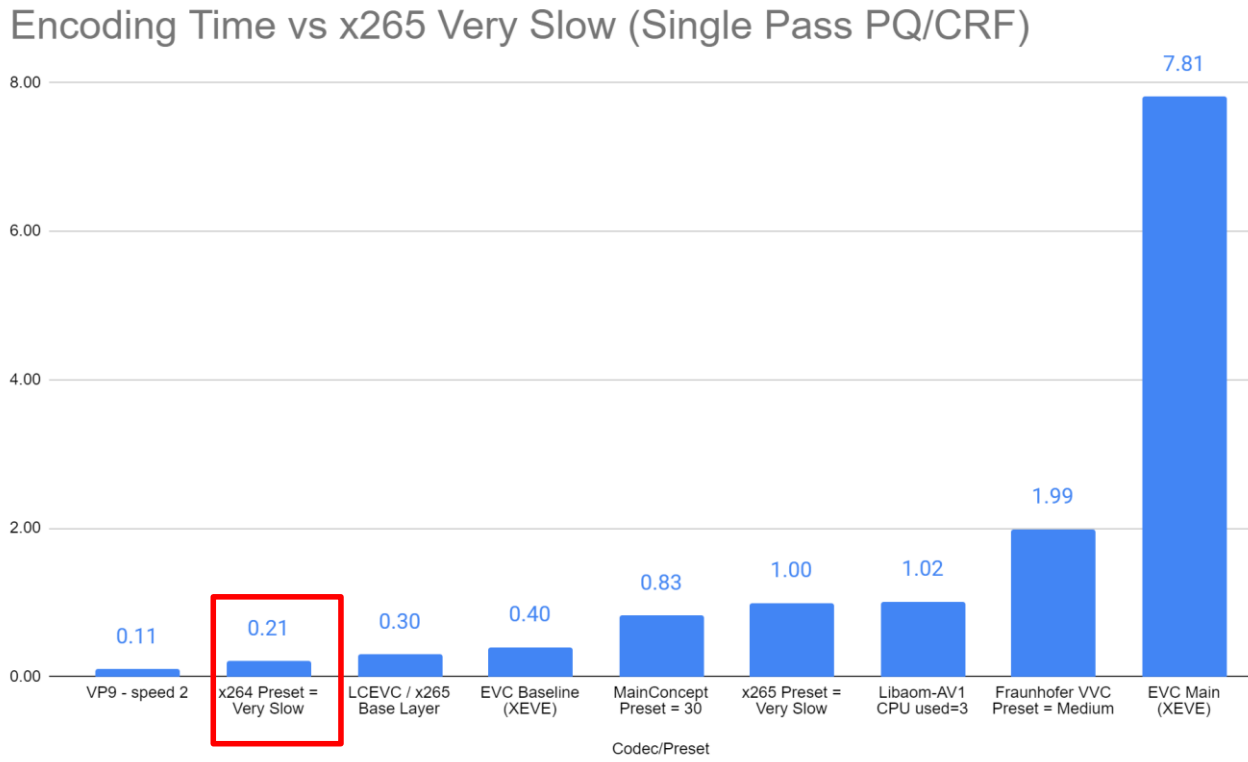
- Can you affordably produce the codec in software?
- What about live origination and transcode?
  - Software?
  - Hardware?

Producibility - Software

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)

- H.264 is one of the least expensive codecs to produce
- Can be produced very efficiently in software
- Supported by every desktop and cloud encoder, for-fee and open source



Cloud Pricing

	AWS	Azure	Bitmovin	Brightcove	Tencent
Highest base charge (30 fps/1080p)	$0.042	$0.03	~$0.02	$0.08	$0.0215
	go.aws/37IbODX	bit.ly/Azure_pricing	bit.ly/BM_pricing	bit.ly/BC_pricing	bit.ly/TC_pricing

FFmpeg Command Strings

Single Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libx264  -b:v 3350K -an -preset
veryfast -threads 8 -g 60 -keyint_min 60 -sc_threshold 0
output_x264.mp4
```

Two-Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libx264  -b:v 2500K -preset veryslow -
g 60 -keyint_min 60 -sc_threshold 0  -pass 1 -f mp4 NUL & \

ffmpeg -i input.mp4 -c:v libx264 -b:v 2500K -maxrate 5000K  -
bufsize 5000k  -preset veryslow   -g 60 -keyint_min 60 -
sc_threshold 0  -pass 2 output.mp4
```

Producibility –Hardware Origination/Transcoding for Live

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility								
- Encoder support	Ubiquitous	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Live software/ hardware	Yes	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

- Ubiquitous support but much less efficient than HEVC
- Important for live-origination, where outbound bandwidth is expensive

Playability

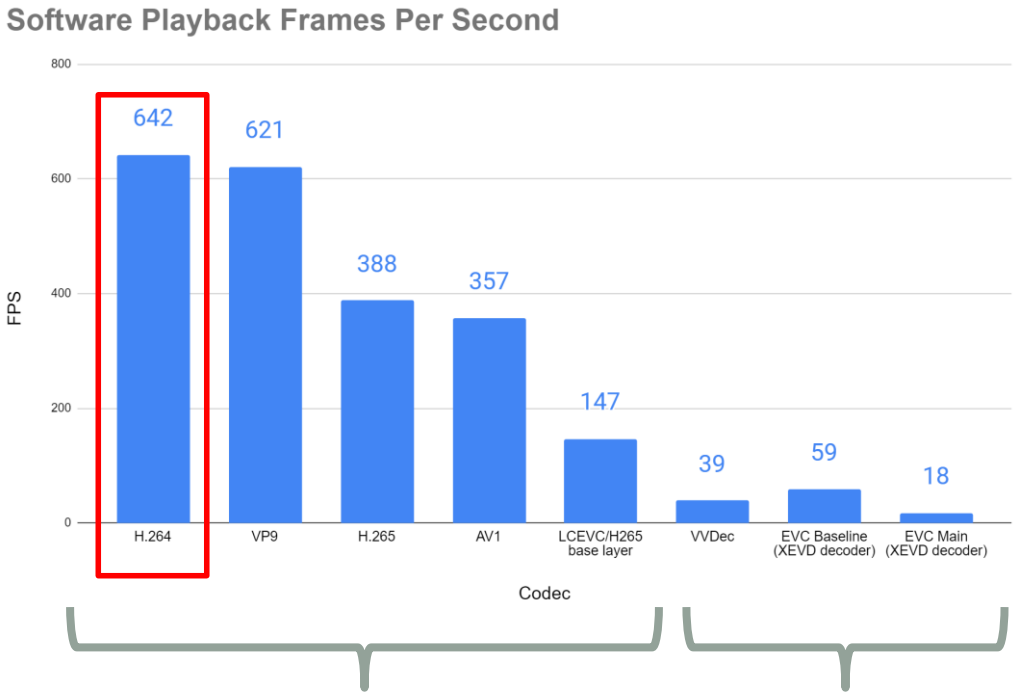
- Software playback status
  - Desktop/mobile
- Hardware playback status
  - Mobile/Living Room

Playability - Performance

- Can the codec play in software?
  - H.264 is supported in hardware on most platforms
  - But can play efficiently without hardware acceleration
    - No problem

Device specifications

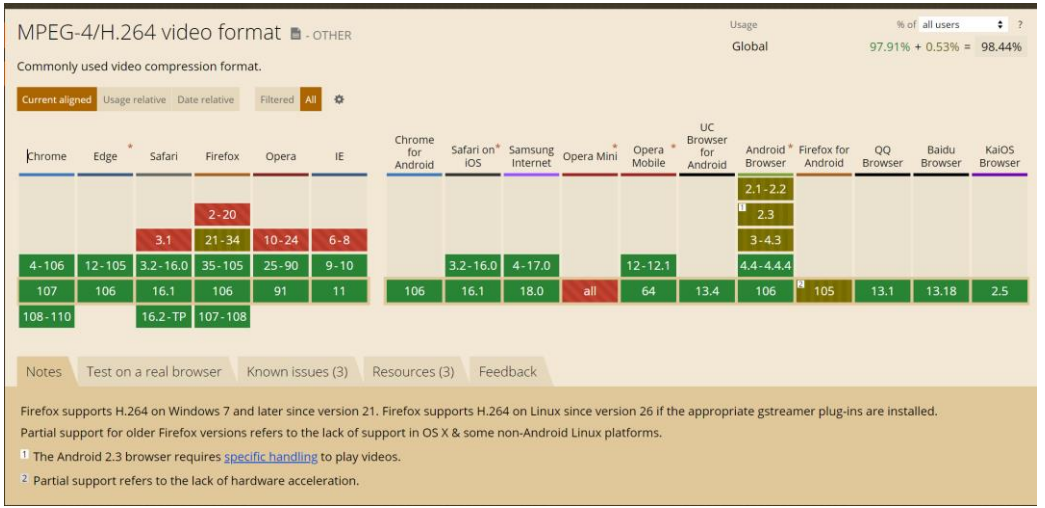
Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



Playability – Compatibility - Computer and Mobile Browser Support

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	642 fps	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	98.44	22.91%	97.64%	73.2%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	NA	No	NA	NA	No	Yes	No	No

- H.264 can play in software, but how is platform support?
- H.264 superpower is near ubiquitous playback



https://caniuse.com/?search=h.264

H.264 Chip Support – Mobile

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- H.264 is fully supported in Apple and Android phones
- Safe choice for power consumption

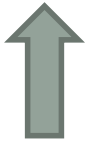
Chip Support –TV

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices	Fully supported in most living room devices with HDR	• Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek			

Supported but HEVC is format of choice for HDR and 4K

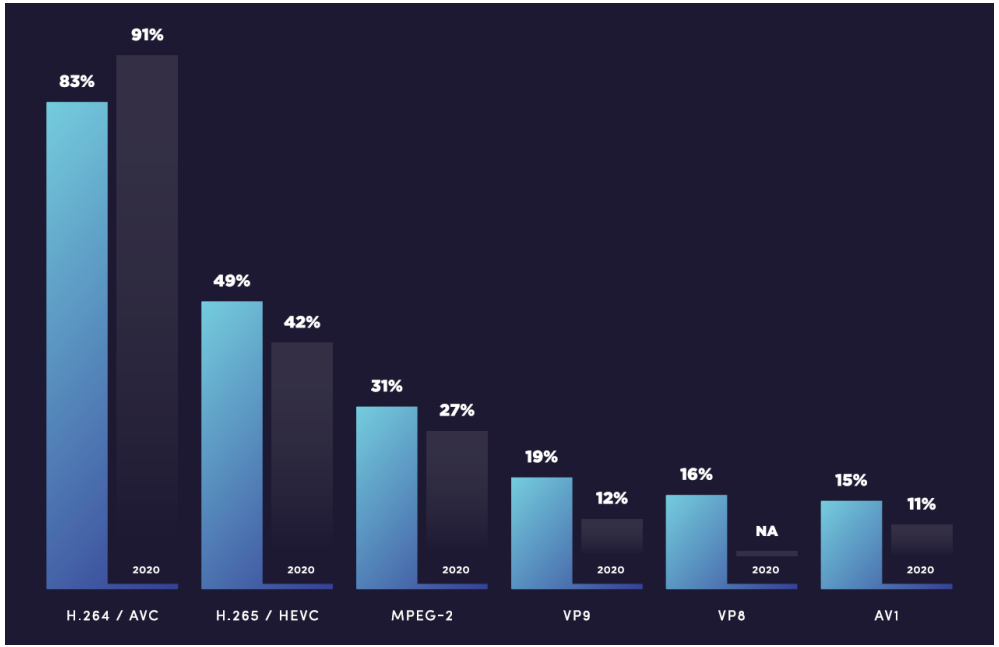
Timing of Mainstream Adoption

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	642 fps	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser	Now	Never	Now	Now	Never	Never	Never	Never
- Browser workaround	**NA**	**$$$$**	NA	NA	**$$$$**	**Yes**	?	?
- Mobile – hardware	Now	Now	Now	2024+	2025+	NA	Not on radar	Not on radar
- Mobile - software	Now	NA	NA	Caution	Stakeholders	Today	Not on radar	Not on radar
- Smart TV/STB	Now (but no HDR)	Ubiquitous	Ubiquitous	Mid 2023	Mid - 2025	Software-only	Not on radar	Not on radar



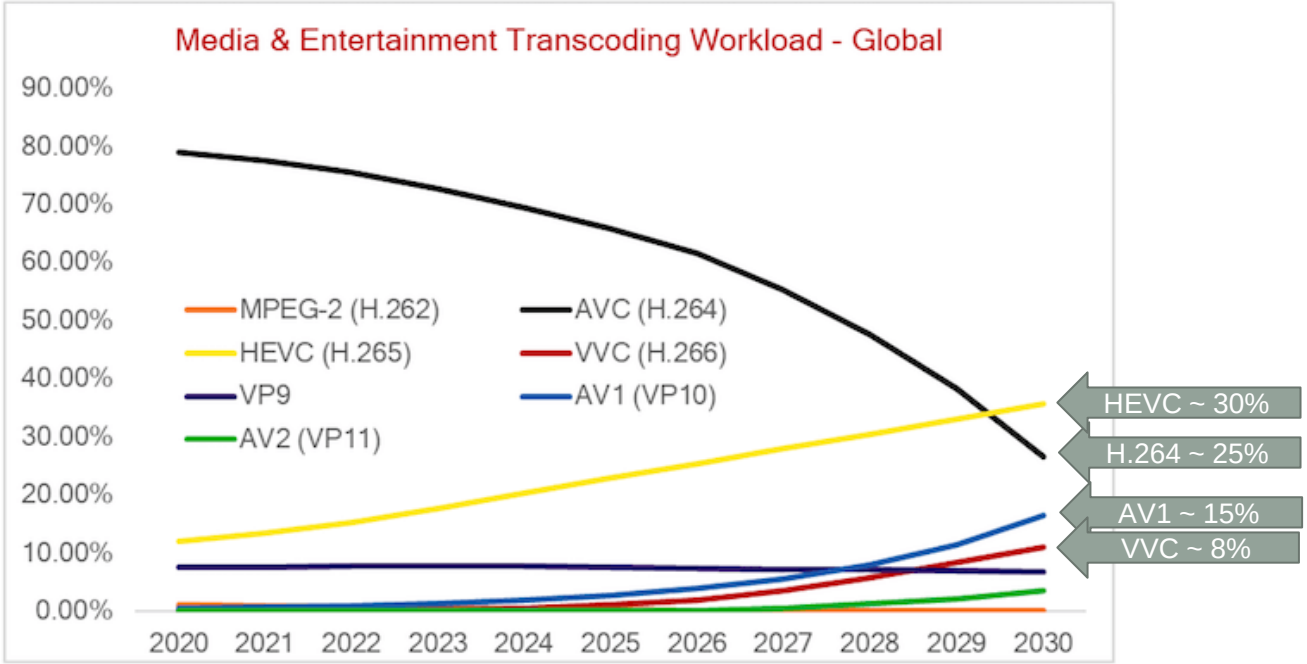
Third-Party Predictions

- 83% currently using H.264
  - Down from 91% in 2020
  - Hard to reconcile since H.264 is almost universally deployed for playback on legacy devices



Bitmovin - Bitmovin Video Developer Report

Third-Party Predictions



- Rethink TV –H.264 usage will decline over the next 8 years

http://bit.ly/rethink_codec

HEVC – 2022 Perspective

Should be 9:35

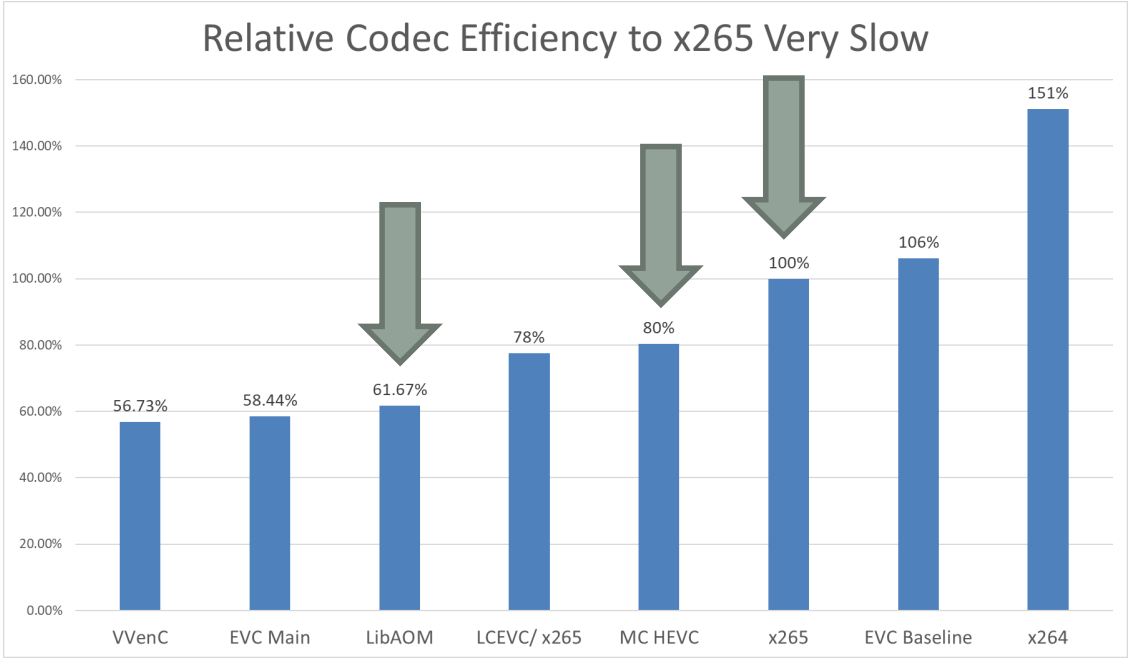
- About HEVC
- Video quality
- Known royalty costs
- Unique selling proposition
- Rich parents (key stakeholders)
- Producibility
- Playability

About HEVC

- Stands for High Efficiency Video Coding
- Standards-based codec from MPEG/ITU
  - MPEG – HEVC
  - ITU – H.265
- Published – January 25, 2013
- Standards-based successor to H.264

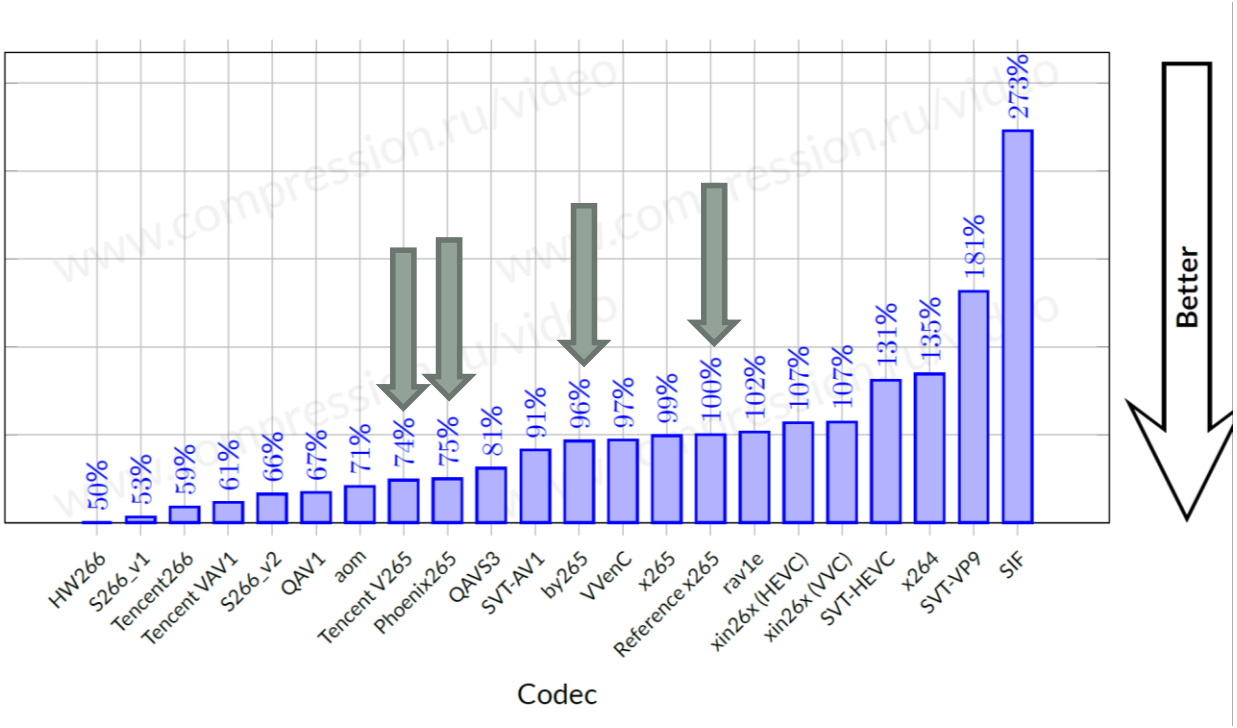
Streaming Media Magazine – HEVC Quality

- Depends upon the codec implementation
  - Most use open source x265
    - About 33% more efficient than x264
  - MainConcept was about 47% more efficient
- Both well behind AV1
  - 58% more efficient than x264



Moscow State University

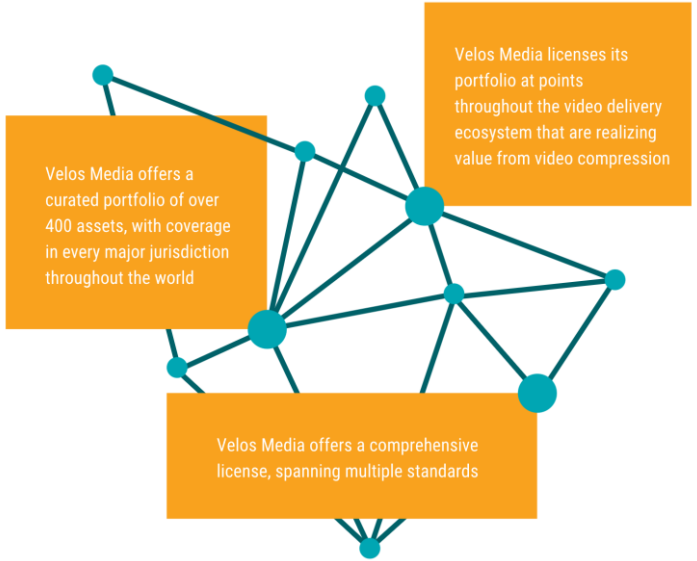
- There are many higher quality alternatives to x265
  - Here's the reference
  - ByteDance
  - Phoenix
  - Tencent
- The problem is:
  - May not be for sale or license
  - May be for private use (ByteDance)
  - Or for cloud encoding
  - Many big licensing companies not represented
    - MainConcept
    - Beamr
    - Fraunhoffer



http://bit.ly/MSU_codec_2021

Known Royalty Cost

- Three pools
  - MPEG LA
  - Access Advance (formerly HEVC Advance)
  - Velos
    - No longer traditional pool
    - Appears to be licensing their own patents across different video standards
    - No royalty charges provided
    - Former members (like Qualcomm) likely licensing directly
    - Bottom line – still a mess



Royalties – HEVC – MPEG LA

- **Decoder-Encoder Sublicenses**
  - **HEVC Products Sold to End Users by a Licensee with (a) ownership/control of the brand name or (b) if the HEVC Product bears no brand name, with discretion over decision to Sell**
    - **0 - 100,000 units/year = no royalty (available to one Legal Entity in an affiliated group)**
    - **US $0.20 per unit after first 100,000 units each year**
    - **Maximum annual royalty payable by an Enterprise (Legal Entity and Affiliates) is $25M**

No content royalties

bit.ly/mpegla_HEVC

Royalties – HEVC – Access Advance

Device Category and Examples	Selling Price	Per-Device Royalty[1] All Profiles and Optional Features	Annual In-Compliance Device Category Caps[2] for the Period up to 1/1/2021	Annual In-Compliance Device Category Caps[2] for the Period on/after 1/1/2021 unless suspension applies[3]	Annual In-Compliance Enterprise Credit and Cap[2] for the Period up to 1/1/2021	Annual In-Compliance Enterprise Credit and Cap[2] for the Period on/after 1/1/2021 unless suspension applies[3]
Mobile Devices: Mobile Phone, Tablet, Laptop	All price ranges	$0.40/$0.20	$30MM $20MM (If entity does not sell phones)	$36MM $24MM (If entity does not sell phones)		
Connected Home & Other Devices: Set-Top Box, Game Console, Blu-ray Player, Desktop PC, non-4k UHD+ TV, Surveillance Cameras, Conferencing Products, Medical Imaging, Digital Signage, HEVC Software	Devices ≤$80.00[4] $20 or less $20.01-$30.00 $30.01-$40.00 $40.01-$50.00 $50.01-$60.00 $60.01-$70.00 $70.01-$80.00	$0.20/$0.20 $0.25/$0.25 $0.35/$0.35 $0.45/$0.40 $0.55/$0.40 $0.65/$0.40 $0.75/$0.40	$20MM	$24MM	Annual Enterprise Cap $40 million Annual Enterprise Credit $25,000	Annual Enterprise Cap $48 million Annual Enterprise Credit $25,000
	Devices >$80.00[5] and All HEVC Software	$0.80/$0.40				
4K UHD+ Televisions/Displays	All price ranges	$1.20/$0.60	$20MM	$24MM		
Digital Media Storage Blu-ray Discs, Other Storage Devices	All price ranges	Per Disc/Title $.0225/$.01125	$2.5MM	$3.0MM		

- Region Definitions:
  - Region 1 = U.S., EU, UK, Japan, S. Korea, Australia, New Zealand, etc. See a complete list of countries/territories on the Advance website.
  - Region 2 = All countries/territories outside of Region 1.

https://bit.ly/AA_HEVC

Codec USPs

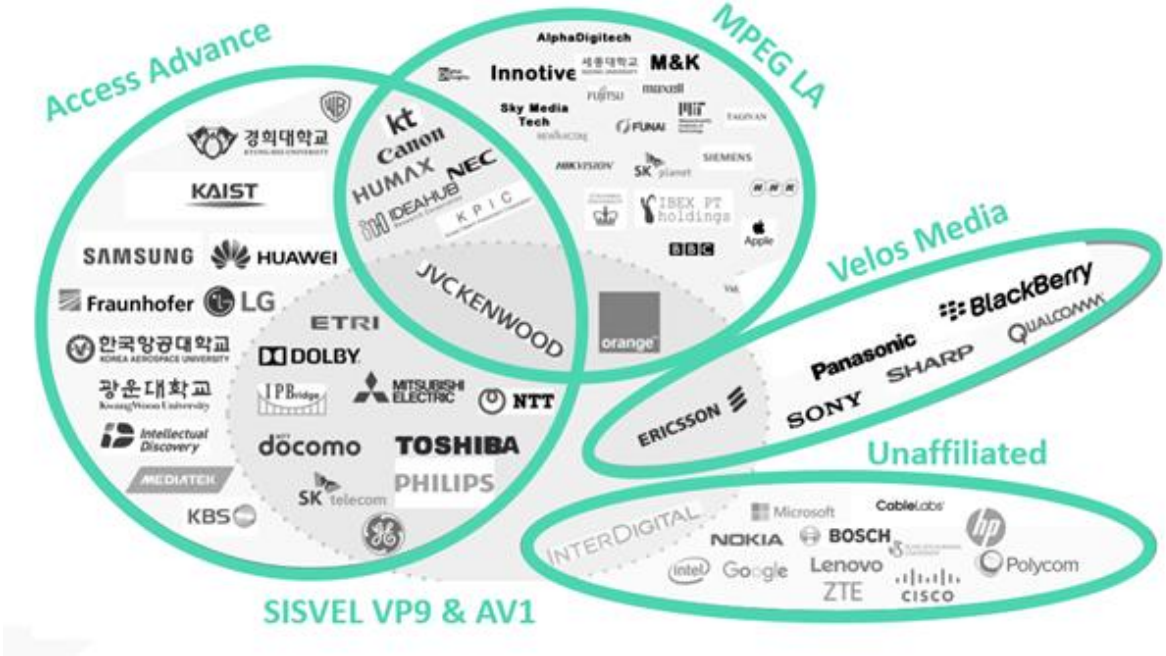
- HEVC – Proven HDR
- Platform support
  - Living room
  - Mobile
  - Browser
    - Apple Safari
    - Chrome (no DRM)

HEVC USP – Proven HDR

- HDR is key to premium content distribution
  - DV Profiles - https://sforce.co/3JDQJIx`
  - HEVC is the only HDR codec supported by Dolby Vision
- HEVC is supported in all other HDR standards
  - AV1 has some support (HDR 10/10+)
  - Google going after Dolby Vision/Atmos with Caviar (more in AV1 section

Dolby Vision bitstream profile ID	Representative Dolby Vision bitstream profile string	BL/EL codec	BL:EL	BL signal cross-compatibility ID (CCID for pro-tools and content creation)
4	dvhe.04	10-bit HEVC	1:¼	2
5	dvhe.05	10-bit HEVC	N/A	0
7	dvhe.07	10-bit HEVC	1:¼ for UHD; 1:1 for FHD	6
8	dvhe.08	10-bit HEVC	N/A	1, 2, or 4
9	dvav.09	8-bit AVC	N/A	2

Rich Parents - HEVC



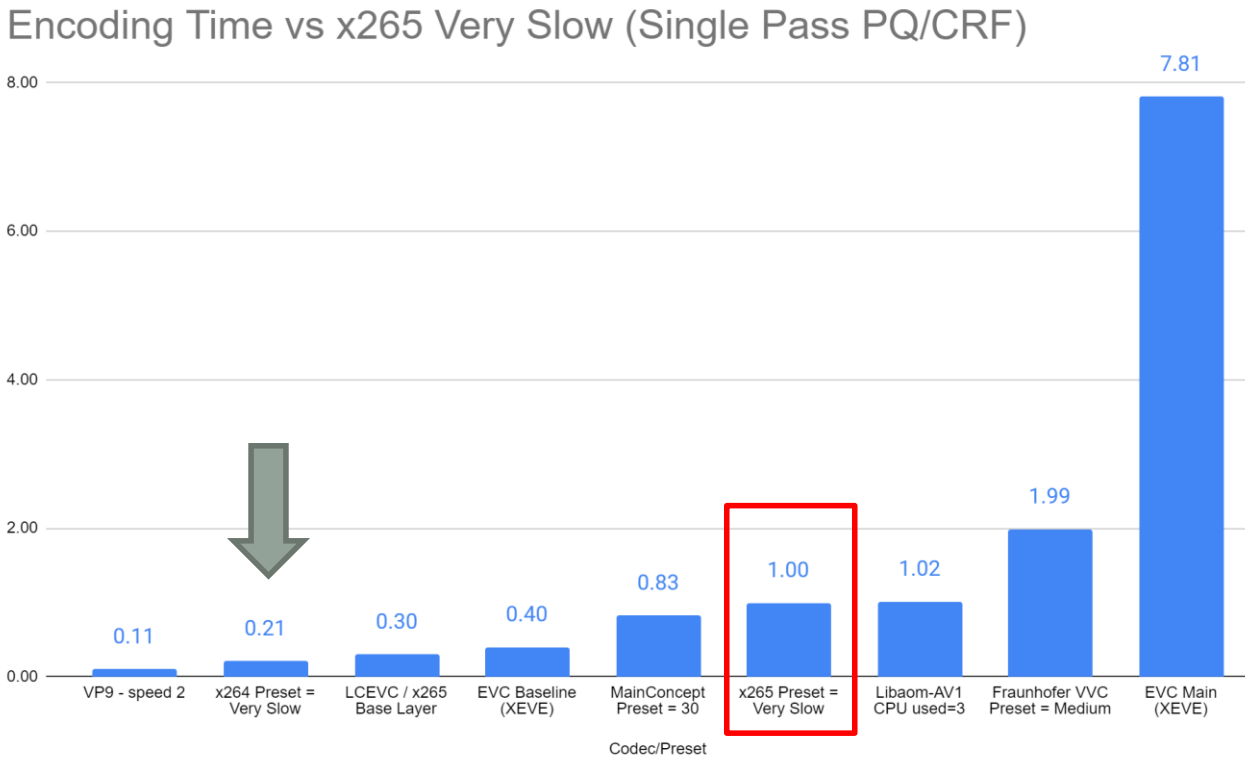
- Patent pool structure was a mess, but primarily irritated publishers (and AOM founders)
- HEVC in most smartphones, tablets, all smart TVs, and many computers because contributing companies had a stake

Producibility - Software

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)

- HEVC is still ~5x more costly to encode than H.264



Cloud Pricing

	AWS	Azure	Bitmovin	Brightcove	Tencent
Highest quality H.264 charge (30 fps/1080p)	$0.042	$0.03	~$0.02	$0.08	$0.0215
HEVC multiplier/cost	8x ($0.336)	~5x ($0.161)	2x (~$0.04)	None ($0.08)	2.5x ($0.0494)
	go.aws/37IbODX	bit.ly/Azure_pricing	bit.ly/BM_pricing	bit.ly/BC_pricing	bit.ly/TC_pricing

- Not listed
  - Encoding.com – doesn't share pricing details
  - Hybrik – doesn't charge on a per-minute basis - bit.ly/hybrik_report

	Monthly Source Hours							
Service Cost	**1**	**10**	**50**	**100**	**200**	**300**	**400**	**1000**
AWS MediaConvert	$17	$170	$849	$1,698	$3,396	$5,094	$6,792	$16,980
Azure Media Services	$12	$122	$608	$1,215	$2,430	$3,645	$4,860	$12,150
Bitmovin	$25	$246	$1,228	$2,456	$4,912	$7,369	$9,825	$24,562
Dolby Hybrik	$1,001	$1,007	$1,037	$1,074	$1,148	$1,222	$1,296	$1,740
Encoding.com	$17	$167	$833	$1,666	$3,332	$4,999	$6,665	$16,662
Telestream Cloud	$8	$84	$420	$840	$1,680	$2,520	$3,360	$8,400
Zencoder	$40	$300	$1,215	$2,000	$3,240	$4,860	$6,480	$16,200

Table 1. Monthly cost summary per hour of source for H.264 encoding.

FFmpeg Command Strings

Single Pass CRF

```
ffmpeg -y -i input.mp4 -c:v libx265  -b:v 3600K -an -preset
veryfast  -threads 4 -tune ssim  -x265-params keyint=60:min-
keyint=60:scenecut=0:open-gop=0 output_x265.mp4
```

Two-Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libx265  -b:v 2500K -preset veryslow -
g 60 -keyint_min 60 -sc_threshold 0  -pass 1 -f mp4 NUL & \

ffmpeg -i input.mp4 -c:v libx265 -b:v 2500K -maxrate 5000K  -
bufsize 5000k  -preset veryslow   -g 60 -keyint_min 60 -
sc_threshold 0  -pass 2 output.mp4
```

Producibility – Hardware Transcoding/Origination

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Live software/hardware	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

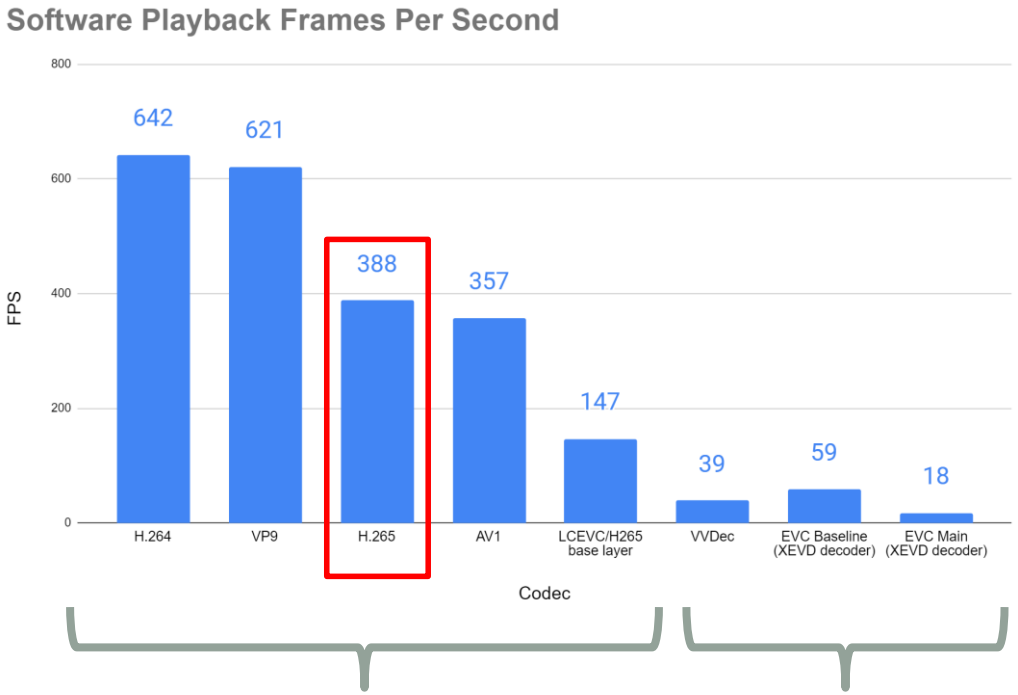
With H.264, the best option

Playability - Performance

- Can the codec play in software?
  - HEVC is supported in hardware on all relevant platforms, but plays well software-only on computers

Device specifications

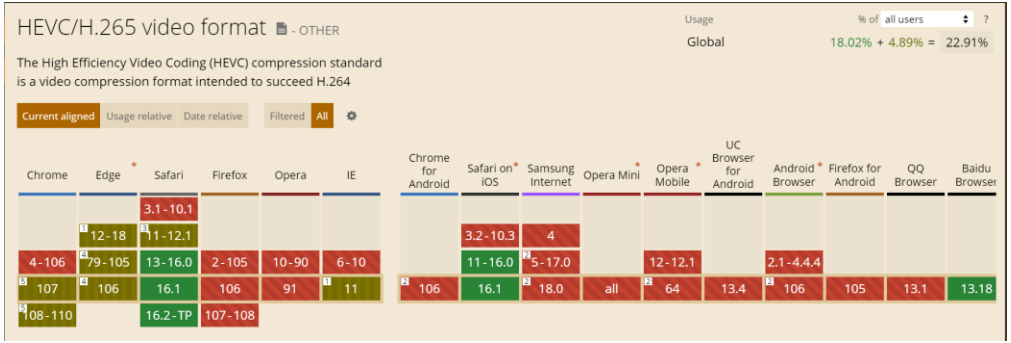
Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



Playability – Compatibility - Computer and Mobile Browser Support

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	22.91%	97.1%	74.6%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	Yes	NA	NA	No	**Yes**	No	No

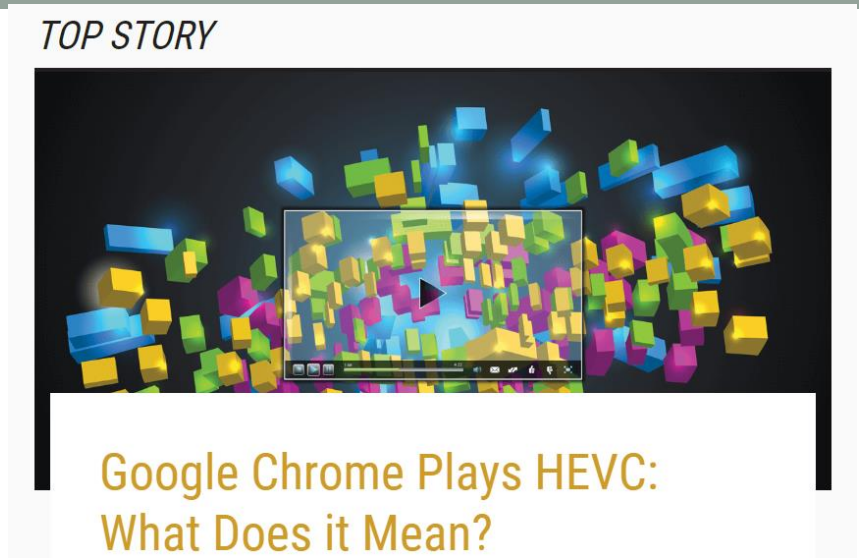
- Everything changed in October



https://caniuse.com/?search=hevc

Chrome Plays HEVC

- Versions – 104 – 107
- Requires decode on OS
  - All recent Macs/iOS have it
  - All premium Android devices have it
  - Most recent Windows computers have it
- No Widevine support
  - Hurts premium content distributors who want to play in the browser
    - Might be supported in Canary
  - Not an issue for unprotected content
- Why did Google decide to support HEVC?
  - So much HEVC encoding in phones/tablets (including Google's). HEVC decode became critical feature
  - Antitrust scrutiny in the EU on AV1 licensing terms (maybe)



- HEVC support always made sense, always would have made Chrome a better and more useful browser.
- Somebody realized that it was better for Google to deliver a more capable browser than to attempt to promote what's essentially a third-party video codec.

HEVC Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- HEVC is fully supported in Apple and most premium Android phones

HEVC – Operating System Support

HEVC support by different operating systems

	Microsoft Windows	macOS	Android OS	iOS
Codec support	Add-on required	Yes	Yes	Yes
Container support	MP4 (.mp4, .m4v) QuickTime File Format (.mov) Matroska (.mkv)	MP4 (.mp4, .m4v) QuickTime File Format (.mov)	MP4 (.mp4, .m4v) Matroska (.mkv)	MP4 (.mp4, .m4v) QuickTime File Format (.mov)
Notes	- Support introduced in Windows 10 version 1507. - Built-in support was removed in Windows 10 version 1709 due to licensing costs. The HEVC Video Extensions add-on can be purchased from the Microsoft Store to enable HEVC playback on the default media player app Microsoft Movies & TV.[112]	Support introduced in macOS 10.13 High Sierra[118]	Support introduced in Android 5.0[113]	Support introduced in iOS 11.0[119]

- Is HEVC supported in Windows hardware?
  - Intel CPU support – Skylake – 2016 (sixth gen Intel Core)
  - AMD – Ryzen Gen 1- 2016
- Most reasonably current Windows computers should play HEVC in hardware
  - Which means that Chrome playback should work

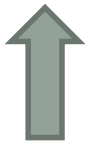
Chip Support –TV

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices with HDR	• Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek			

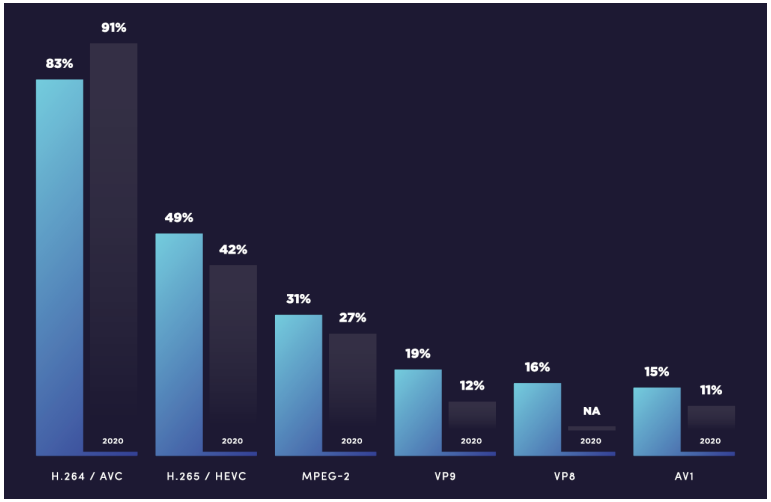
Codec of choice for HDR and premium content, particularly 4K

Timing of Mainstream Adoption

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser	2022/23	Now	Now	Never	Never	Never	Never
- Browser workaround	NA	NA	NA	**$$$$**	**Yes**	?	?
- Mobile – hardware	Now	Now	2024+	2025+	NA	Not on radar	Not on radar
- Mobile - software	NA	NA	Caution	Stakeholders	Today	Not on radar	Not on radar
- Smart TV/STB	Ubiquitous	Ubiquitous	Mid 2023	Mid - 2025	Software-only	Not on radar	Not on radar



Third-Party Predictions

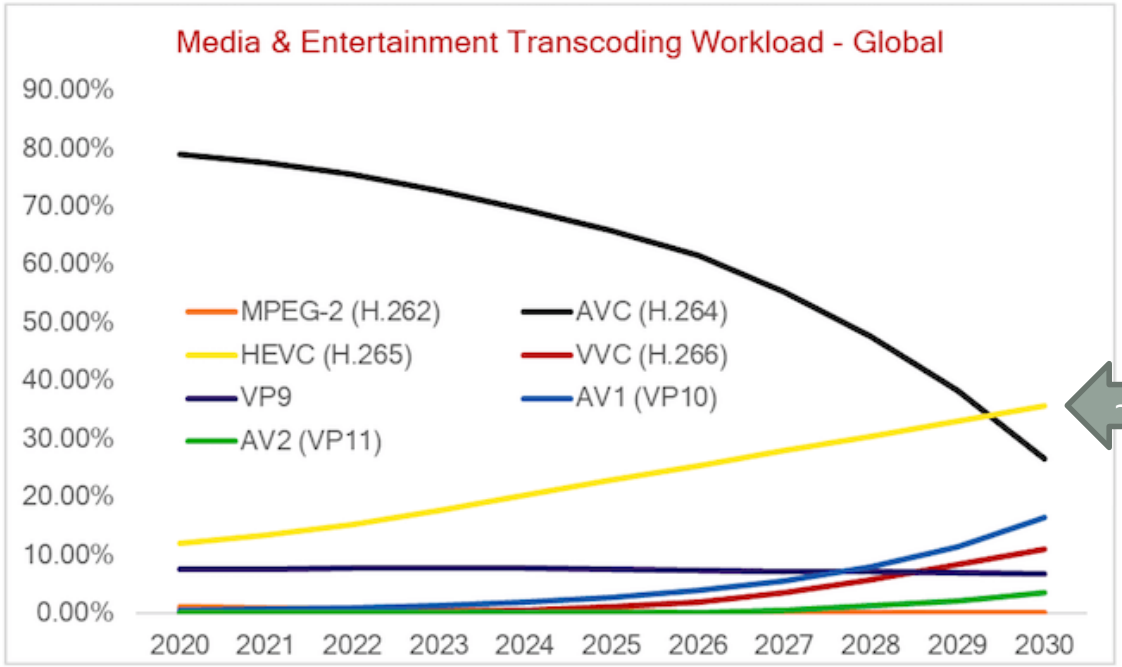


- 49% currently using HEVC
- Up from 42% in 2020

- 25% plan to deploy HEVC in 2022

Bitmovin - [Bitmovin Video Developer Report]

Third-Party Predictions



- Rethink TV – HEVC is biggest mover

http://bit.ly/rethink_codec

VP9 – 2022 Perspective

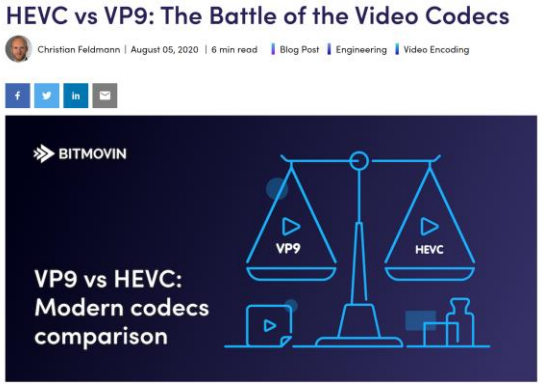
Should be 9:50

- About VP9
- Quality
- Royalty status
- Rich parents (key stakeholders)
- Producibility
- Playability

About – VP9

- Developed by Google
  - From technology acquired from On2 in 2010
  - Successor to VP8
  - Released June 17, 2013
  - Predominantly used by YouTube
    - More recently also used by Netflix and Facebook
- Goal – open-source/royalty free
- Sisvel announced patent pool in March 2019

VP9 Quality - Bitmovin



		BD-rate PSNR	BD-rate SSIM	BD-rate VMAF
Fixed resolution	x265 vs x264	-45.14 %	-39.81 %	-56.75 %
	libvpx-vp9 vs x264	-52.10 %	-50.93 %	-47.18 %
Bitrate Ladder	x265 vs x264	-33.25 %	-28.21	-38.70%
	libvpx-vp9 vs x264	-36.88 %	-36.23 %	-39.27 %

- Fixed resolution – HEVC wins
- Full bitrate ladder, VP9 slightly more efficient than HEVC
- About a 40% savings compared to x264 (bitrate ladder)

https://bitmovin.com/vp9-vs-hevc-h265/

Known Royalty Cost

- Key Takeaways
  - VP9 – Google says VP9 is open source and royalty free
    - But, doesn't indemnify if sued for patent infringement
  - Sisvel – VP9 pool claims decoder royalties
  - No existing claim for content royalties of any kind

Consumer Display Devices

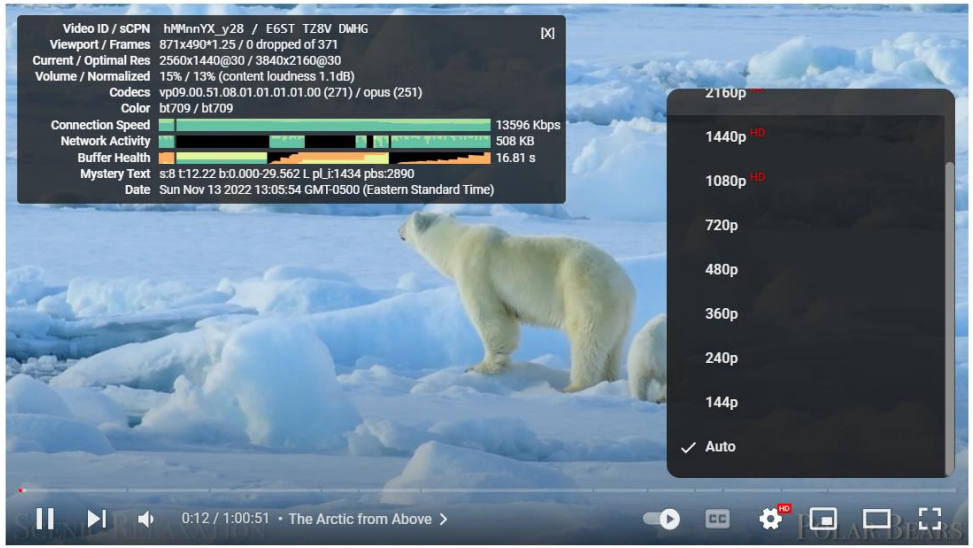
Minimum Commitment threshold (no. of units)	Maximum Commitment threshold (no. of units)	Applicable royalty rate per unit
1	100,000	EUR 0.126
100,001	1,000,000	EUR 0.117
1,000,001	25,000,000	EUR 0.108
25,000,001	75,000,000	EUR 0.099
75,000,001 or above	unlimited	EUR 0.090

Consumer Non-Display Devices

Minimum Commitment threshold (no. of units)	Maximum Commitment threshold (no. of units)	Applicable royalty rate per unit
1	20,000	EUR 0.042
20,001	200,000	EUR 0.039
200,001	5,000,000	EUR 0.036
5,000,001	14,000,000	EUR 0.033
14,000,001 or above	unlimited	EUR 0.030

http://bit.ly/Sis_VP9

Rich Parents – VP9 - One Primary Parent (But a Big One)



The Arctic 4K - Scenic Wildlife Film With Calming Music

HT TECH
MAKE LIFE SIMPLE

Apple TV 4K finally gets support for 4K YouTube videos but with some limitations

One of the highlights of tvOS 14 is the support for 4K videos on YouTube. The feature is finally rolling out months after the official announcement.

engadget

Apple TV now plays YouTube videos in 4K, with limits

The update is rolling out gradually.

ai

iPhones, iPads can now stream 4K YouTube videos in iOS 14

Mike Peterson | Jun 23, 2020

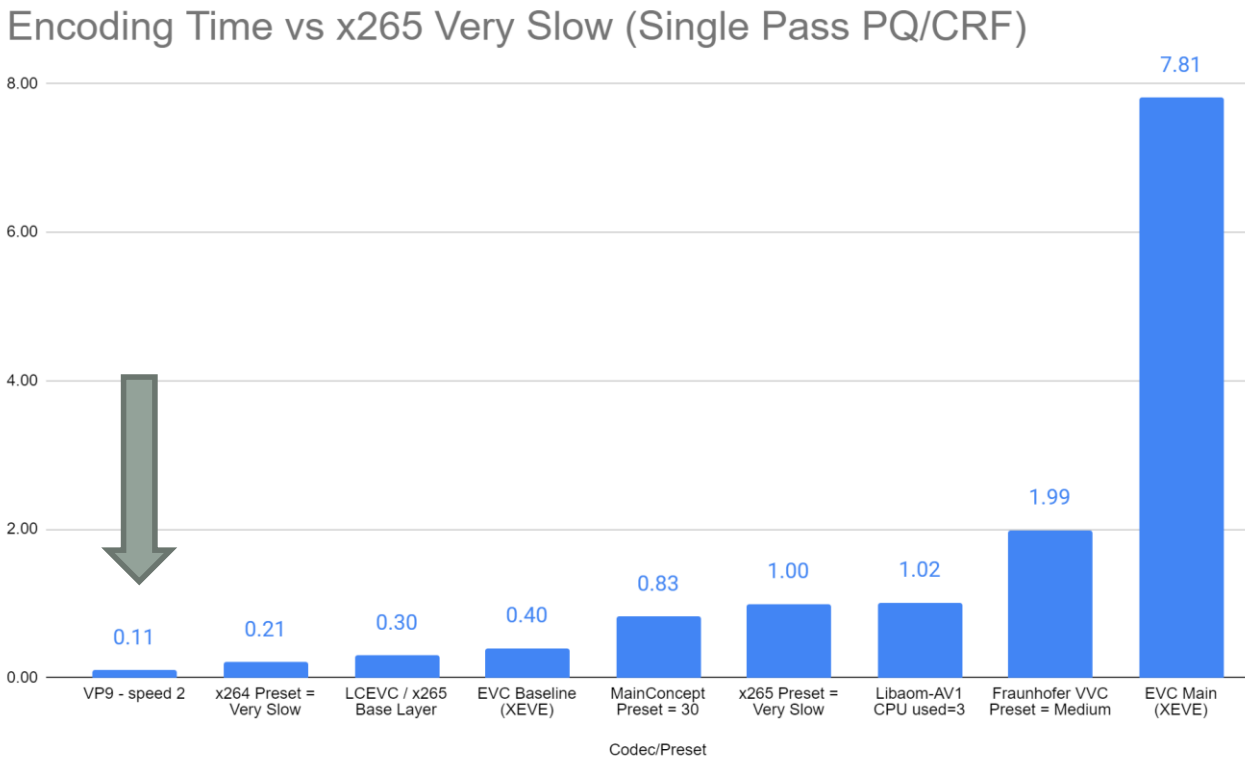
- YouTube max encode for H.264 videos is 1080p; all 4K in VP9/AV1
- This alone convinced most smart TV vendors to include VP9 decode (and Apple)

Producibility - Software

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)

- VP9 – speed 2 – fastest (.11x) ~ 10x more efficient than AV1
- Twice as fast as x264 very slow (.21x) (in single pass configuration)



FFmpeg Command Strings

Single Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libvpx-vp9 -b:v 3600 -an -speed 4
output_VP9.webm
```

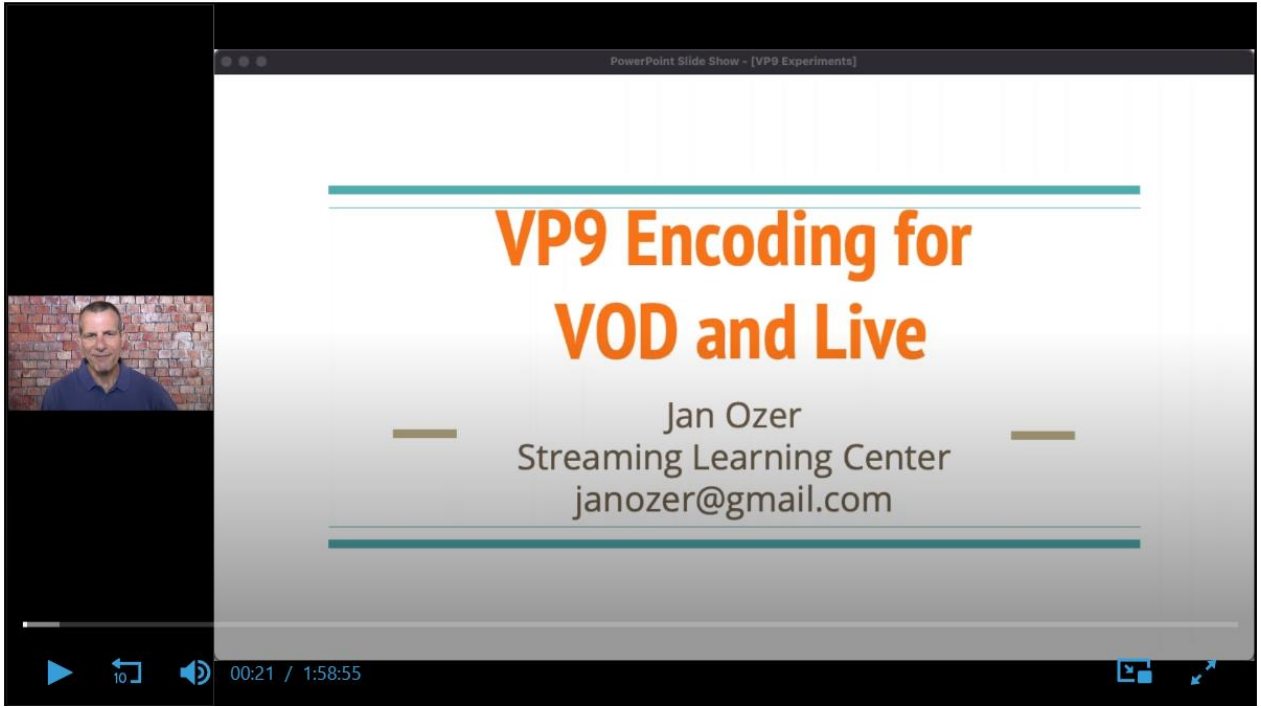
Two-Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libvpx-vp9 -pass 1 -b:v 2500K -g 60 -
keyint_min 60 -speed 4 -threads 8 -quality good -tile-columns 4 -auto-alt-
ref 1 -lag-in-frames 25 -frame-parallel 1 -f -row-mt 1 webm NUL && \

ffmpeg -y -i input.mp4 -c:v libvpx-vp9 -pass 2 -b:v 2500K -maxrate 5000K
-g 60 -keyint_min 60 -speed 2 -threads 8 -quality good -tile-columns 4 -
auto-alt-ref 1 -lag-in-frames 25 -frame-parallel 1 -row-mt 1 output.webm
```

VP9 Encoding Resources

- Free webinar
- Works through optimal VP9 encoding string
  - Shown above
  - If you want to learn what the switches are and what they do
  - What's enabled by default and what isn't



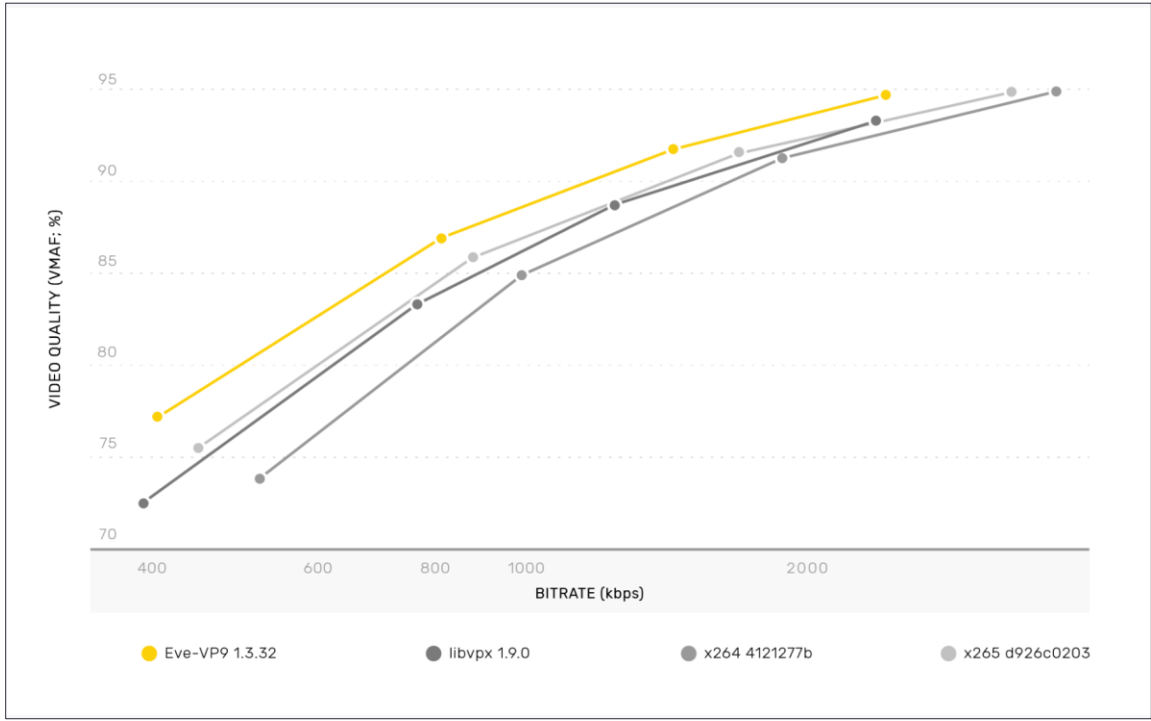
https://bit.ly/Produce_VP9

Cloud Pricing

	AWS	Azure	Bitmovin	Brightcove	Tencent
Highest base charge (30 fps/1080p)	$0.042	$0.03	~$0.02	$0.08	$0.0215
HEVC multiplier/cost	8x - $0.336	~5x - $0.161	2x - ~$0.04	None -$0.08	2.3x - $0.0494
VP9	~4x - $0.1575	Not supported	2x - ~$0.04	None ($0.08)	Not supported
	go.aws/37IbODX	bit.ly/Azure_pricing	bit.ly/BM_pricing	bit.ly/BC_pricing	bit.ly/TC_pricing

VP9 Encoding Quality

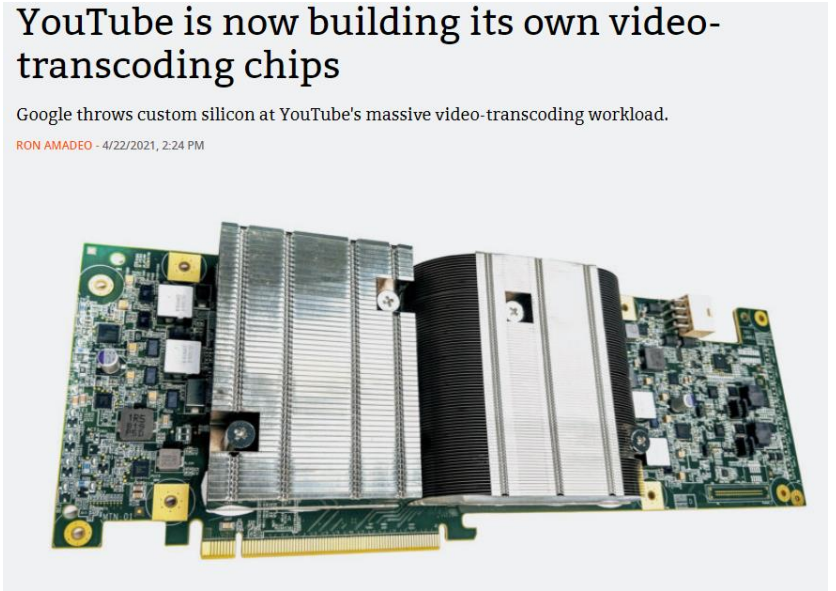
- Most VP9 encoding is FFmpeg-based
- There is at least one premium codec from Two Orioles
  - I believe it's used by Netflix
  - Terms unknown



https://www.twoorioles.com/eve-vp9

Argos VCU

- Software transcoding is very efficient
- When you need to encode 500 hours a minute you need hardware
- Google built their own VP9 encoding chipset
  - Argos VCU
  - Not available commercially



Producibility – Software and Hardware

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Live software/hardware	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

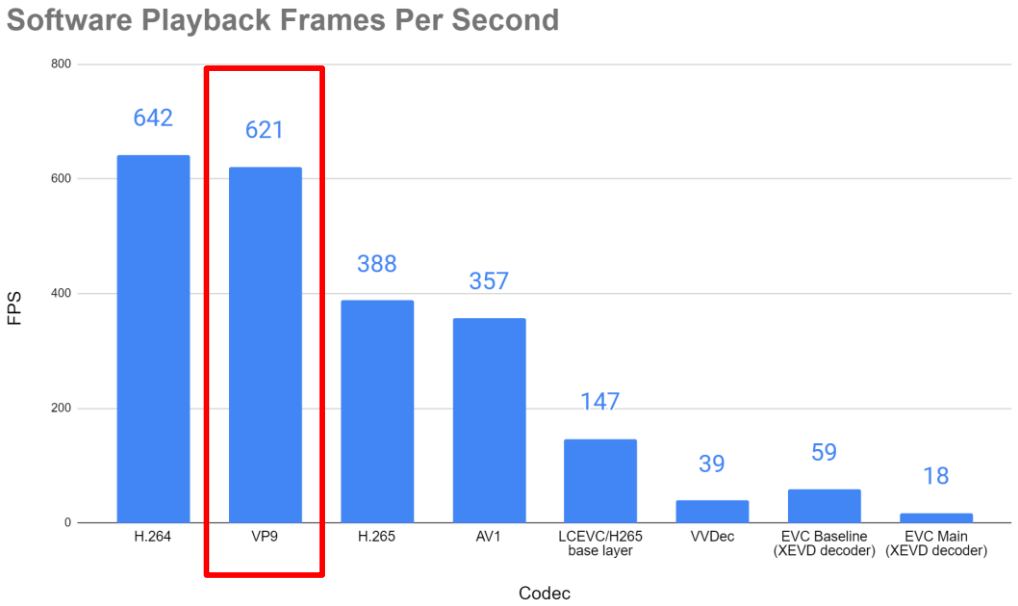
Fringe application for VP9 Xilinx (now AMD), and FPGA encoder for Twitch.tv, but not for general resale

Playability - Performance

- VP9 very efficient; can play in software
  - Hardware support on all major mobile platforms

Device specifications

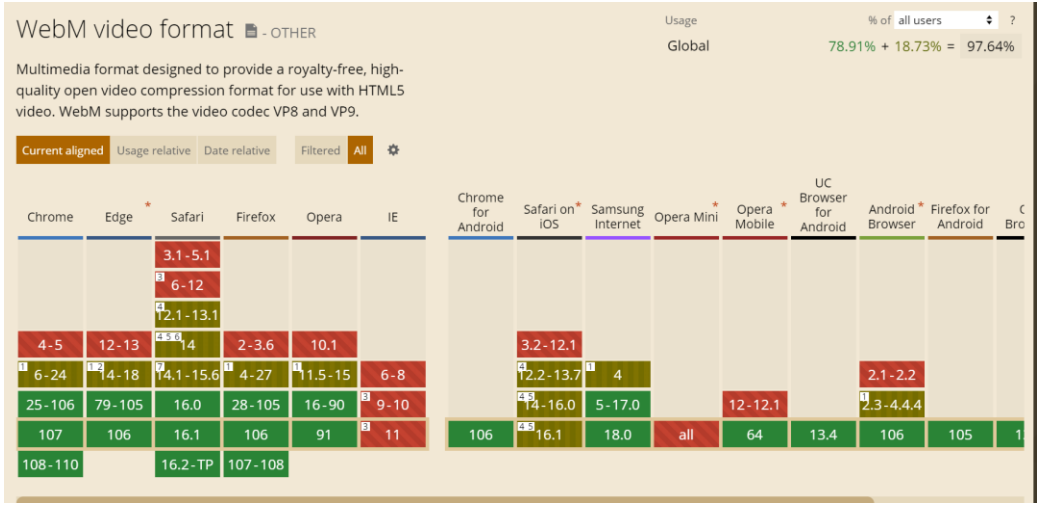
Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



Playability – Compatibility - Computer and Mobile Browser Support

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	22.91%	97.64%	73.2%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	No	NA	NA	No	Yes	No	No

- CanIUse shows compatibility percentage
  - Browser support is a key strength for VP9
  - That's why it's used by YouTube and Facebook and other non-premium publishers



https://caniuse.com/?search=vp9

Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • Apple • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- Hardware support by Apple and most premium Android suppliers

VP9 – Mobile Deployments

- Apple
  - Added support in August 2020
    - bit.ly/apple_vp9
- Android
  - Google added support with version 4.4
    - bit.ly/and_supportedmedia
    - Netflix started delivering downloads in VP9 in December 2016

bit.ly/ios_vp9

bit.ly/3p7xZcm

Chip Support –TV

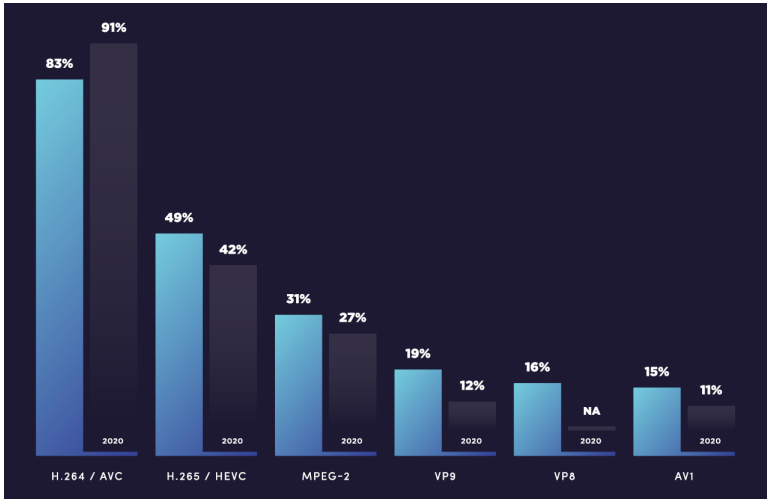
	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices with HDR	• Apple (Apple TV) • Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek			

Can support HDR10+ but not Dolby Vision

- Very widely supported by TV operating systems (the 4K YouTube effect)
  - See link below for HDR10+ support

https://developers.google.com/media/vp9/hdr-encoding

Third-Party Predictions

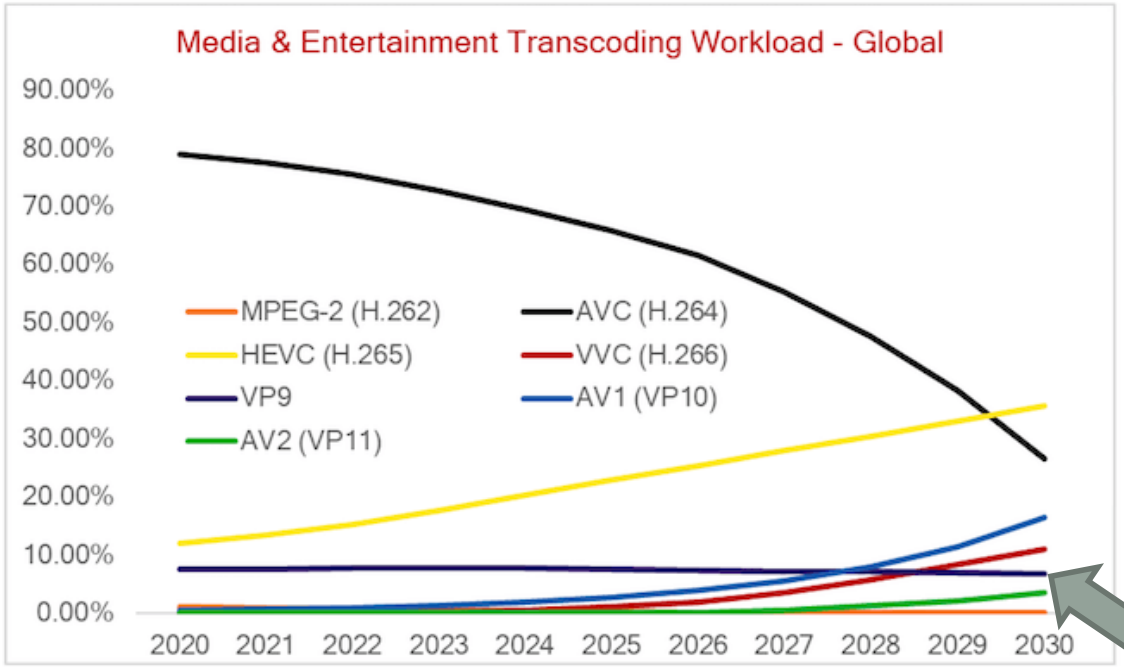


- 19% currently using VP9
- Up from 12% in 2020

- 15% plan to deploy VP9 in 2022

Bitmovin - [Bitmovin Video Developer Report]

Third-Party Predictions



- Rethink TV – VP9 currently around 8% and doesn't lose much through 2030

http://bit.ly/rethink_codec

AV1 – 2022 Perspective

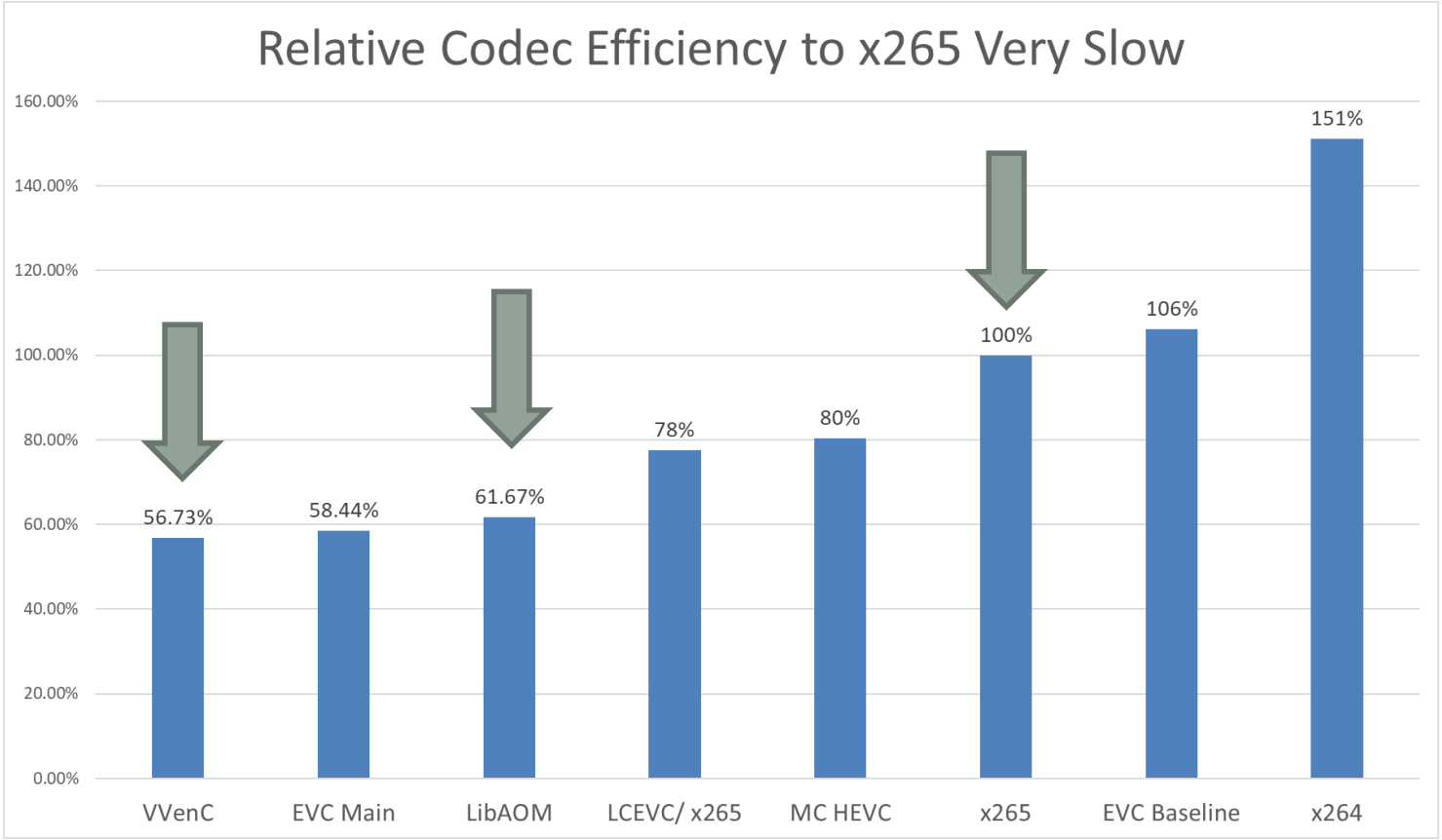
Should be 10:10

- About AV1
- Quality/USP
- Royalty status
- Rich parents (key stakeholders)
- Producibility
- Playability

About – AV1

- Developed by the Alliance for Open Media
  - Released March 28, 2018
  - AV1 = AOMedia Video 1
- Goal – open-source/royalty free
- Sisvel announced patent pool in March 2019

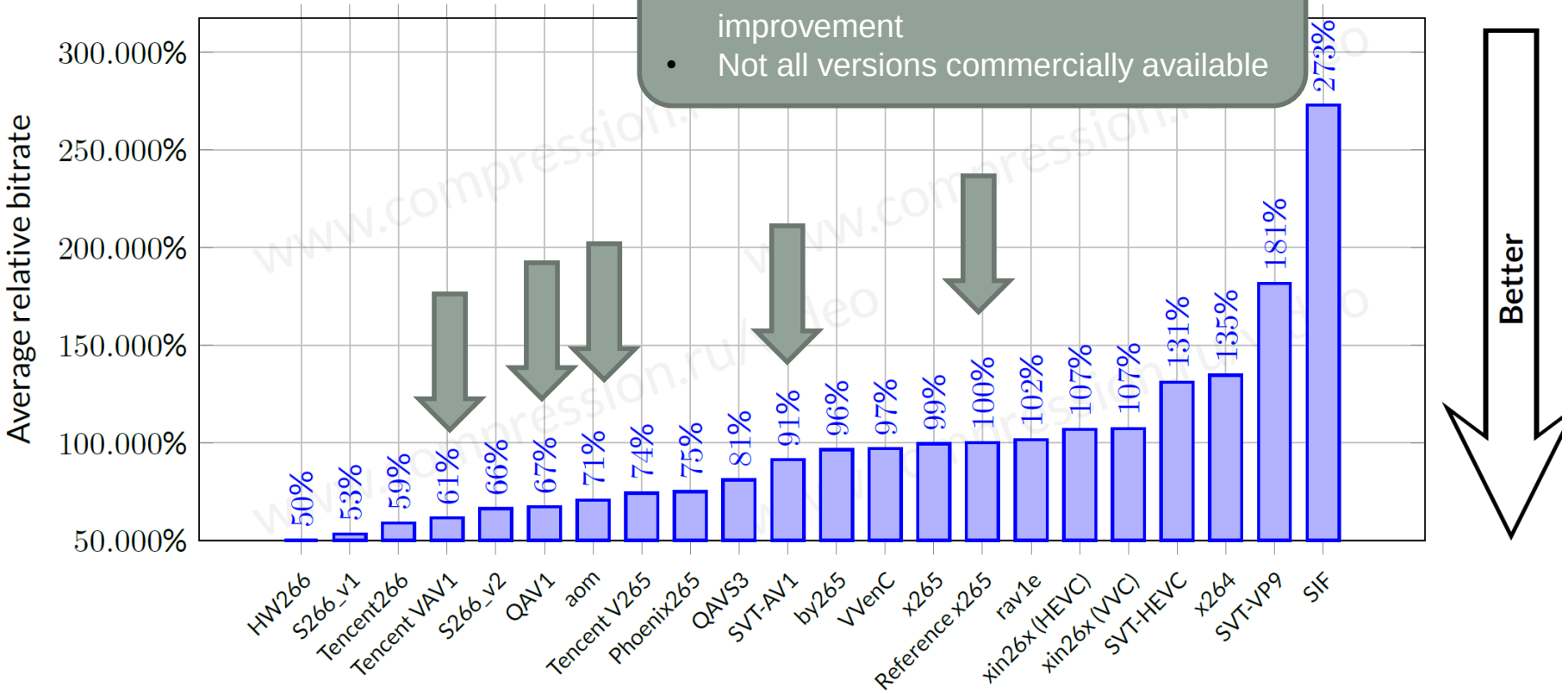
Streaming Media Magazine



https://bit.ly/codec_soup

Moscow State University

- Multiple AV1 codecs
- SVT-AV1 1.0/1.3 is substantial improvement
- Not all versions commercially available



http://bit.ly/MSU_codec_2021

Known Royalty Cost

- Status: AOMedia says open-source/royalty free
  - Patent defense fund but no indemnification
  - Sisvel has an AV1 patent pool with multiple licensees
- Royalty uncertainty detracted from AV1 deployment
  - Joe Inzerillo, then CTO of BAMTech (now Disney), “serious companies” shouldn’t waste time with a “free” technology that ultimately is unproven legally.”
    - http://bit.ly/inzerillo_av1
  - Robert J.L. Moore – patent attorney - It’s telling, I think, that AOM doesn’t indemnify AV1 implementers against patent liability. If Google actually thought they had secured the rights implementers need, they would offer implementers indemnity.
    - http://bit.ly/moore_indemnity

Known Royalty Cost

- Key Takeaways
  - Royalties on display/non-display
  - No current content royalties

Consumer Display Devices

Minimum Commitment threshold (no. of units)	Maximum Commitment threshold (no. of units)	Applicable royalty rate per unit
1	100,000	EUR 0.168
100,001	1,000,000	EUR 0.156
1,000,001	25,000,000	EUR 0.144
25,000,001	75,000,000	EUR 0.132
75,000,001 or above	unlimited	EUR 0.120

Consumer Non-Display Devices

Minimum Commitment threshold (no. of units)	Maximum Commitment threshold (no. of units)	Applicable royalty rate per unit
1	20,000	EUR 0.056
20,001	200,000	EUR 0.052
200,001	5,000,000	EUR 0.048
5,000,001	14,000,000	EUR 0.044
14,000,001 or above	unlimited	EUR 0.040

http://bit.ly/Sis_AV1

Rich Parents – AV1 – Alliance for Open Media

- Prominent members include:
  - Desktop and mobile OS – Apple, Microsoft, Google
  - Device – Apple, Google, Samsung, Amazon
  - Component – Intel, NVIDIA, ARM, Ittiam
  - Content – YouTube, Netflix, Amazon, Facebook, Hulu,
  - Infrastructure – Bitmovin, Ateme, AWS Elemental
  - **Key point – lots of major companies pushing for AV1 to succeed**

Control Desktop OS

Control Mobile OS/hardware

Control Browsers

Control Components

Dominate Content

Other Content Viewing Platforms

Control Infrastructure Adoption

AV1 Enjoyed a Ton of Industry Support

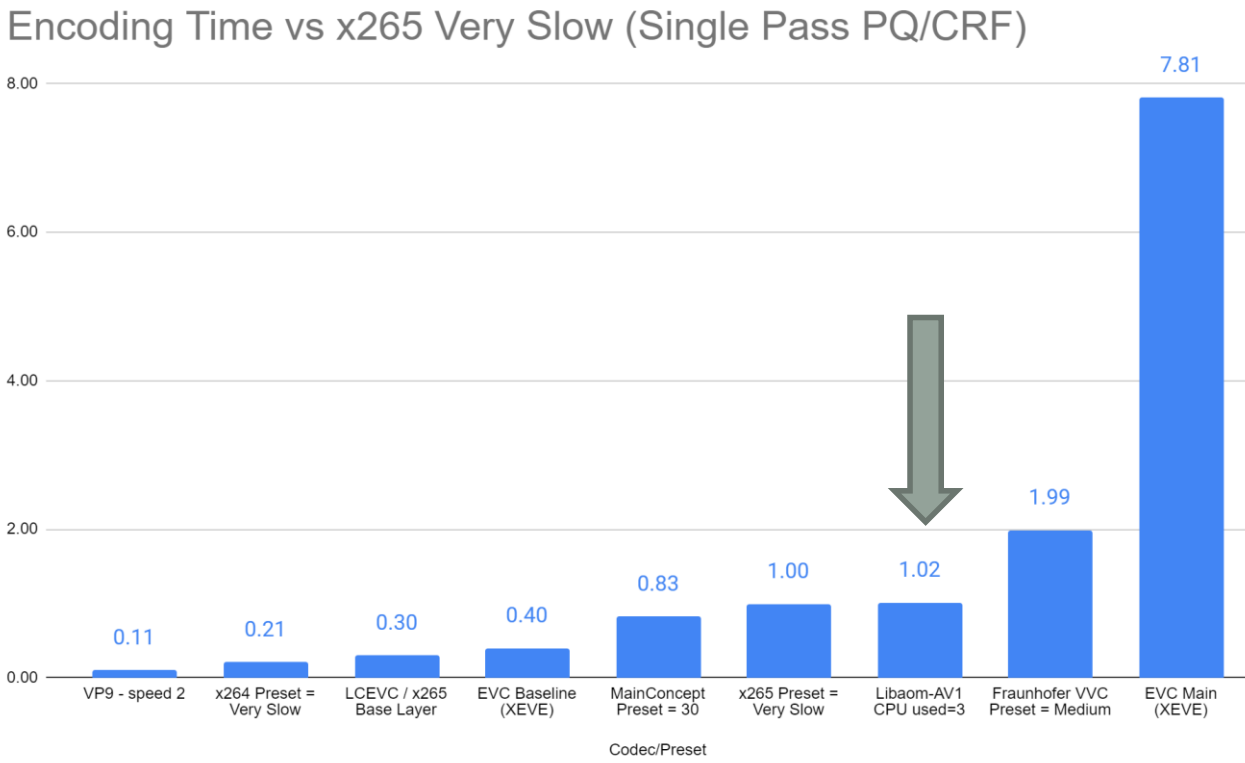
- Accelerated deployment perhaps faster than otherwise
  - YouTube deployed when encoding times were glacial
- Held back competing codecs; particularly HEVC
  - No support in Chrome
  - Initial support in Edge; later reversed
- Chrome decision is monumental
  - “Part of the argument for AV1 was that HEVC was not workable in its use cases, so now that is seemingly no longer the case.”
  - From “Chrome Plays HEVC. What Does It Mean?”

Producibility - Software

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)

- LibAOM –1.02x (CPU used 3)
- About the same as x265
  - This is FFmpeg/libaom-AV1
  - SVT-AV1 will be much, much faster



AV1's Performance Journey

780 times slower than x265

	Encoding Time (seconds)	Times Real Time
AV1	226,080	45,216
x265	289	58
LibVPx	226	45
x264	18	4

August 2018

bit.ly/AV1_firstlook

~2x slower than x265

10-second segments of Football and Freedom clips	Encoding Time	Bitrate	VMAF
AV1 Codecs as Tested			
SVT-AV1 - cpu-used 2	0:11:31	1823	88.70
AOMedia aomenc	0:10:27	1821	88.90
FFmpeg libaom	0:08:37	1826	88.68
Visionular	0:04:59	1774	88.61
Other Codecs as Tested			
x265 - veryslow	0:04:57	1843	86.01
x264 - veryslow	0:00:23	1890	75.60
For Reference			
x265 - slow	0:00:45	1837	84.39
SVT-AV1 - cpu-used 7	0:01:46	1893	84.66

September 2020

bit.ly/av1_comps

About the same as x265

Codecs and Encoders	Time	Compared to x265	Times Real Time
x264 Preset = Very Slow	0:02:19	0.21	7
LCEVC / x265 Base Layer	0:03:19	0.30	10
x265 Preset = Very Slow	0:11:03	NA	33
MainConcept Preset = 30	0:09:07	0.83	27
Libaom-AV1 CPU used=3	0:11:15	1.02	34
Fraunhofer VVC Preset = Medium	0:22:01	1.99	66
EVC Baseline (XEVE)	0:04:27	0.40	13
EVC Main (XEVE)	1:26:19	7.81	259

December 2021

bit.ly/codec_soup

Encoding Performance – Average for 10 seconds

SVT-AV1

Preset	Time (10 seconds)
0	0:53:35
1	0:27:31
2	0:15:46
3	0:03:48
4	0:01:38
5	0:00:57
6	0:00:29
7	0:00:19
8	0:00:12
9	0:00:10
10	0:00:08
11	0:00:06
12	0:00:05

Single file Real-time

Libaom- AV1

Preset	Time (10 seconds)
0	3:24:33
1	0:53:47
2	0:18:58
3	0:06:29
4	0:04:24
5	0:02:12
6	0:01:26
7	0:01:26
8	0:01:06

.15x Real-time

FFmpeg Command Strings

Single Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libaom-av1 -b:v 3000k -g 60 -
keyint_min 60  -cpu-used 8  -auto-alt-ref 1 -threads 4 -tile-
columns 1 -tile-rows 0 -row-mt 1 -lag-in-frames 25  output_AV1.mkv
```

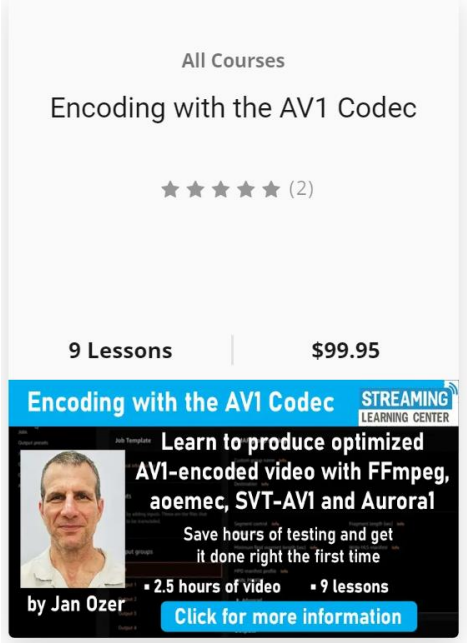
Two-Pass VBR

```
ffmpeg -y -i input.mp4 -c:v libaom-av1 -b:v 1500K -g 60 -
keyint_min 60 -cpu-used 8 -threads 8 -tile-columns 1 -tile-rows 1
-row-mt 1 -pass 1  -f matroska NUL & \

ffmpeg -y -i freedom_10.mp4 -c:v libaom-av1 -b:v 1500K -maxrate
3000K -g 60 -keyint_min 60 -cpu-used 4  -threads 8 -tile-columns 1
-tile-rows 1  -row-mt 1 -pass 2 output.mkv
```

AV1 Encoding Resources

- Course
- Articles:
  - Choosing the Optimal Preset for AV1 Encoding (and Other Questions) – Streaming Learning Center
  - AV1 Video Encoding Guide – FFmpeg Wiki
  - AV1 Has Arrived: Comparing Codecs from AOMedia, Visionular, and Intel/Netflix, Streaming Media Magazine



https://bit.ly/slc_encode_av1

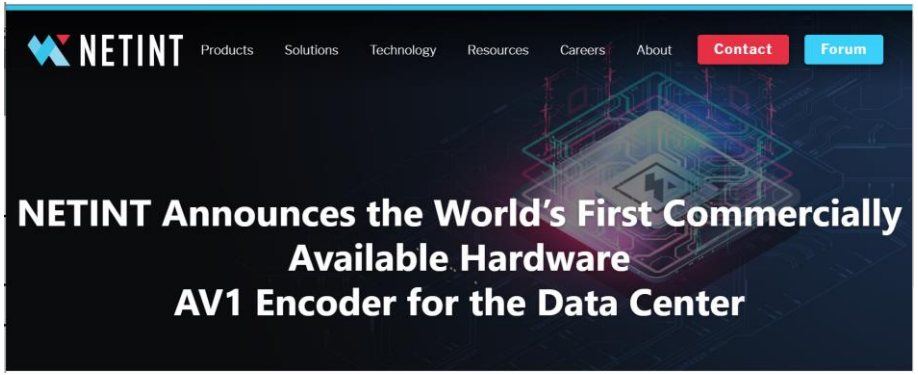
Cloud Pricing – 6-40x H.264

	AWS	Azure	Bitmovin	Brightcove	Tencent
Highest base charge (30 fps/1080p)	$0.042	$0.03	~$0.02	$0.08	$0.0215
HEVC multiplier/cost	8x - $0.336	~5x - $0.161	2x - ~$0.04	None -$0.08	2.3x - $0.0494
VP9	~4x - $0.1575	Not supported	2x - ~$0.04	None ($0.08)	Not supported
AV1	~41x - $1.728	Not supported	10x - ~$0.20	Supported, no price	6.7x - $0.1445
	go.aws/37IbODX	bit.ly/Azure_pricing	bit.ly/BM_pricing	bit.ly/BC_pricing	bit.ly/TC_pricing

Producibility

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Live software/hardware	Yes/Yes	Yes/Minimal	Yes	Min/Min	Yes	No/No	No/No

- AV1 – Multiple
  - NETINT – first hardware transcoder
  - Later entrants
    - NVIDIA
    - Intel
    - Xilinx coming

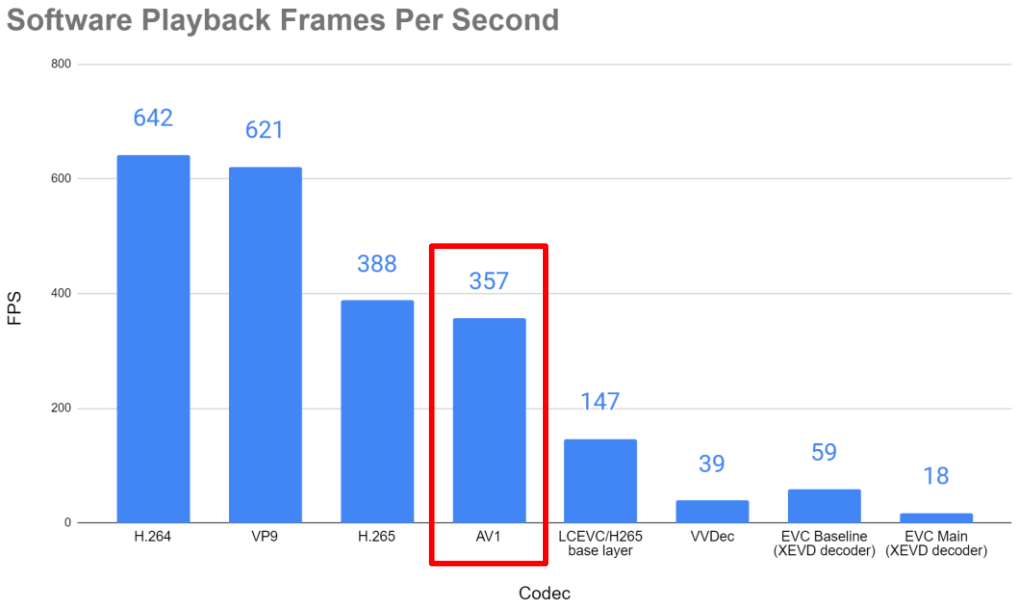


Playability - Performance

- Where can the codec play
  - Does it need hardware acceleration?
    - Runs in software very effectively on very old CPU
  - Not supported in hardware on any mobile platforms
    - Different story for mobile

Device specifications

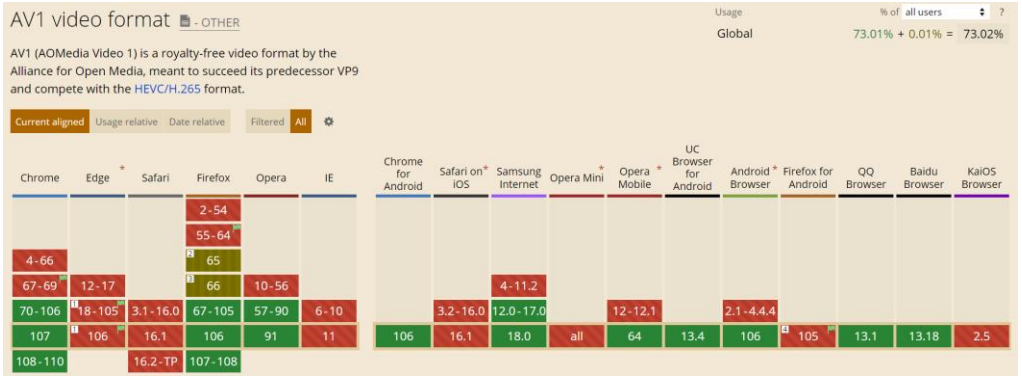
Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



Playability – Compatibility - Computer and Mobile Browser Support

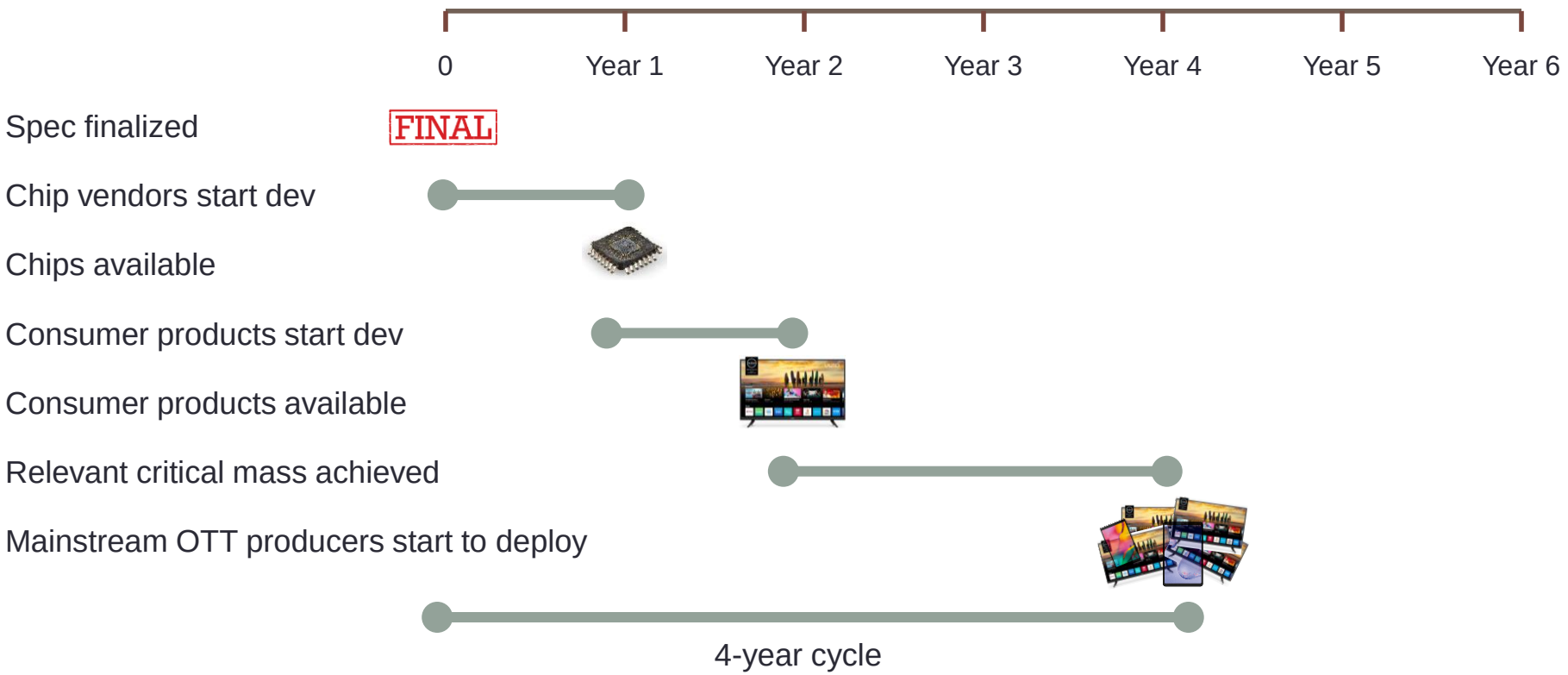
	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	22.91%	97.64	73.2%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	No	NA	NA	No	Yes	No	No

- CanIUse shows compatibility percentage
  - Very good browser support (most except for Apple)
  - Was a key strength vs. MPEG codecs
    - Chrome now plays HEVC



https://caniuse.com/?search=av1

Codec Deployment – Hardware / Best Case



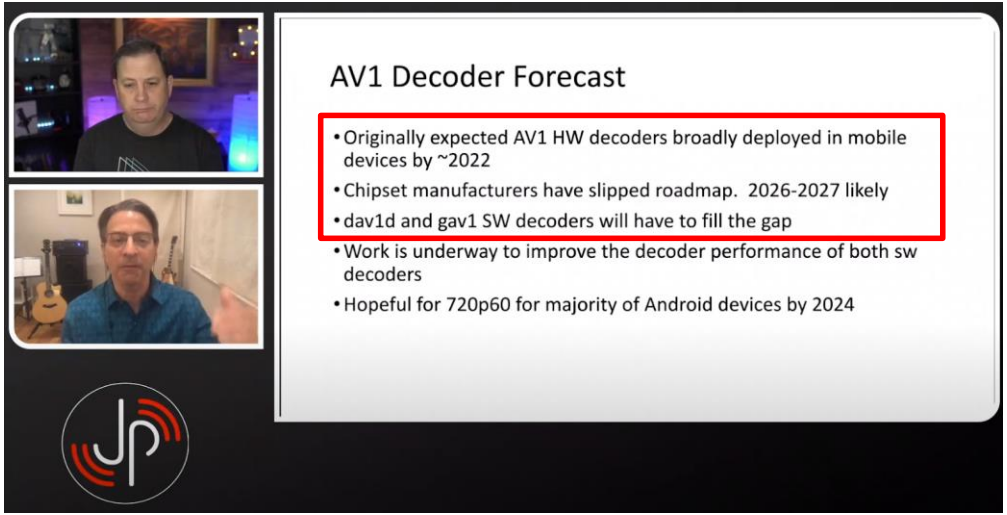
Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- Most data from Wikipedia
  - Lots of announced chip level support

AV1 – Mobile Deployments

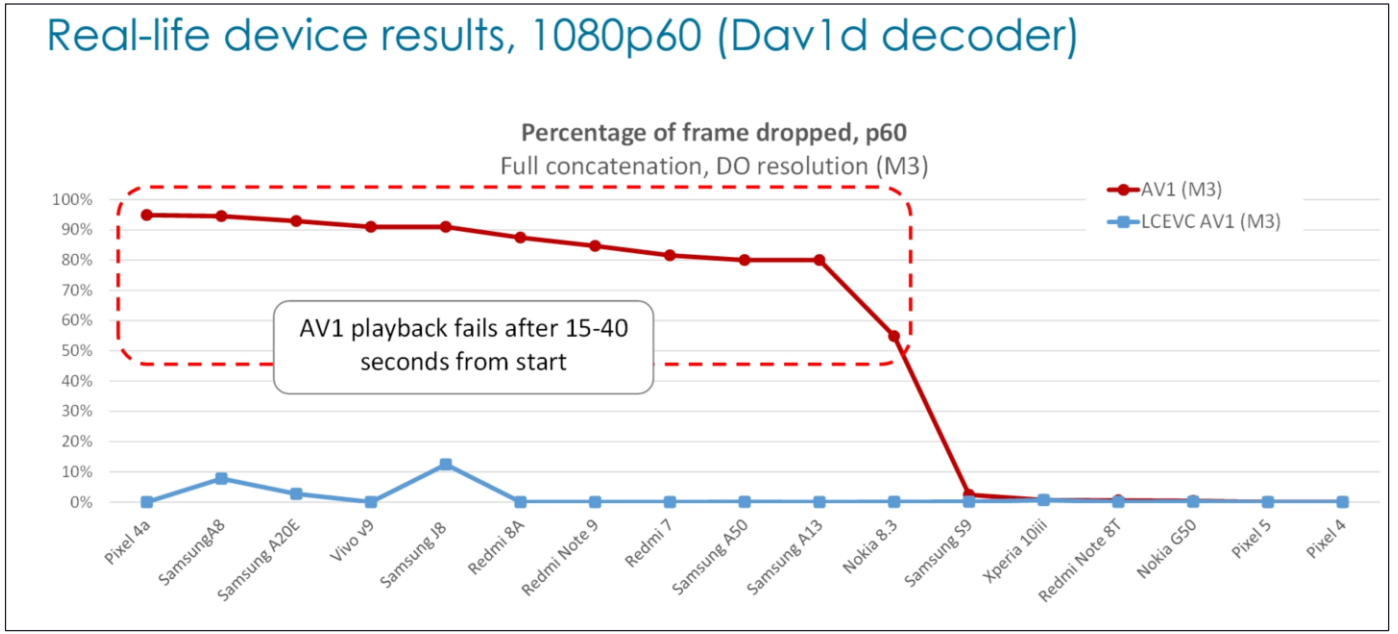
- Apple
  - No hardware or software support for AV1
- Android
  - Software support in Android OS and browsers since Android 10.0
    - bit.ly/and_supportedmedia
  - General hardware support dragging
  - Focus on software playback
    - Hopeful for 720p60 on majority of Android devices by 2024
    - Netflix has been distributing AV1 to Android phones since 2/2020
    - bit.ly/nf_and_av1



https://youtu.be/3qL5FdEBiGA

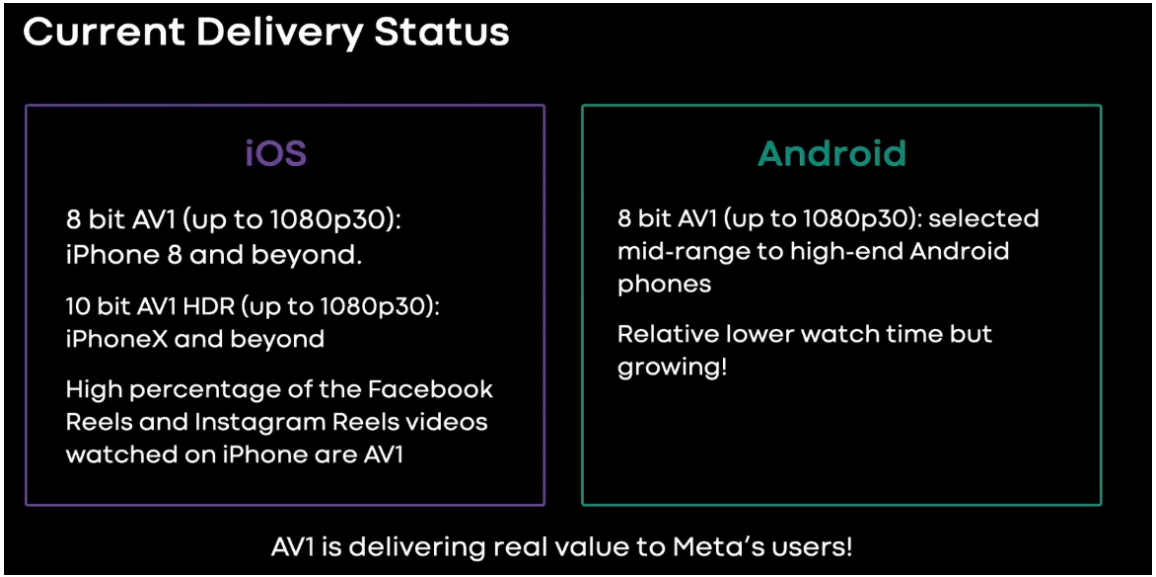
Software Playback Performance

- From V-Nova presentation
- 1080p60 AV1 fails on older devices
  - LCEVC/AV1 plays smoothly
- Point? Mobile devices still iffy without hardware acceleration
  - 720p60 appears to be the target for most producers
  - LCEVC/AV1 also significantly extended the battery life of phones



https://bit.ly/LCEVC_SVT

Meta AV1 Mobile Deployments



- Meta is benchmarking Android phones to determine which to send AV1 to

AV1 vs HEVC on Android

AV1

- Pros:
  - Supported by OS
  - Supported by Chrome
  - No content royalties
- Cons
  - Software player
    - Dropped frames
    - Drains batter life
    - No browser support for iOS

HEVC

- Pros:
  - Supported by OS
  - Supported by Chrome (10/22)
  - No content royalties
  - Hardware player on most premium models
  - Full support (browser and OS) on iOS
- Cons
  - ?

Chip Support –TV

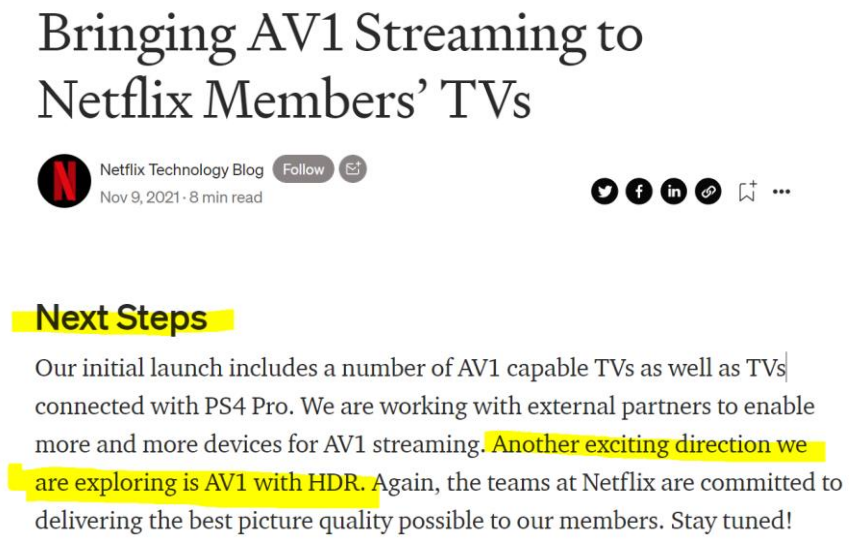
	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices with HDR	• Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek			

HDR 10+ support
No Dolby Vision

https://bit.ly/av1_HDR10plus

Netflix

- Initial distribution of AV1 to smart TVs does not support HDR
- Assume that most premium content publishers won't make same decision without HDR
  - At least for HDR content



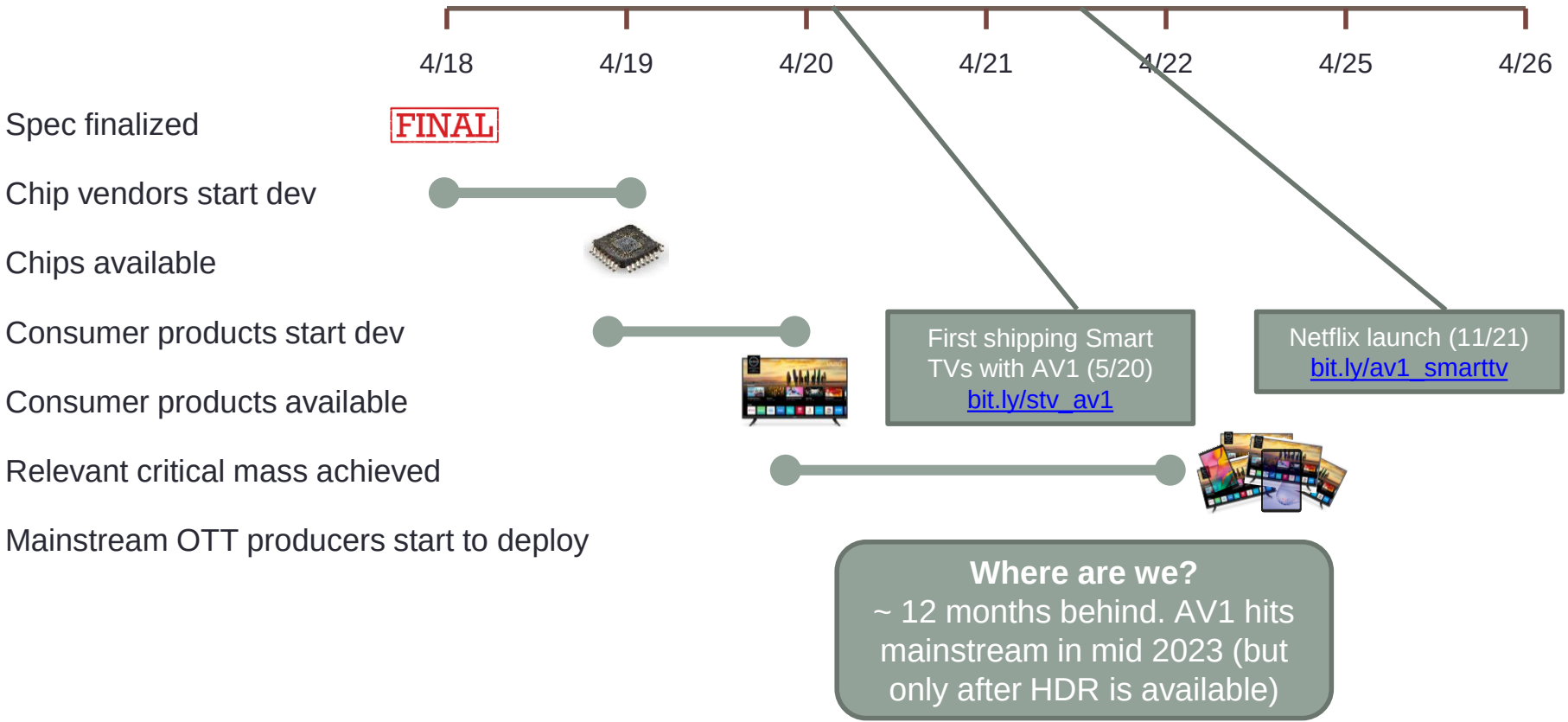
Bringing AV1 Streaming to Netflix Members' TVs

Netflix Technology Blog Follow
Nov 9, 2021 · 8 min read

Next Steps

Our initial launch includes a number of AV1 capable TVs as well as TVs connected with PS4 Pro. We are working with external partners to enable more and more devices for AV1 streaming. Another exciting direction we are exploring is AV1 with HDR. Again, the teams at Netflix are committed to delivering the best picture quality possible to our members. Stay tuned!

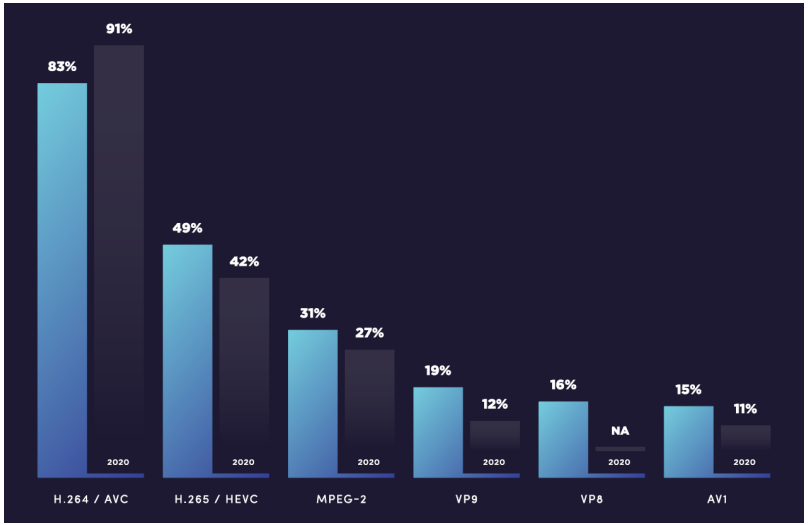
Codec Deployment – AV1 – Smart TVs



Timing of Mainstream Adoption

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser	2022/23	Now	Now	Never	Never	Never	Never
- Browser workaround	**NA**	NA	NA	**$$$$**	**Yes**	?	?
- Mobile – hardware	Now	Now	2024+	2025+	NA	Not on radar	Not on radar
- Mobile - software	NA	NA	Caution	Stakeholders	Today	Not on radar	Not on radar
- Smart TV/STB	Ubiquitous	Ubiquitous	Mid 2023	Mid - 2025	Software-only	Not on radar	Not on radar

Third-Party Predictions

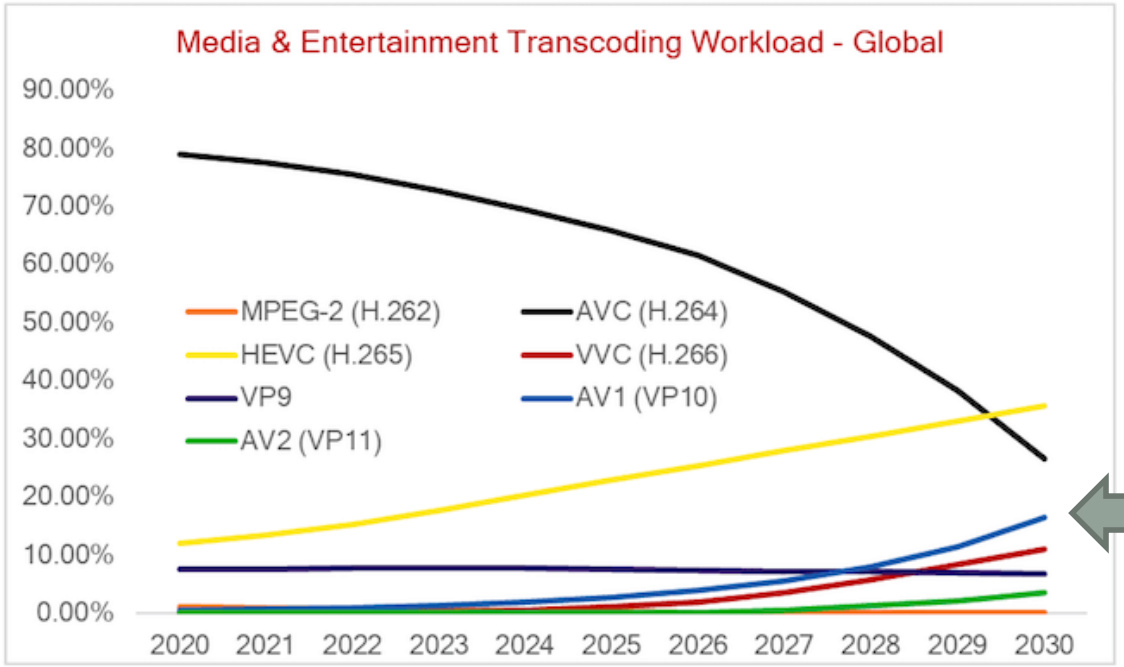


- 15% currently using AV1
- Up from 11% in 2020

- 22% plan to deploy in 2022

Bitmovin - [Bitmovin Video Developer Report]

Third-Party Predictions



- Rethink TV – Very little AV1 usage through 2025

http://bit.ly/rethink_codec

Versatile Video Coding (VVC) - 2022 Perspective

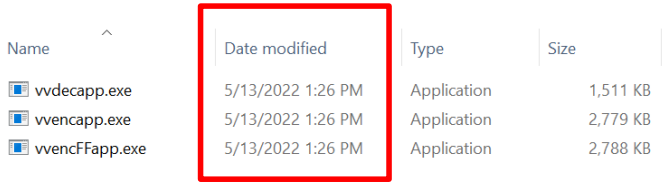
- About VVC
- Quality
- Known royalty
- Unique selling proposition
- Rich parents (key stakeholders)
- Producibility
- Playability

Should be 10:45

Start encode

VVEnCapp Command Strings

Windows executables:
http://forpub.s3.amazonaws.com/vvenc_vvdec_bin.zip



Name	Date modified	Type	Size
vvdecapp.exe	5/13/2022 1:26 PM	Application	1,511 KB
vvencapp.exe	5/13/2022 1:26 PM	Application	2,779 KB
vvencFFapp.exe	5/13/2022 1:26 PM	Application	2,788 KB

https://github.com/fraunhoferhhi/vvenc

VVC Workflow

1. Convert source to Y4M, which is YUV with metadata

```
ffmpeg -y -i input.mp4   -pix_fmt yuv420p -vsync 0  input.yuv
```

2. Encode with vvencapp (single-pass)

```
vvencapp -i input.yuv -s 1920x1080 -c yuv420 -r 30 --preset fast --qp 28 --qpa 0 -
ip 64 -t 4 -o output_vvc_28.266
```

3. Decode to YUV with vvdecapp

```
vvdecapp -b output_vvc_28.266 -o output_vvc_28.yuv
```

VVEnCapp Command Strings

Two-Pass VBR

```
vvencapp.exe -i input.yuv -c yuv420/yuv420_10 -s WxH --fps FRN[/FRD] -o output.266
--preset medium -b R -p 2 -rs 2 -rt cra_cre
```

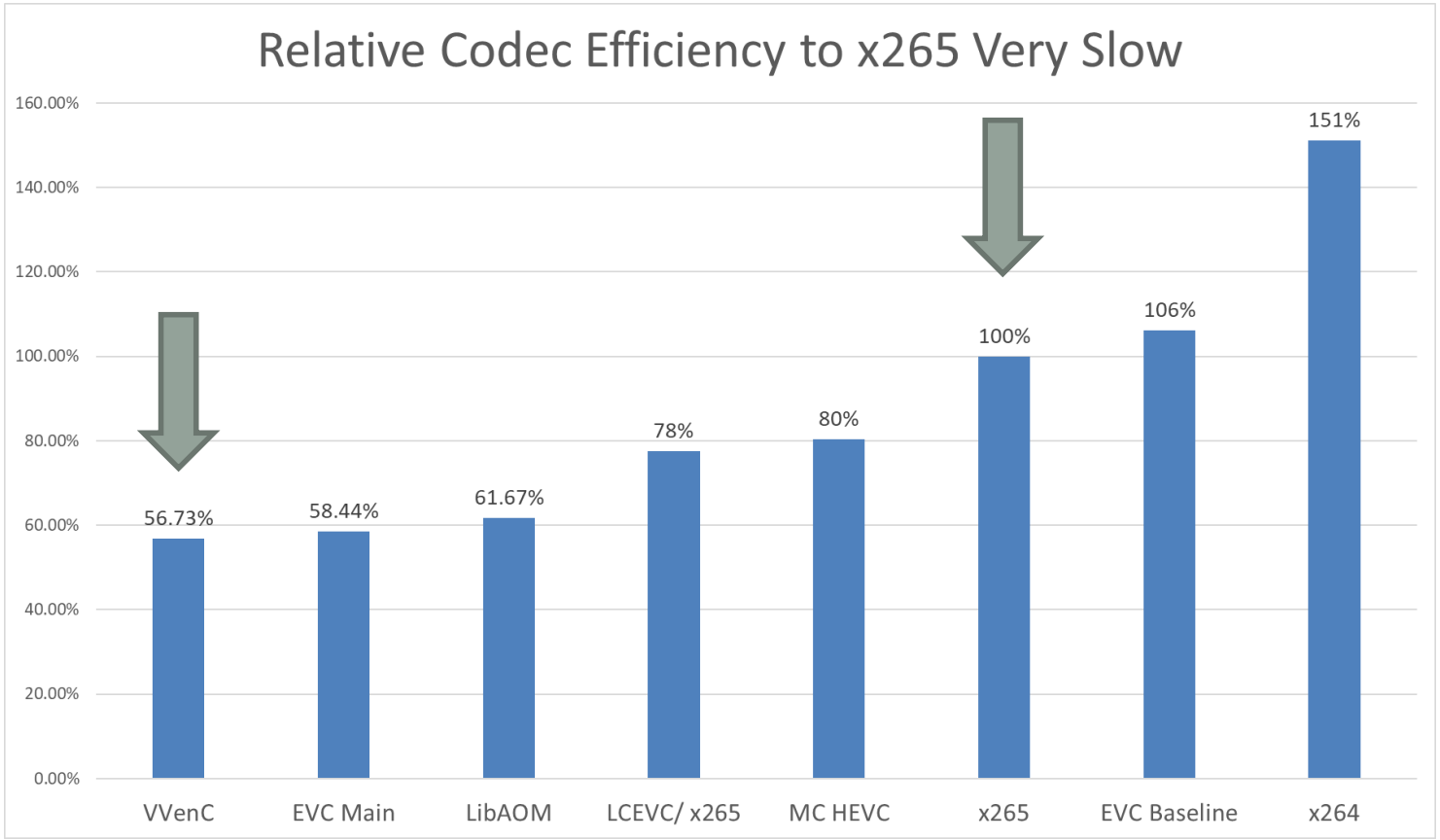
Explanation:

-i input.yuv: specifies your input data, can also be a Y4M file
-c yuv420/yuv420_10: specifies if your input is 8 or 10 bit (can be skipped if using Y4M)
-s WxH: specifies the dimensions of your input (can be skipped if using Y4M)
--fps FRN[/FRD]: specifies the frame-rate of your input, can be either an integer (e.g. 24, 29, 60), or a fraction (e.g. 60000/1001) (can be skipped if using Y4M)
-o output.266: specifies the output bitstream
--preset medium: a commercially viable preset. You could also use fast.
-b R: specifies the target bitrate R, the encoder also now understand postfixes: M, Mbps, K, kbps
-p 2: use two-pass encoding
-rs 2: use a two-second intra period (you can also use -ip X instead if you want to specify the intra-period in frames instead of seconds)
-rt cra_cre: use an open GOP configuration compatible with ABR streaming.

About – VVC/H.266

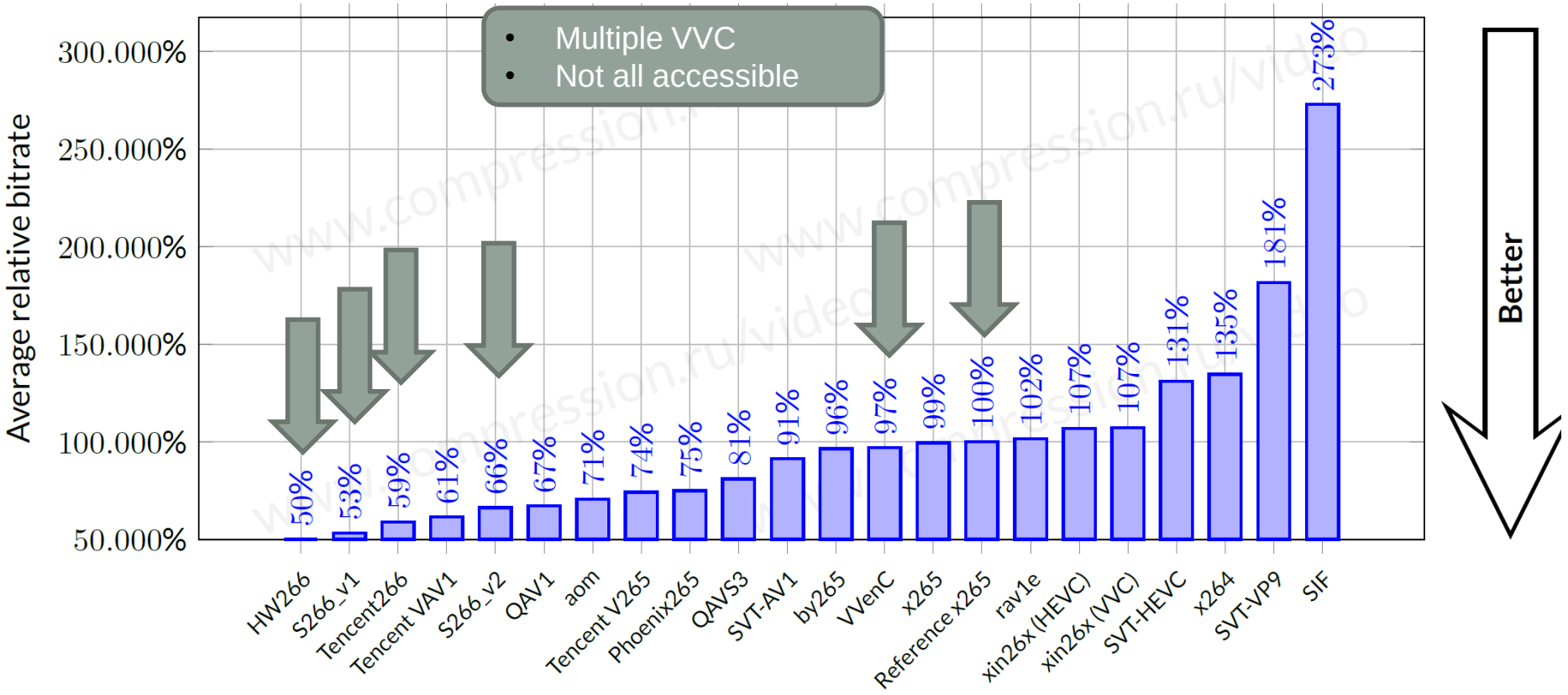
- Standards-based codec
  - MPEG/ITU - Published July 6, 2020
- Typical MPEG codec (successor to HEVC/H.264)
  - Dozens of contributors
  - Five-year development cycle
  - Royalty-bearing
- Key goals
  - Best possible quality (irrespective of complexity)
  - Simpler licensing structure than HEVC

Streaming Media Magazine



https://bit.ly/codec_soup

Moscow State University



http://bit.ly/MSU_codec_2021

Known Royalty Cost - VVC

VVC-Only Platform License - Royalty Rate Structure for Licensees In-Compliance with Trademark Discount, Effective January 1, 2022

Device Category and Examples	Selling Price	Per-Device Royalty[1] All Profiles	Annual In-Compliance Device Category Caps[2]	Annual In-Compliance Enterprise Credit and Cap[2]
Mobile Devices: Mobile Phone, Tablet, Laptop	All price ranges	$0.50/$0.25	$45MM $30MM (If entity does not sell phones)	
Connected Home & Other Devices: Consumer Products: Set-Top Box, Game Console, Blu-ray Player, Desktop PC, non-4k UHD+ TV, HEVC Software, Surveillance Cameras, Conferencing Products, Medical Imaging, Digital Signage	Devices ≤$80.00[2] $20 or less $20.01-$30.00 $30.01-$40.00 $40.01-$50.00 $50.01-$60.00 $60.01-$70.00 $70.01-$80.00	$0.25/$0.25 $0.3125/$0.3125 $0.4375/$0.4375 $0.5625/$0.50 $0.6875/$0.50 $0.8125/$0.50 $0.9375/$0.50	$30MM	Annual Enterprise Cap $60 million Annual Enterprise Credit $25,000
	Devices >$80.00 and All VVC Software	$1.00/$0.50		
4K UHD+ Television/Display	All price ranges	$1.50/$0.75	$30MM	
Digital Media Storage Blu-ray Discs, Other Storage Devices	All price ranges	Per Disc/Title $.028/$.014	$3.75MM	

- Access Advance
  - Multi-Codec Bridging Agreement (“MCBA”) for companies that license both VVC and HEVC
  - “Providing an effective 45% discount”
  - Pool has signaled they may be willing to work with companies regarding HEVC/VVC in free software, but nothing definitive yet

bit.ly/vvc_pools

	De minimus	Royalty	Annual Cap
Hardware/paid software	100,000 units	$0.20	$30 million
VVC free software	1,000,000 units	$0.05	$8 million

- MPEG LA
  - Recently waived royalties on software (subject to some conditions)
  - Granted 25% discount for new licensees

https://bit.ly/mpegla_vvc

VVC - USPs

Cutting the bitrate with Versatile Video Coding

The development of video compression will be key to enabling tomorrow's Ultra HD (8K resolution), VR/AR and 360° video technologies. Below, we follow the progress of the Versatile Video Coding standard which, when finalized in 2020, is expected to reduce the bitrate by roughly half.

JUL 18, 2019 | 1 min.

Per Fröjdh

Director of International Standards

CATEGORY

Research

HASHTAGS

#VVC #MPEG #Bitrate

- VR/AR and 360 features

VVC - USPs

Apple Glasses

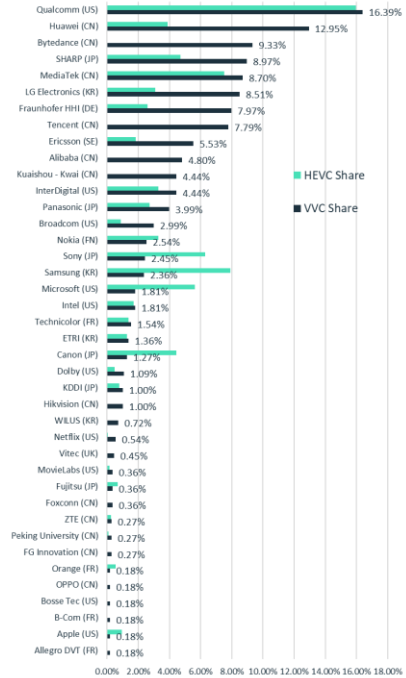
Apple is rumored have a secret team of hundreds of employees working on virtual and augmented reality projects.

By MacRumors Staff on February 14, 2022

bit.ly/3s8rilK

- VR/AR and 360 features
- Apple is VVC patent owner and recently bought more VVC patents – speculation is that patents were for Apple Glasses
- These features could give VVC an early advantage in these markets

Rich Parents – VVC



Patent Owner	Perc.	Chip Vendor	Product Mfgr	Streaming Publisher	Infrastructure Provider	Technology Provider
Qualcomm	16.39%	Yes				
Huawei	12.95%		Yes			
Bytedance	9.33%			TikTok/ Toutiao		
Sharp	8.97%		Yes			
MediaTek	8.70%	Yes				
LG Electronics	8.51%		Yes			
Fraunhofer	7.97%					Yes
Tencent	7.79%			Tencent QQ	Yes	
Ericsson	5.53%				Yes	
Alibaba	4.80%				Yes	
InterDigital	4.44%					Yes
Kuaishou - Kwai	4.44%			Video sharing		
Panasonic	3.99%		Yes			
Broadcom	2.99%	Yes				
Nokia	2.54%		Yes			
Sony	2.45%		Yes			
Samsung	2.36%		Yes			
Intel	1.81%	Yes				
Microsoft	1.81%		Yes	Yes		
Technicolor	1.54%				Yes	
ETRI	1.36%					Yes
Canon	1.27%		Yes			
Dolby	1.09%				Yes	
Hikvision	1.00%		Yes			
KDDI	1.00%				Yes	
WILUS	0.72%					Yes
Netflix	0.54%			Yes		
Vitec	0.45%		Business			
MovieLabs	0.36%					Yes

- Most of the early software playback trials are VVC patent owners
  - Bytedance (TikTok), Kuaishou/Kwai, TenCent

bit.ly/VVC_POs

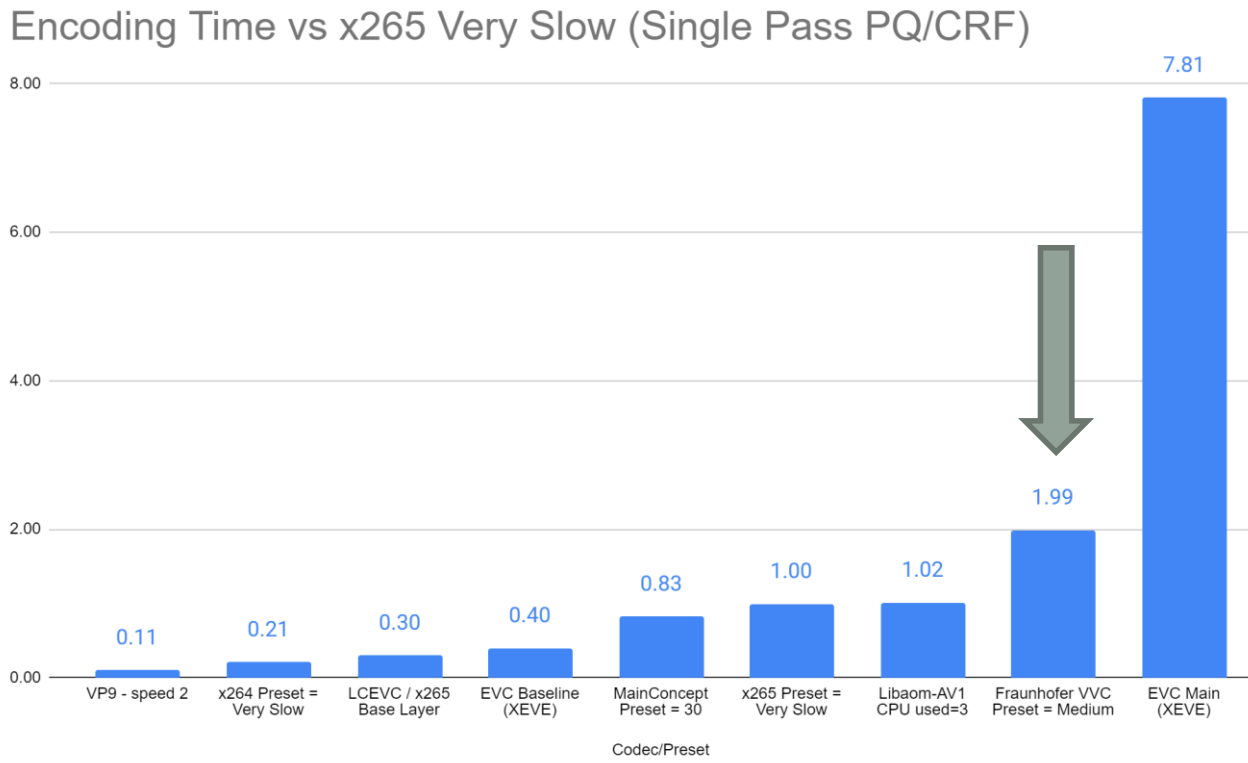
- Early chip support
  - MediaTek
  - Allegro
- Close to matching AOM in coverage and heft (nice parents to have)

Producibility - Software

- Encoding times for newer codecs quite impressive vs x265 very slow
- VVC ~ 2x
  - Very impressive

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



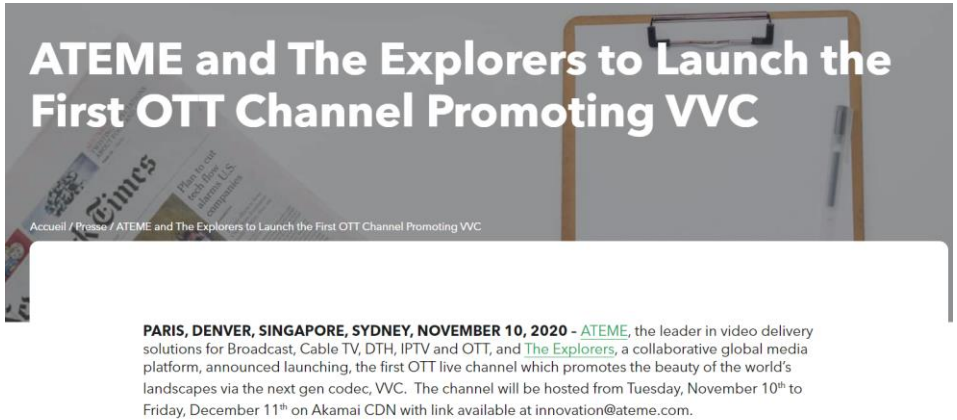
Cloud Pricing

	AWS	Azure	Bitmovin	Brightcove	Telestream
Highest base charge (30 fps/1080p)	$0.042	$0.03	~$0.02	$0.08	$0.02
HEVC multiplier/cost	8x - $0.336	~5x - $0.161	2x - ~$0.04	None -$0.08	4x - $0.08
VP9	~4x - $0.1575	Not supported	2x - ~$0.04	None ($0.08)	4x - $0.08
AV1	~41x - $1.728	Not supported	10x - ~$0.20	Supported, no pricing	Not supported
VVC	Not supported	Not supported	Not supported	Not supported	Not supported
	go.aws/37IbODX	bit.ly/Azure_pricing	bit.ly/BM_pricing	bit.ly/BC_pricing	bit.ly/TS_pricing

Producibility – Hardware

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Live software/hardware	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

- VVC - Ateme announced first live VVC encoder

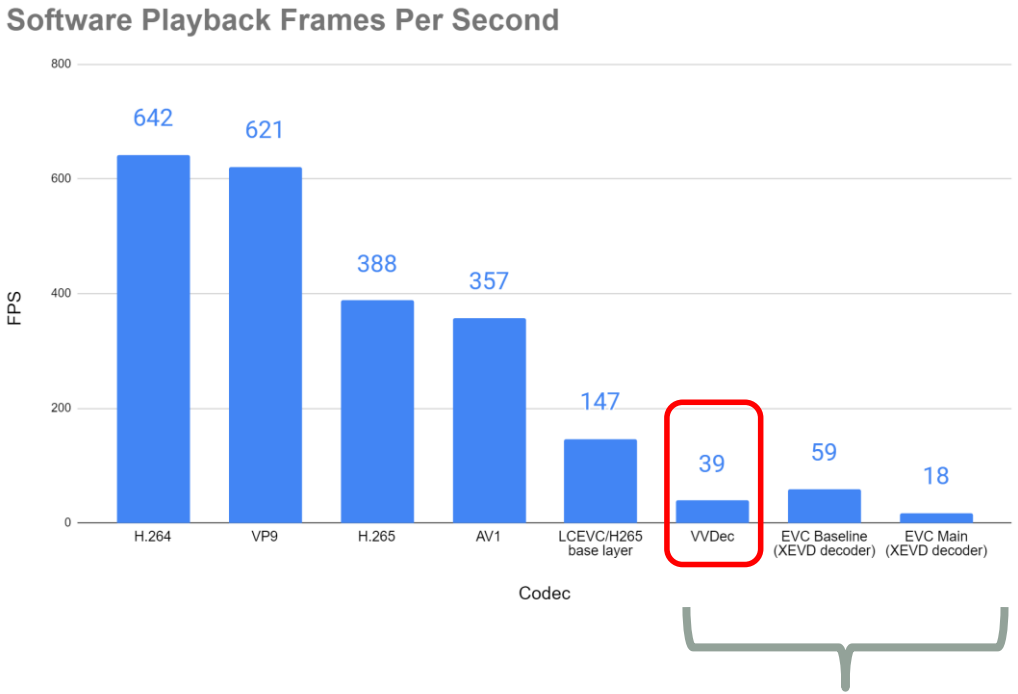


Playability - Performance

- Where can the codec play
  - IMHO - VVC is a “hardware codecs” that will require hardware decoding for mass deployment even on computers

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



VVC Trials – VVC Stakeholders

Results for Android Platform

- Kwai UGC Sequences

	VTM-11.0	K266Dec				Speedup			
# threads	1	1	2	4	8	1	2	4	8
Huawei P40	26.66	97.49	173.85	270.26	178.75	4.82	8.59	13.35	8.83
Oppo R17	10.59	40.95	78.40	100.52	116.97	5.17	9.89	12.68	14.76
VIVO Y93s	5.82	19.06	35.28	60.10	56.63	4.39	8.12	13.83	13.03

link

Performance on iPhone13

	BVC (CPU+GPU) vs. VTM-11.0						
	RA						
	VTM-11.0 (fps)	BVC (CPU+GPU)(fps)			Speedup ratio		
		T-1	T-2	T-4	T-1	T-2	T-4
class A1	2.2	39.5	60.7	67.7	17.6	27.2	30.3
class A2	2.0	30.8	48.8	54.1	15.3	24.2	26.8
class B	9.8	144.3	205.0	217.7	14.8	21.0	22.3
class C	53.5	473.3	563.7	630.3	8.9	10.5	11.8
class D	206.6	970.5	1043.5	1074.2	4.7	5.1	5.2
class F	43.6	444.1	527.6	616.0	10.2	12.1	14.1

- For 4K 8-bit CTC bitstreams
  - *Achieve 35 fps with single thread on average*
  - *15x faster than the VTM11.0 reference decoder with single thread*

link

ByteDance

- What's the point?
  - Their players could be much more efficient
  - Normally, implementors require hardware support
- As with AV1, stakeholders could deploy VVC much earlier than a third-party company
  - This will prime the pump, accelerating hardware/software support and additional deployments

Playability – Compatibility - Computer and Mobile Browser Support

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	22.91%	97.64	73.2%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	No	NA	NA	No	**Yes**	No	No

- CanIUse shows compatibility percentage
  - VVC not yet listed

https://caniuse.com/?search=VVC

Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- Most data from Wikipedia
  - No announced VVC support for mobile SOCs

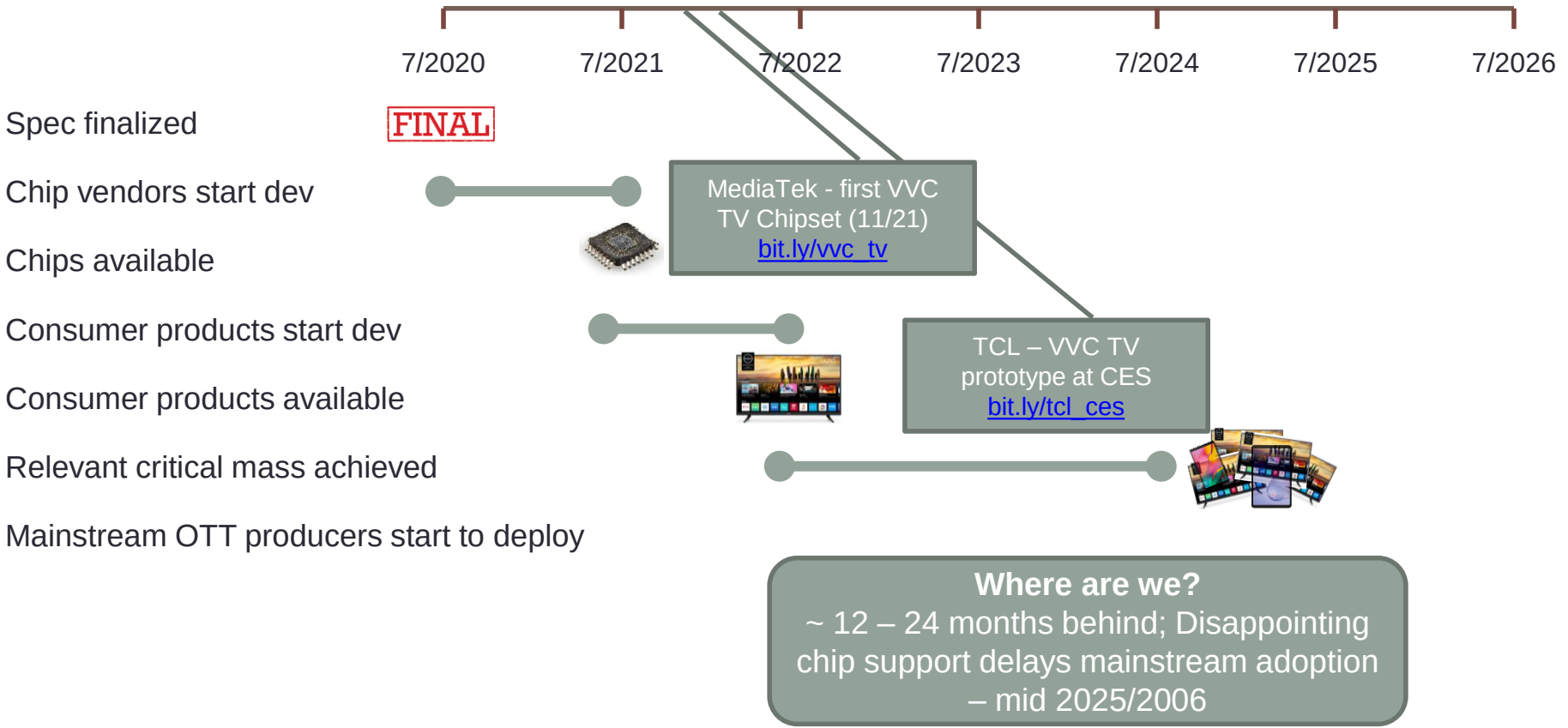
Mobile Deployments

- VVC
  - Stakeholders may attempt to play software-only
  - Most other publishers will wait for hardware

Chip Support –TV

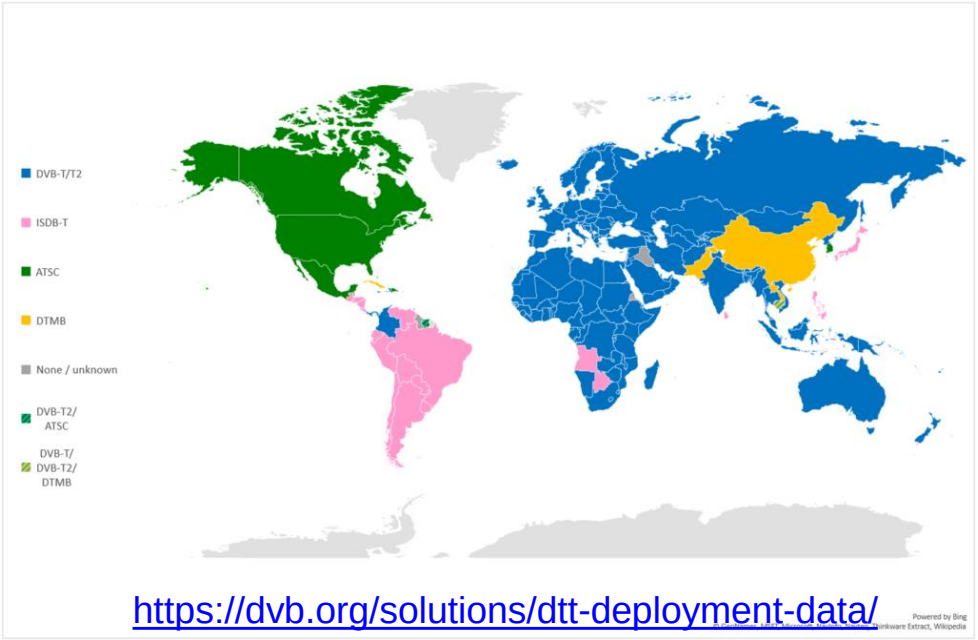
	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices with HDR	• Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek • RealTek			

Codec Deployment – VVC – TV/Mobile Hardware



Other Factors

bit.ly/DVB_VVC2

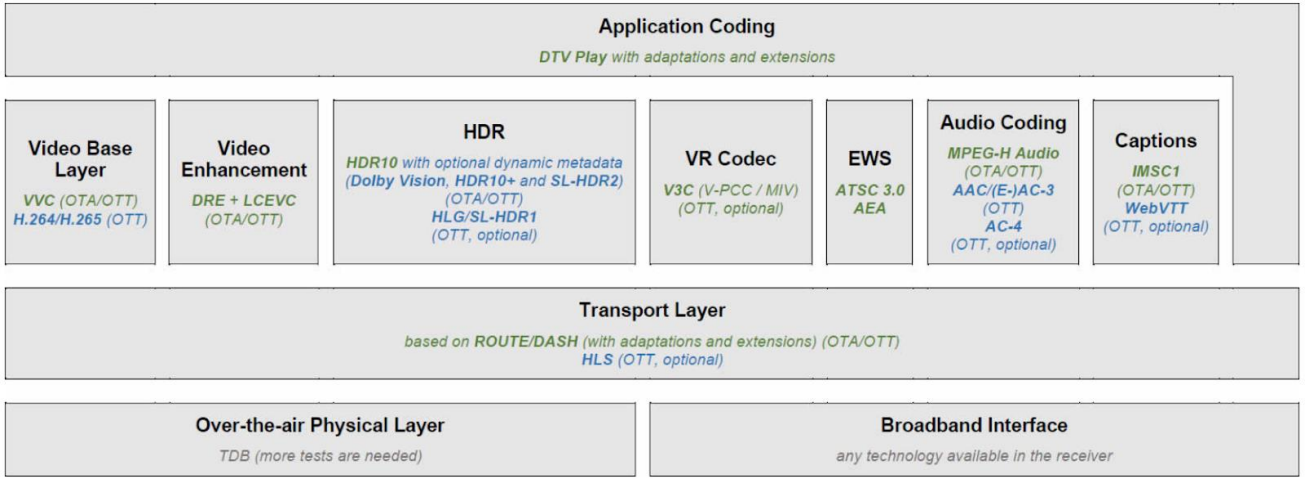


https://dvb.org/solutions/dtt-deployment-data/

- VVC added to DVB tuner specification

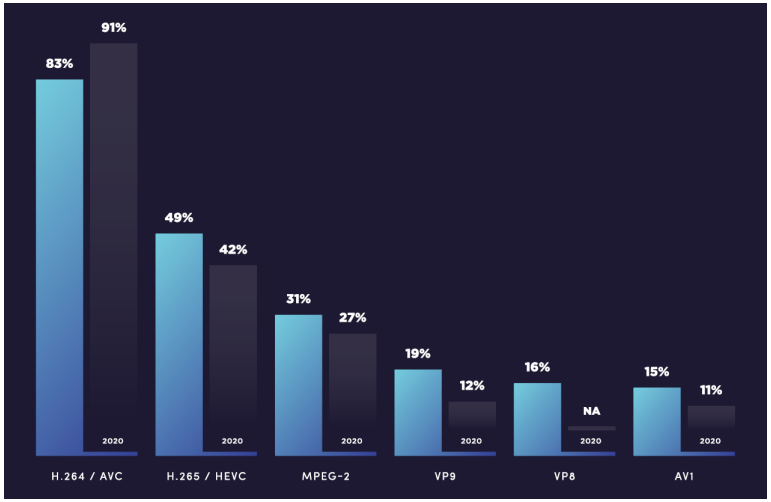
- From the press release – “Having completed the addition of VVC on schedule, the group is continuing to work intensively, with the AVS3 codec as the current focus and **AV1 next in line for evaluation.”**

Other Factors



- VVC and LCEVC were included in Brazil's recent TV 3.0 project (Above)
- Should advance adoption of both codes

Third-Party Predictions

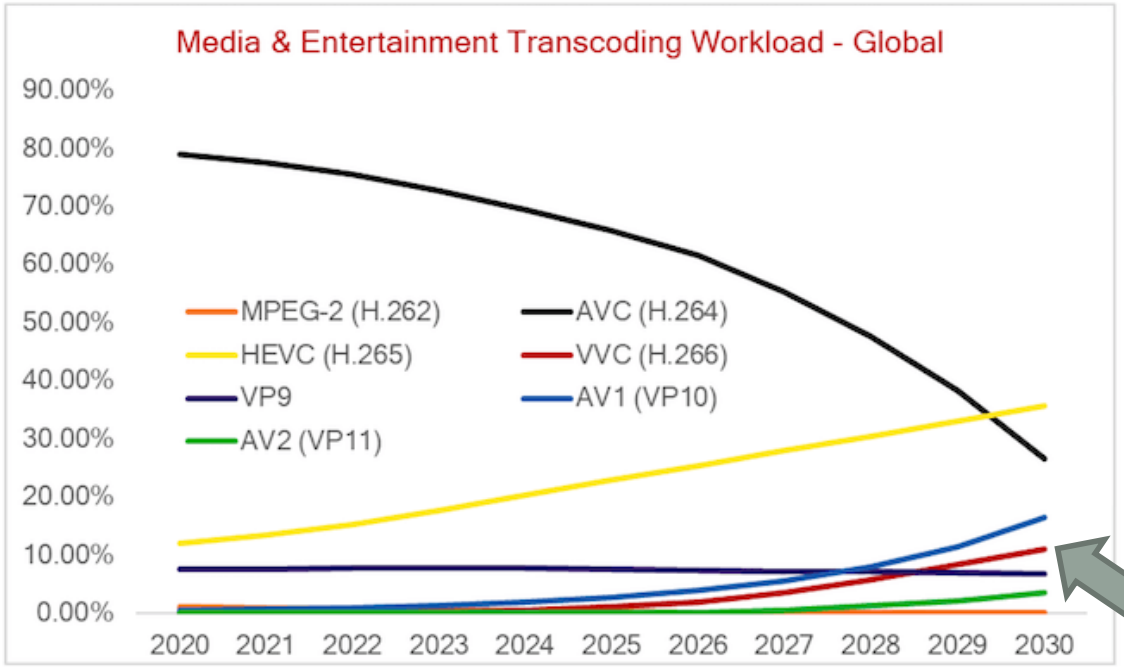


- No existing usage

- 20% plan to deploy VVC in 2022
  - This includes entire ecosystem – not just content publishers
  - So, CDN, encode, decode, etc.

Bitmovin - Bitmovin Video Developer Report

Third-Party Predictions

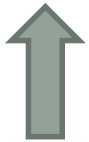


- Rethink TV – Pretty bullish on VVC, but still only 10% by 2030
  - Dwarfed by HEVC, H.264, and AV1

http://bit.ly/rethink_codec

Timing of Mainstream Adoption

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser	2022/23	Now	Now	Never	Never	Never	Never
- Browser workaround	**NA**	NA	NA	**$$$$**	**Yes**	?	?
- Mobile – hardware	Now	Now	2024+	2025+	NA	Not on radar	Not on radar
- Mobile - software	NA	NA	Caution	Stakeholders	Today	Not on radar	Not on radar
- Smart TV/STB	Ubiquitous	Ubiquitous	Mid 2023	Mid - 2025	Software-only	Not on radar	Not on radar



LCEVC – 2022 Perspective

Should be 11:15

- About LCEVC
- Quality
- Known royalty
- Unique selling proposition (USP)
- Rich parents – key stakeholders
- Producibility
- Playability

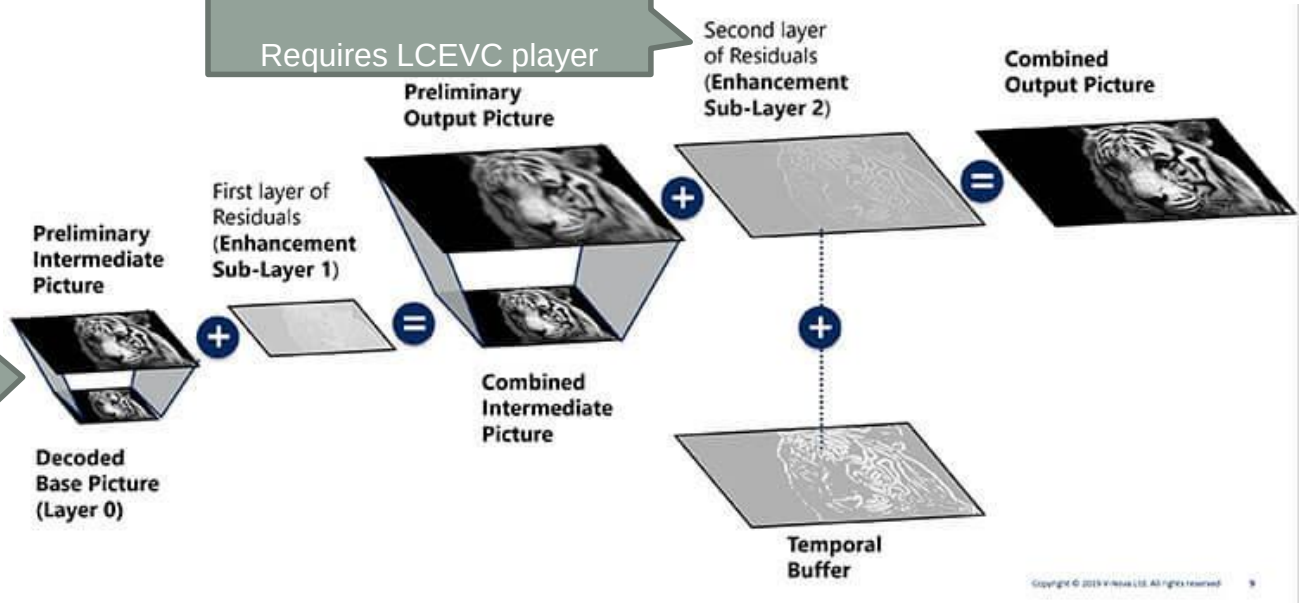
About - LCEVC

- Low Complexity Enhancement Video Coding
  - MPEG/ITU codec (MPEG-5)
  - Formalization of V-Nova Perseus Technology
    - Primary IP contributor
  - Published October 2020
- Goals
  - Low complexity (green)
  - Simple licensing structure
- Enhancement codec
  - Base layer – existing codec
  - Enhancement layer - LCEVC

LCEVC Description – Enhancement Codec

LCEVC Enhancement Layer to full resolution

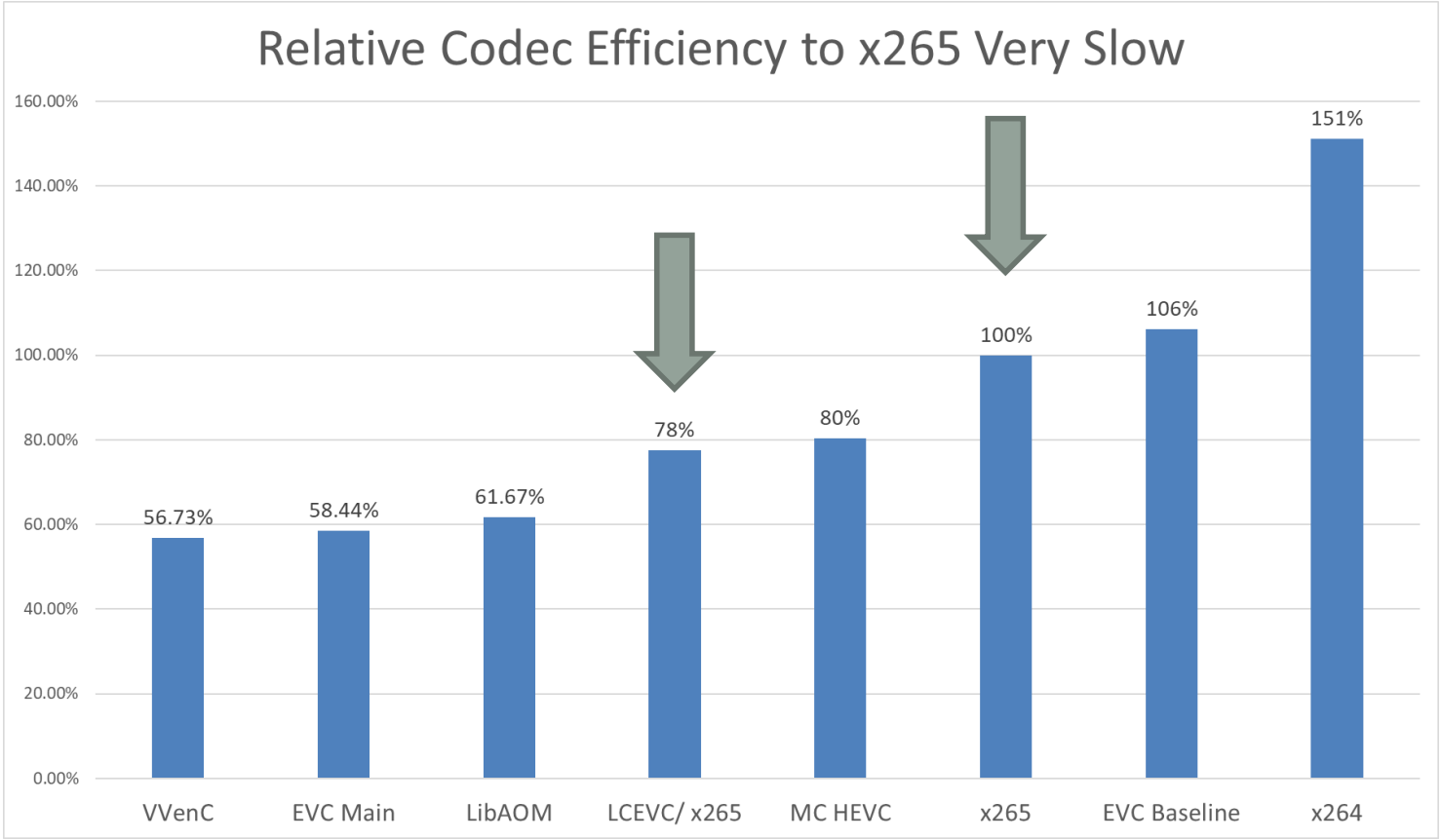
Requires LCEVC player



Base layer (x264, x265, AV1) at lower resolution

Plays on any platform compatible with base layer codec.

Streaming Media Magazine



https://bit.ly/codec_soup

LCEVC Performance Varies with Base Layer

- My findings:
  - LCEVC/x264 as base layer – 40% more efficient than x264
  - LCEVC/x265 as base layer – 22% more efficient than x265
  - LCEVC/AV1 as base layer – 12% more efficient than AV1
    - Other benefits:
    - 3-4x faster encoding speed
    - Equal or more efficient playback

LCEVC Performance Varies with Base Layer

- Evaluation of MPEG-5 Part 2 (LCEVC) for Live Gaming Video Streaming Applications
  - VMAF
    - LCEVC enhancing x264 (medium) BD-rate-VMAF of −42.14% over x264
    - LCEVC enhancing x265 (veryfast) BD-rate-VMAF of −38.86% for x265
    - LCEVC -x264 (medium) outperforms x265 (veryfast) with a BD-rate-VMAF of −13.64%
  - PSNR - while LCEVCx264 outperforms x264, x265 outperforms LCEVC-x265

LCEVC Performance Varies with Base Layer

- Overview of the Low Complexity Enhancement Video Coding (LCEVC) Standard
  - 46% for UHD and 28% for HD for LCEVC enhancing AVC;
  - 31% for UHD and 24% for HD for LCEVC enhancing HEVC;
  - An overall benefit for LCEVC enhancing EVC and VVC

Compared to SVT-AV1 Encode/AV1 decode

Enhancing SVT-AV1 with LCEVC to improve quality-cycles trade-offs and enhance sustainability of VOD transcoding

- Same quality as SVT-AV1 at:
  - 88% lower encoding time (VMAF)
  - 46% lower encoding time (VMAF-NEG)
  - 26% lower encoding time (SSIM)

- Saves battery life on decode
  - Galaxy S9 – 33%
  - Pixel 5 – 41%
  - Nokia 8.3 – 33%

Key Benefits

- Backwards compatibility
  - X264 layer will play even if player not LCEVC compatible
- Bitrate efficiency
  - LCEVC with base layer always more efficient than base layer at full rez
  - LCEVC with x265 base more efficient than x265 at full rez
- Encoding speed
  - LCEVC always encodes faster that base layer at full rez
  - LCEVC with x265 base always encodes faster than x265 at full rez
- Decoding efficiency
  - LCEVC always requires less CPU than base layer at full rez
  - LCEVC with x265 base requires less CPU than x265 base at full rez (assuming no HEVC decode)

Known Royalty Cost - LCEVC

- V-Nova
  - Royalty on content publishers (so the company benefiting pays the royalties)
  - Free for encoding (encoders) and playback (decoders)
  - Different (undisclosed) charges for different business models
    - Examples next page
  - All capped at US$3.7 million
- Key benefits
  - Should accelerate ecosystem support because decode is free
  - Publisher can make deployment decision for $3.7 million (use workarounds)
    - VVC deployment could cost $38 million

bit.ly/lcevc_royalty

Known Royalty Cost - LCEVC

Pricing examples

Subscription streaming service

A global SVOD service accessible via multiple devices such as set-top boxes, mobile or smart TVs.

Users: 80mn

Licence Fees: USD 3.7mn (cap)

$.046/player

Ad based streaming service

An ad-based streaming service where users can freely access content.

Users: 100mn

Licence Fees: USD 1.8mn

$.018/player

TV Everywhere service

A national broadcaster uses LCEVC to upgrade their 'everywhere TV' service.

Users: 12mn

Licence Fees: USD 0.2mn

$.016/player

bit.ly/lcevc_royalty

LCEVC - USPs

- Green codec – more efficient encode than x265 (with x265 as a base layer)
- Software codec
  - Backwards compatible to base layer codec
  - Plays in software on most platforms (later)
- Point Cloud Compression - VR

V-Nova Receives Lumiere Award from The Advanced Imaging Society

V-Nova, developer and provider of video compression systems, has been recognised by The Advanced Imaging Society (AIS) Awards Committee for the successful application of its Point Cloud Compression technology, winning a **Lumiere Award**.

https://bit.ly/LCEVC_pointcloud

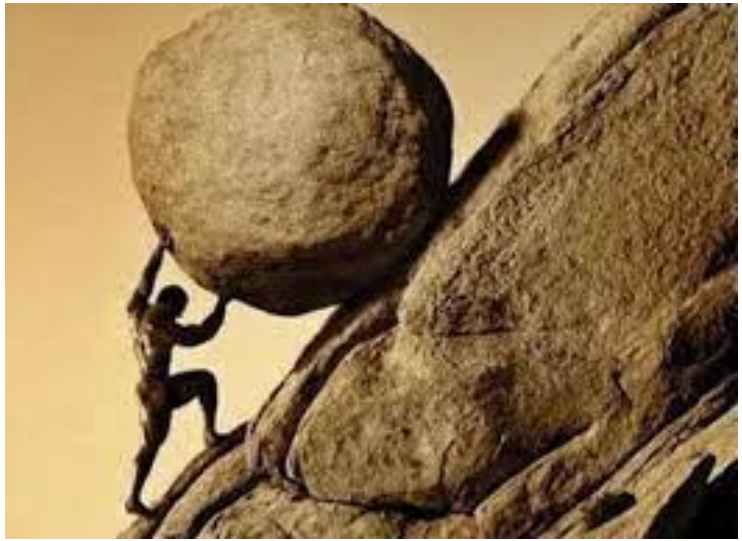
V-Nova Point Cloud Compression achieves compression performance that other technologies cannot attain. The resulting 6DoF technology responds accurately to the orientation and position of a VR headset. This allows the viewer to move around freely within the image with 6 degrees of freedom.

Rich Parents - LCEVC

- Some great investors, but way behind the other codecs

- V-Nova has done a fabulous job:
  - Developing the codec
  - Gaining MPEG approval
  - Proving the value proposition
  - Achieving ecosystem support

Rich Parents - LCEVC



- Some great investors, but way behind the other codecs

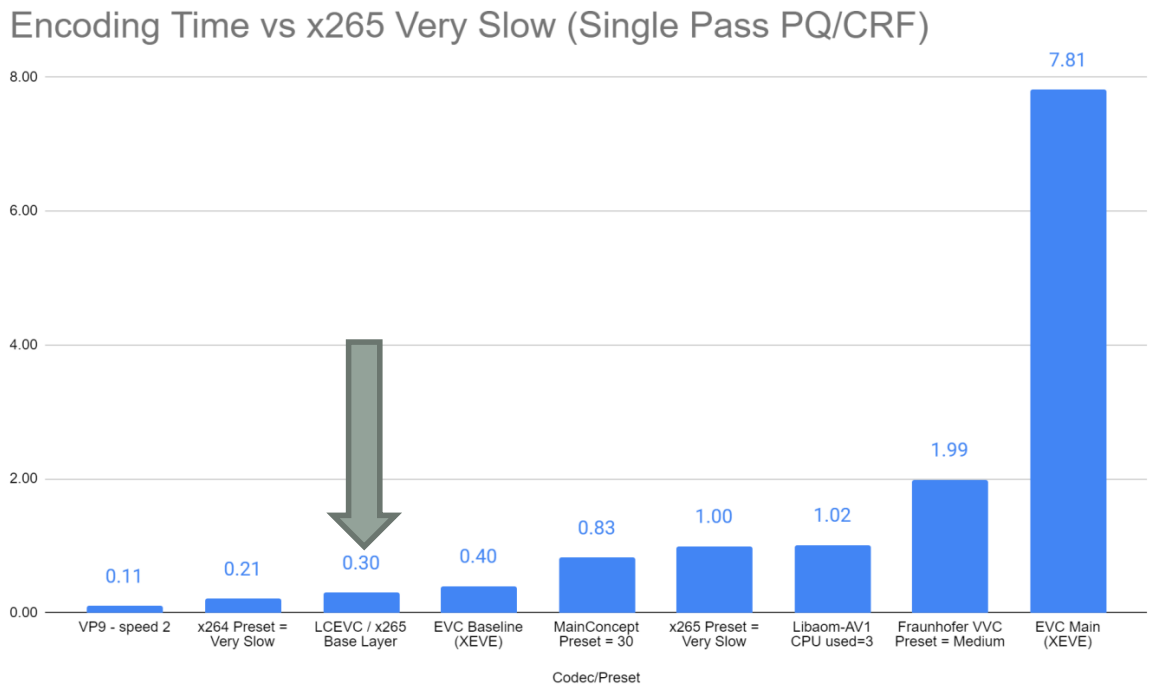
- V-Nova has done a fabulous job:
  - Developing the codec
  - Gaining MPEG approval
  - Proving the value proposition
  - Achieving ecosystem support
- But their effort is Sisyphean compared to other codecs with many more rich parents

Producibility - Software

Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)

- LCEVC/x265 as base (.3x)
- Easily capable of live encoding for origination or transcoding



LCEVC Workflow

Windows executables: Contact Guendalina Cobianchi <guendalina.cobianchi@v-nova.com>

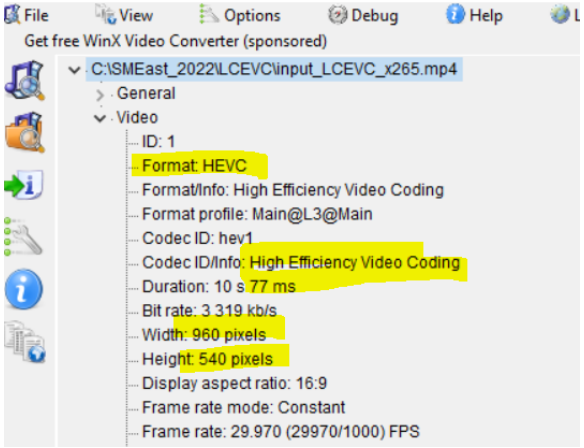
LCEVC Workflow

2. Encode with LCEVC-capable version of FFmpeg (one or two-pass)

```
ffmpeg -y  -i "input.mp4" -g 60 -c:v lcevc_hevc  -
base_encoder x265 -r 29.97 -s 1920x1080 -b:v 2800k -
eil_params "preset=veryslow;scenecut=0;min-
keyint=60;frame-
threads=4;residual_mode_priority_enabled=0;temporal_use
_priority_map=0"  input_LCEVC_x265.mp4
```

3. Decode to Y4M with LCEVC-capable version of FFmpeg

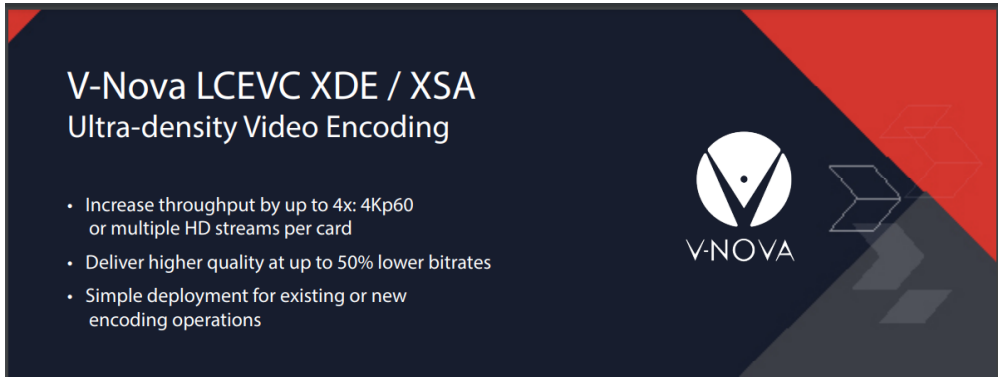
```
ffmpeg -vcodec lcevc_hevc -y -i  input_LCEVC_x265.mp4 -
s 1920x1080  input_LCEVC_x265.y4m
```



Producibility – Hardware

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Encoding time	Baseline	Baseline	1.02x	2x	.3x	.4x	7.8x
- Live software/hardware	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

- LCEVC
  - Harmonic
  - Southworks
  - Red5Pro
  - NETINT
  - Many others



LCEVC and HDR

HDR video coding with MPEG-5 LCEVC

Amaya Jiménez-Moreno
V-Nova Limited
London, UK
amaya.moreno@v-nova.com

Lorenzo Ciccarelli
V-Nova Limited
London, UK
lorenzo.ciccarelli@v-nova.com

Rick Clucas
V-Nova Limited
London, UK
rick.clucas@v-nova.com

Simone Ferrara
V-Nova Limited
London, UK
simone.ferrara@v-nova.com

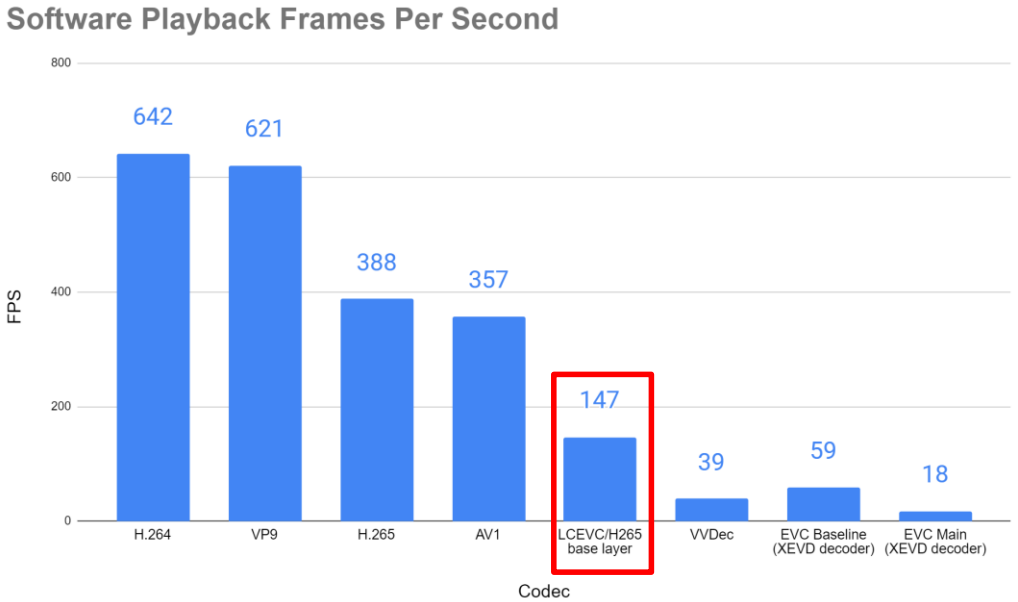
https://bit.ly/LCEVC_HDR

Playability - Performance

- Where can the codec play
  - Does it need hardware acceleration?
    - V-Nova throttles playback speed beyond real-time to limit battery usage
    - More efficient than base layer codec

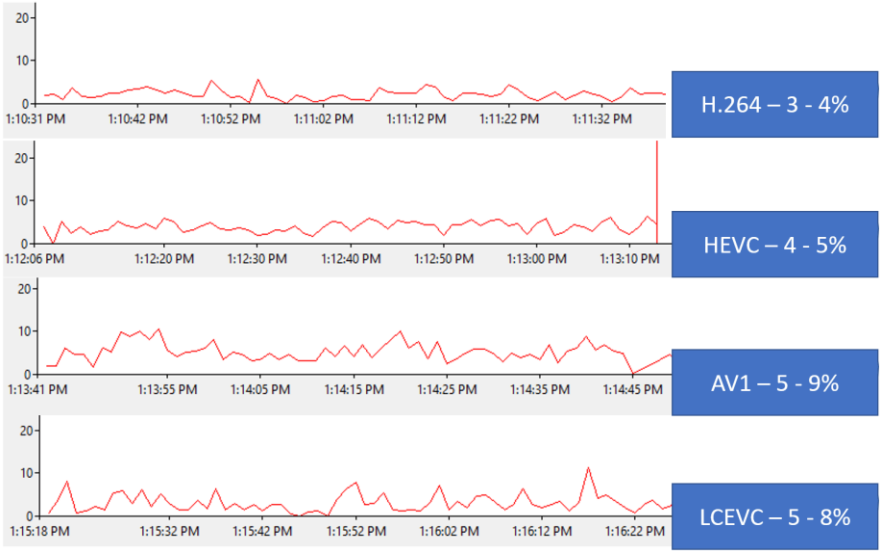
Device specifications

Device name	DESKTOP-E13MMP4
Processor	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed RAM	16.0 GB (15.9 GB usable)



LCEVC CPU Consumption

- Decode 60 seconds, record CPU
- Software-only playback
- FPS results suggest that HEVC is about 2.5x more efficient than LCEVC
- These tests show that LCEVC is about the same
- Bottom line: LCEVC should be capable of software-only playback on most devices



Playability – Compatibility - Computer and Mobile Browser Support

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Playability	388 fps	621 fps	357 fps	39 fps	147fps +	59 fps	18 fps
- Browser support	19.65%	97.1%	74.6%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	No	NA	NA	No	**License**	No	No

- Not currently supported in any browsers
- Supported in many players
  - Next slide

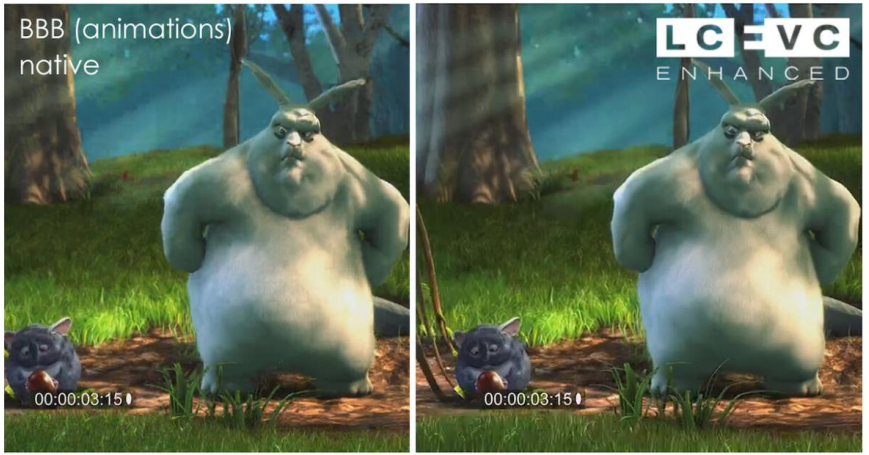
https://caniuse.com/?search=lcevc

Browser/OS Workaround - LCEVC

- Choose compatible encoder
  - Harmonic
  - Southworks
  - Red5Pro
  - NETINT
- Choose a compatible player
  - ExoPlayer for Android
  - AVPlayer for iOS
  - Microsoft UWP for Windows
  - Web players like HLS.js, Shaka Player, video.js.
- Contact V-Nova and negotiate license

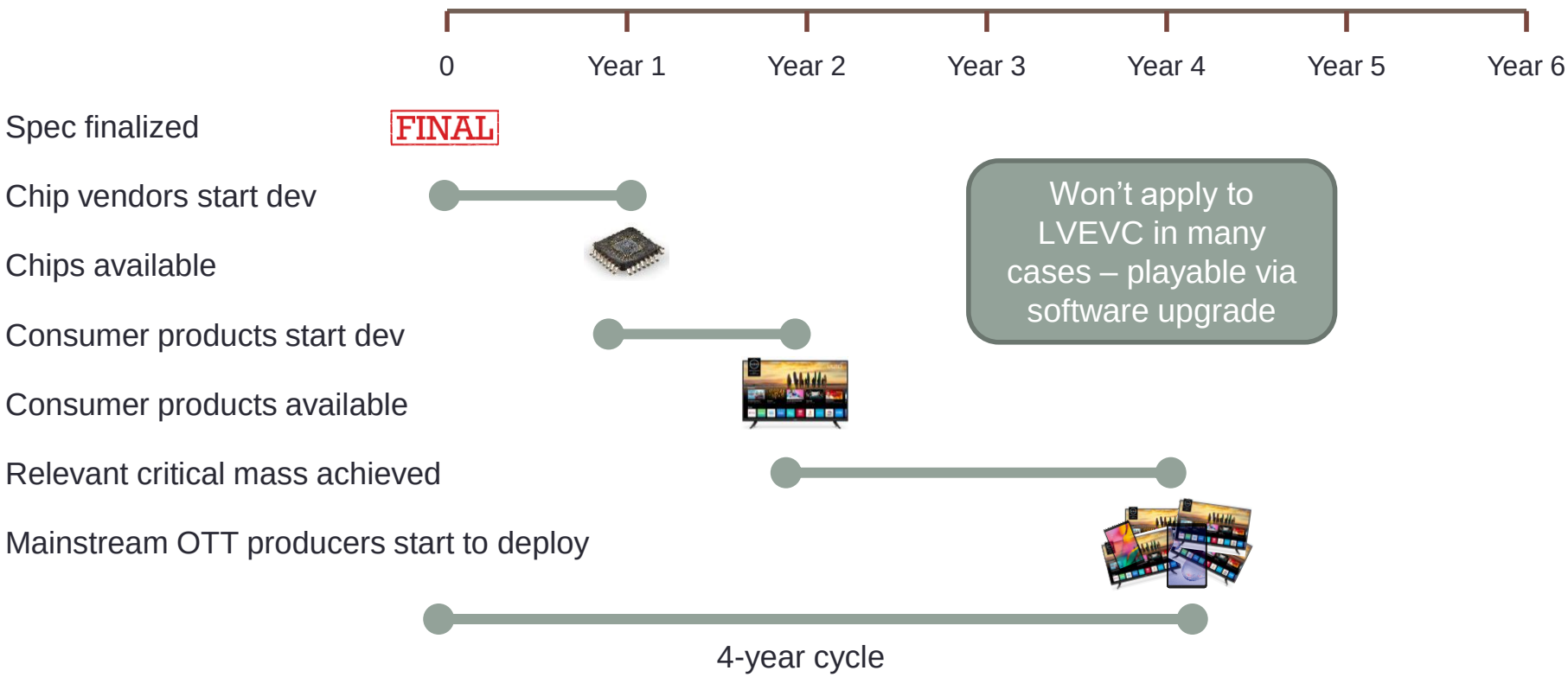
June 29, 2021
By Streaming Media Editorial Staff
Blog

LCEVC: Ready for Primetime



bit.ly/lcevc_primetime

Codec Deployment – Hardware / Best Case



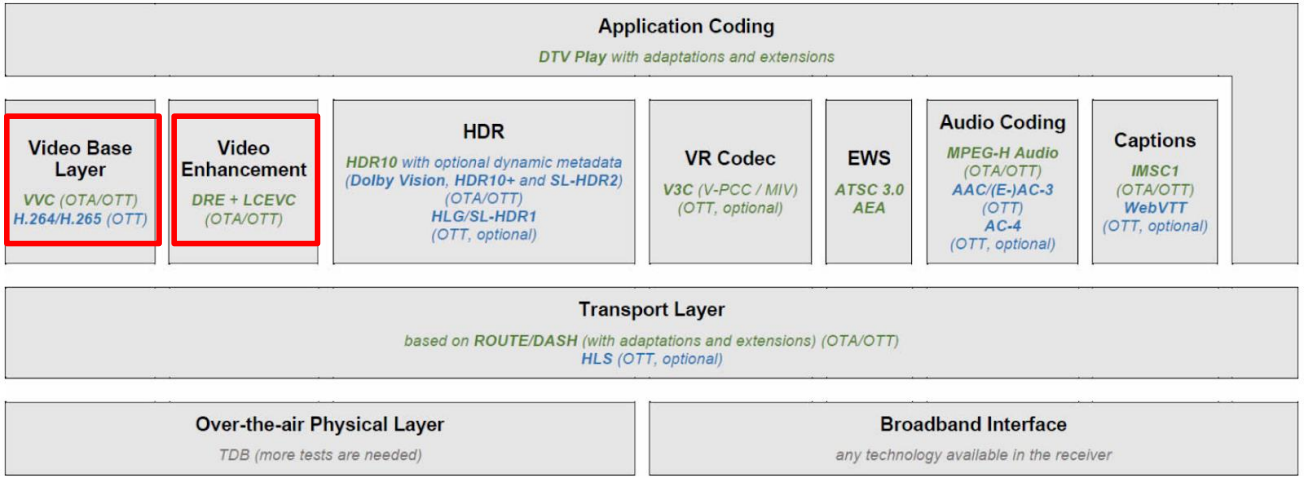
Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

Chip Support –TV

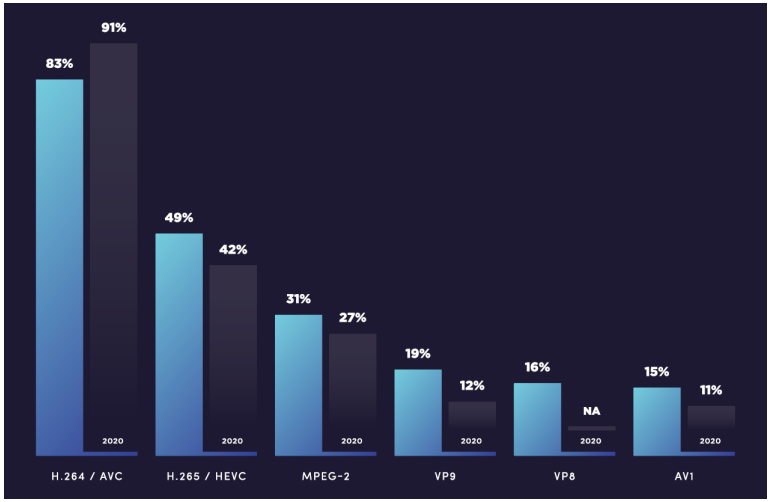
	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
TV Chipsets	Fully supported in most living room devices with HDR	• Amlogic • Imagination • MediaTek • RealTek	• Allegro • Amlogic • Amphion • Broadcom • LG • MediaTek • Realtek • Rockchip • Samsung	• Allegro • MediaTek			

Other Factors



- VVC and LCEVC were included in Brazil's recent TV 3.0 project (Above)
- Should advance adoption of VVC and LCEVC

Third-Party Predictions

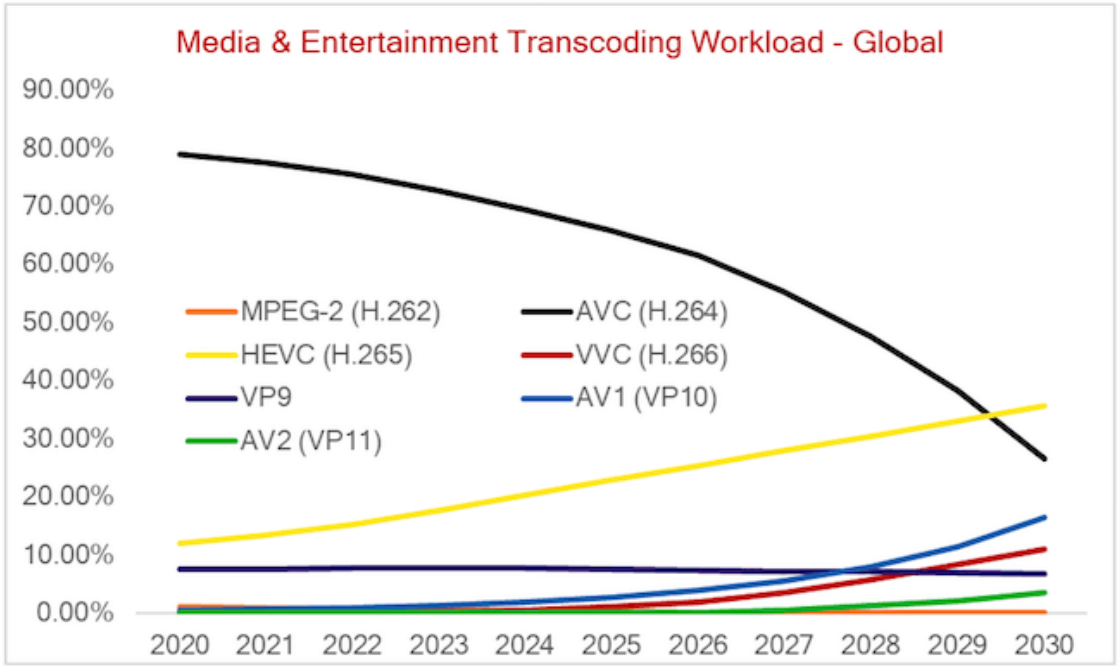


- No use in 2021

- 11% plan to deploy LCEVC in 2022
- Probably more infrastructure providers (encoding/players) than publishers

Bitmovin - Bitmovin Video Developer Report

Third-Party Predictions



- Rethink TV – LCEVC not separately listed
  - Assumed to be enhancement codec for AV1

http://bit.ly/rethink_codec

Essential Video Coding (EVC) – 2022 Perspective

Should be 11:35

- About EVC
- Quality
- Known royalty
- Rich parents (key stakeholders)
- Producibility
- Playability

About - EVC

- Standards-based codec
  - MPEG - Published May 6, 2020
  - Four contributors (Qualcomm, Huawei, Samsung, Divideon)
- Goals
  - Royalty free component (as alternative to AV1)
  - Simplified licensing structure (as alternative to HEVC)

EVC

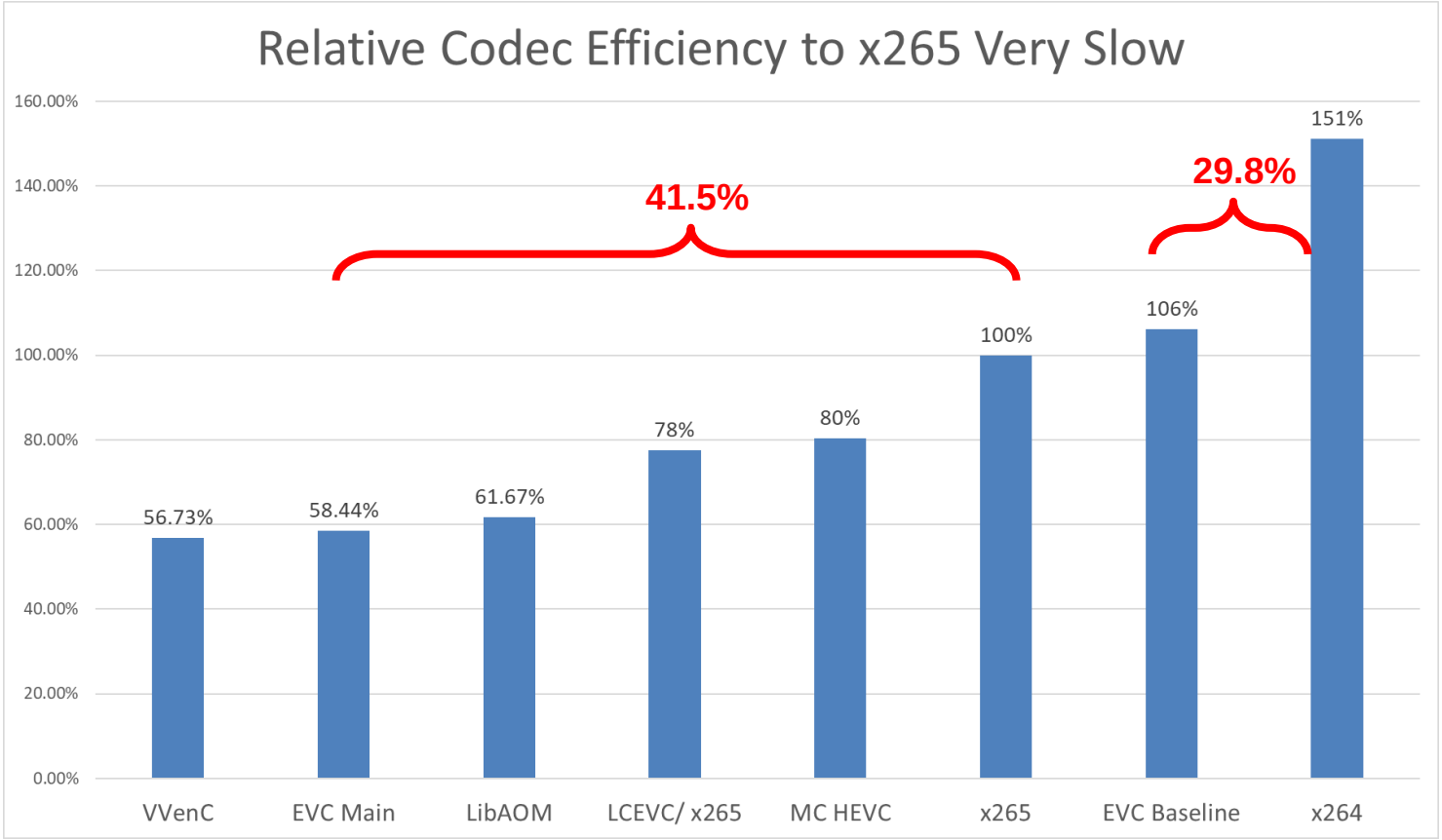
(Essential Video Coding)

MPEG-5

About - EVC

- Two profiles
  - Baseline – targets H.264
    - Uses technologies with expired patents
    - Supposed to be royalty free
    - ~30% more efficient than **H.264**
  - Main – targets HEVC
    - Uses patented technologies from four companies
    - Royalty bearing
    - ~30% more efficient than **HEVC**

Streaming Media Magazine



https://bit.ly/codec_soup

Common Data Points – vs. x265

	Best VVC	EVC Main	Best AV1	LCEVC/ x265	Other HEVC	EVC Baseline	x264
Streaming Media	~43%	~42%	~38%	~22%	~20%	+~6%	+~51%

- Take aways
  - EVC Main – very efficient in early open-source version - ~42% more efficient than x265
  - EVC Baseline - ~30% more efficient than x264

Known Royalty Cost

	HEVC	VP9	AV1	VVC	LCEVC	EVC
Patent pools	3	1 (disputed by Google)	1 (disputed by AO Media)	2	1	?
Schema	- encoder/decoder - per-unit royalty - annual cap	- decoder - per-unit royalty	- decoder - per-unit royalty	- encoder/ decoder - per-unit royalty - annual cap	- Content royalty (publisher pays) - cap	- Unknown - 2-year window
Learn more:	bit.ly/hevc_3	bit.ly/vp9_pool	bit.ly/av1_pool	bit.ly/vvc_pools	bit.ly/lcevc_royalty	

- EVC – No royalty policy may be slowing potential adoption

Rich Parents - EVC

- Some big companies, but no match for VVC/AOM
- All three large companies are major VVC patent owners

Producibility - Software

- Encoding times quite impressive vs x265 very slow
  - EVC Baseline (.4x)
  - Rev 1 EVC Main - ~8x

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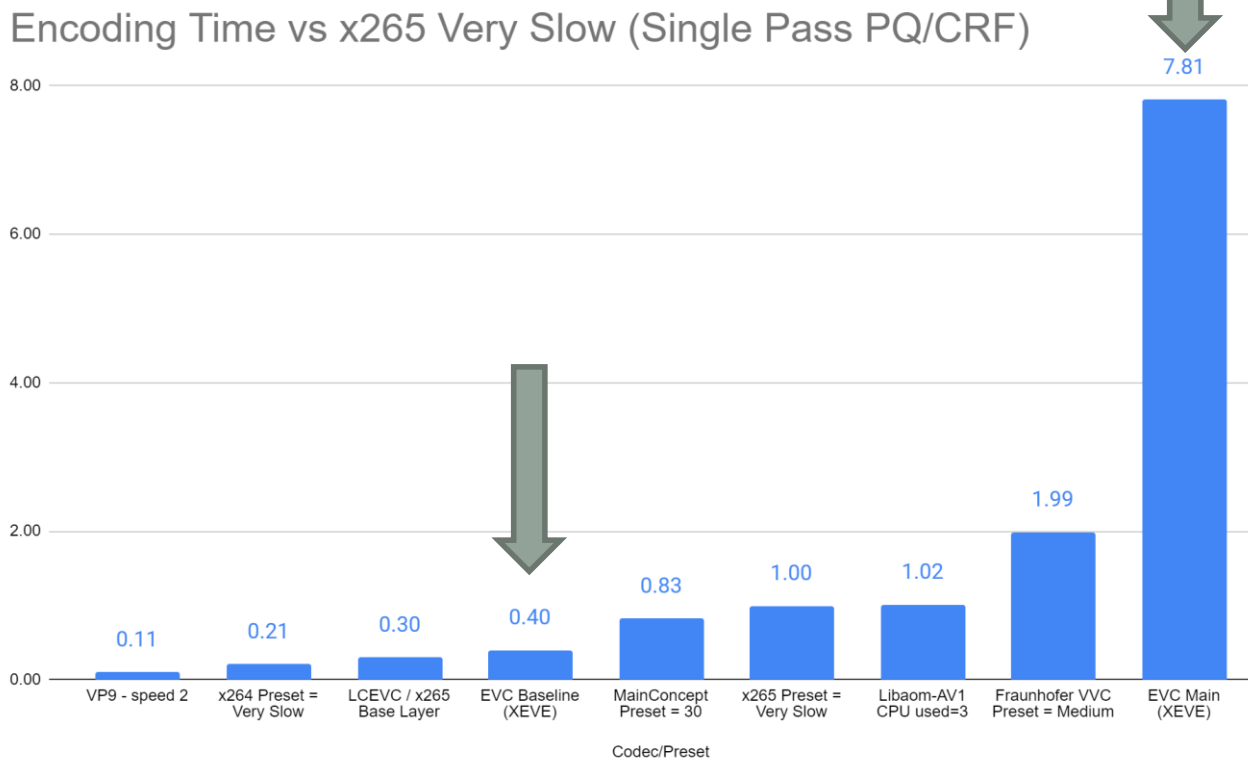
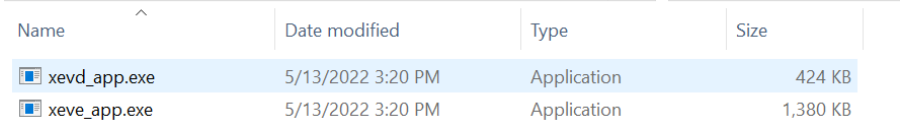


bit.ly/codec_soup

XEVE Command Strings

Windows executables:
http://forpub.s3.amazonaws.com/xeve_xevd.zip



Name	Date modified	Type	Size
xevd_app.exe	5/13/2022 3:20 PM	Application	424 KB
xeve_app.exe	5/13/2022 3:20 PM	Application	1,380 KB

https://github.com/mpeg5/xeve

VVC Workflow

1. Convert source to Y4M, which is YUV with metadata

```
ffmpeg -y -i Football.mp4 -pix_fmt yuv420p Football.y4m
```

2. Encode with xeve_app (single-pass)

```
xeve_app.exe -i input.mp4 -w 1920 -h 1080 -z 30 -o output.evc -r output.yuv  --rc-
type 1 --bitrate 6000 --vbv-bufsize 12000 -v 3 --profile main  --preset slow  -I
60  --closed-gop --threads 4
```

3. Decode to YUV with xevd_app

Not needed – yuv output supplied

Producibility – Hardware

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Producibility							
- Encoder support	Ubiquitous	Ubiquitous	Near Ubiquitous	Nascent	Some	Open source	Open source
- Encoding time	Baseline	Baseline	1.02x	2x	.3x	.4x	7.8x
- Live software/hardware	Yes/Yes	Yes/Minimal	WebRTC/Min	Min/Min	Yes	No/No	No/No

?

A proposal by Samsung, Huawei and Qualcomm forms the basis of EVC.[8]

Implementations [edit]

- XEVE (the eXtra-fast Essential Video Encoder) is self-described as a fast open source EVC encoder. It is written in C99 and supports both the baseline and main profiles of EVC. Its license is a custom 3-clause BSD license.

See also [edit]

- MPEG-5 Part 2 / Low Complexity Enhancement Video Coding / LC EVC
- H.266 / MPEG-I Part 3 / Versatile Video Coding / VVC
- AV1

Playability - Performance

- EVC is a “hardware codec” that will require hardware decoding for mass deployment
  - Expect the same aggressive software strategy we saw with VVC from EVC stakeholders

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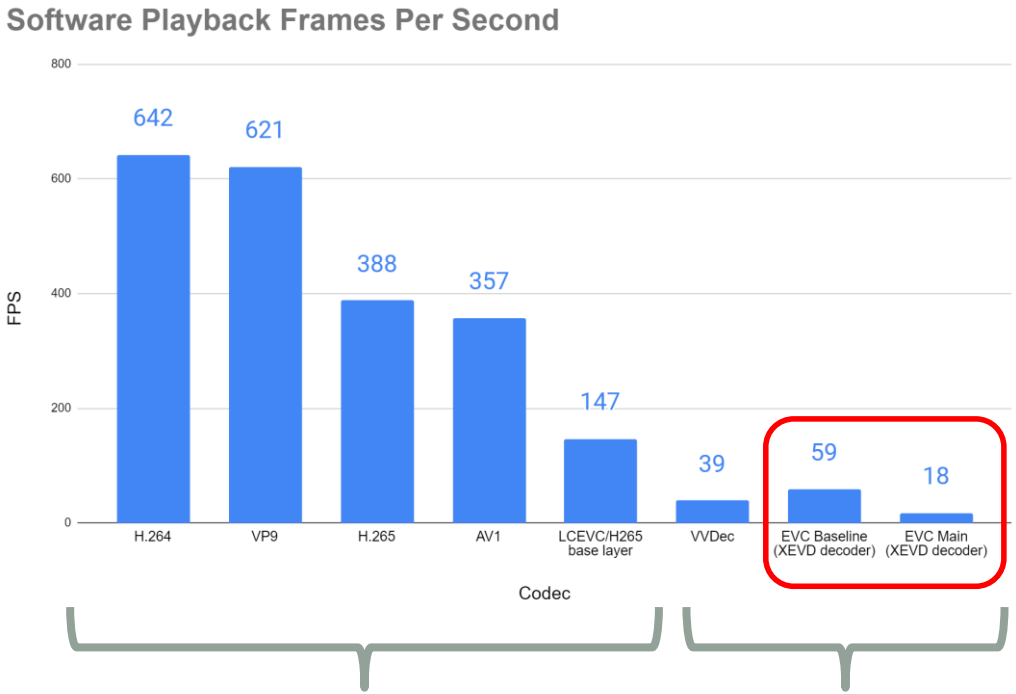

bit.ly/codec_soup

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- Browser support	19.65%	97.1%	74.6%	Not listed	Not listed	Not listed	Not listed
- Browser workaround	No	NA	NA	No	**Yes**	No	No

- No existing OS or browser support for either EVC profile

https://caniuse.com/?search=evc

Chip Support – Mobile

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
Mobile/Computer Device Support	Fully supported in most devices	• AMD • ARM • HiSilicon • Intel • MediaTek • NVIDIA • Qualcomm • Samsung	• AMD • Amphion • Broadcom • Intel • MediaTek • Nvidia • Rockchip • Samsung • Google • Samsung • Qualcomm	None found	NA	None found	None found

- Crickets here

Chip Support –TV

	HEVC	VP9	AV1	VVC	LCEVC	EVC Baseline	EVC Main
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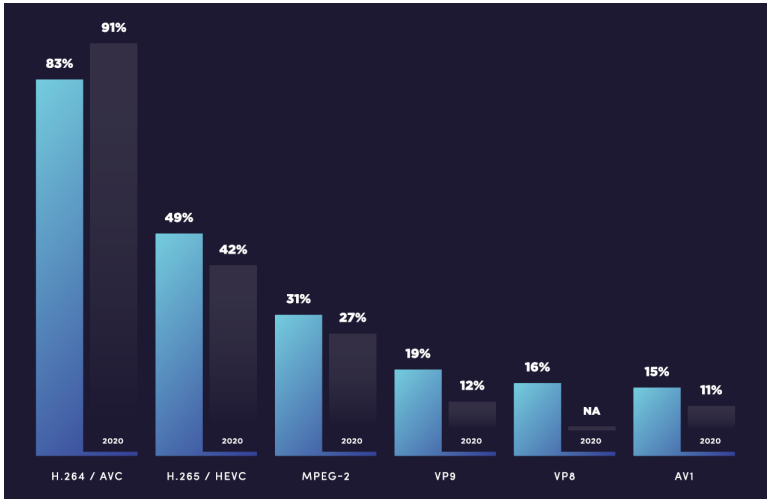
- Crickets here

Bottom Line on EVC

- No support other than key stakeholders
  - They’ve done very little to promote the codec so far
  - Until they do, it’d dead in the water from an implementation perspective

Third-Party Predictions

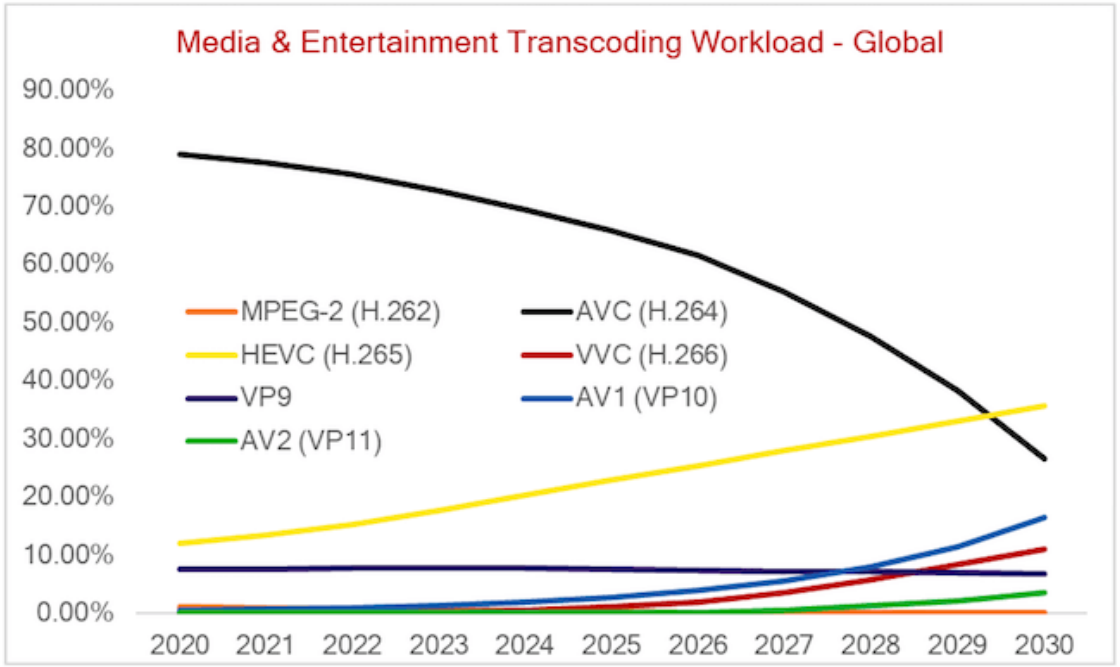


- No use in 2021

- 11% plan to deploy EVC in 2022
- We'll see

Bitmovin - [Bitmovin Video Developer Report]

Third-Party Predictions



- Rethink TV – Doesn’t include EVC

http://bit.ly/rethink_codec

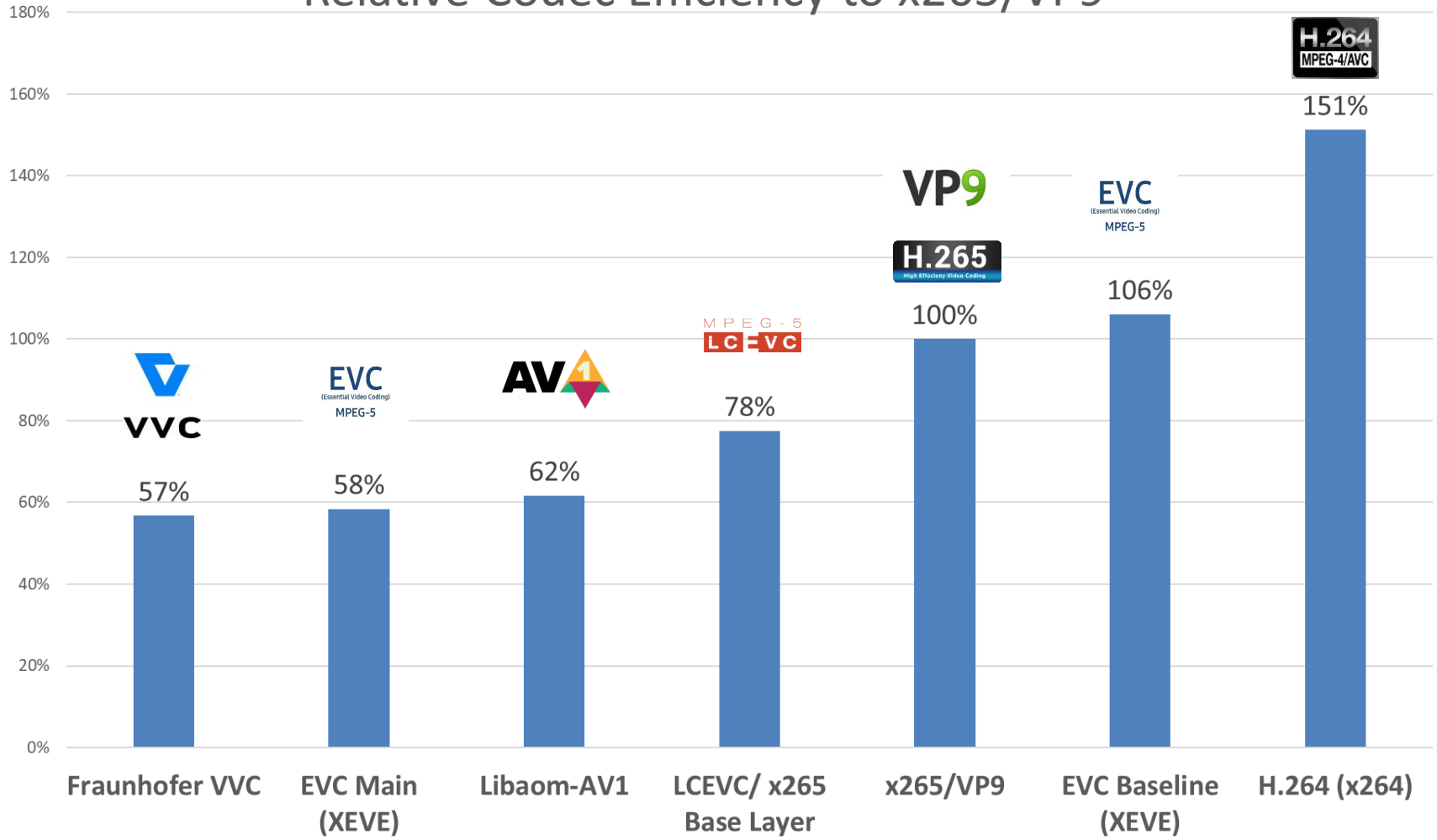
Questions

When to Care

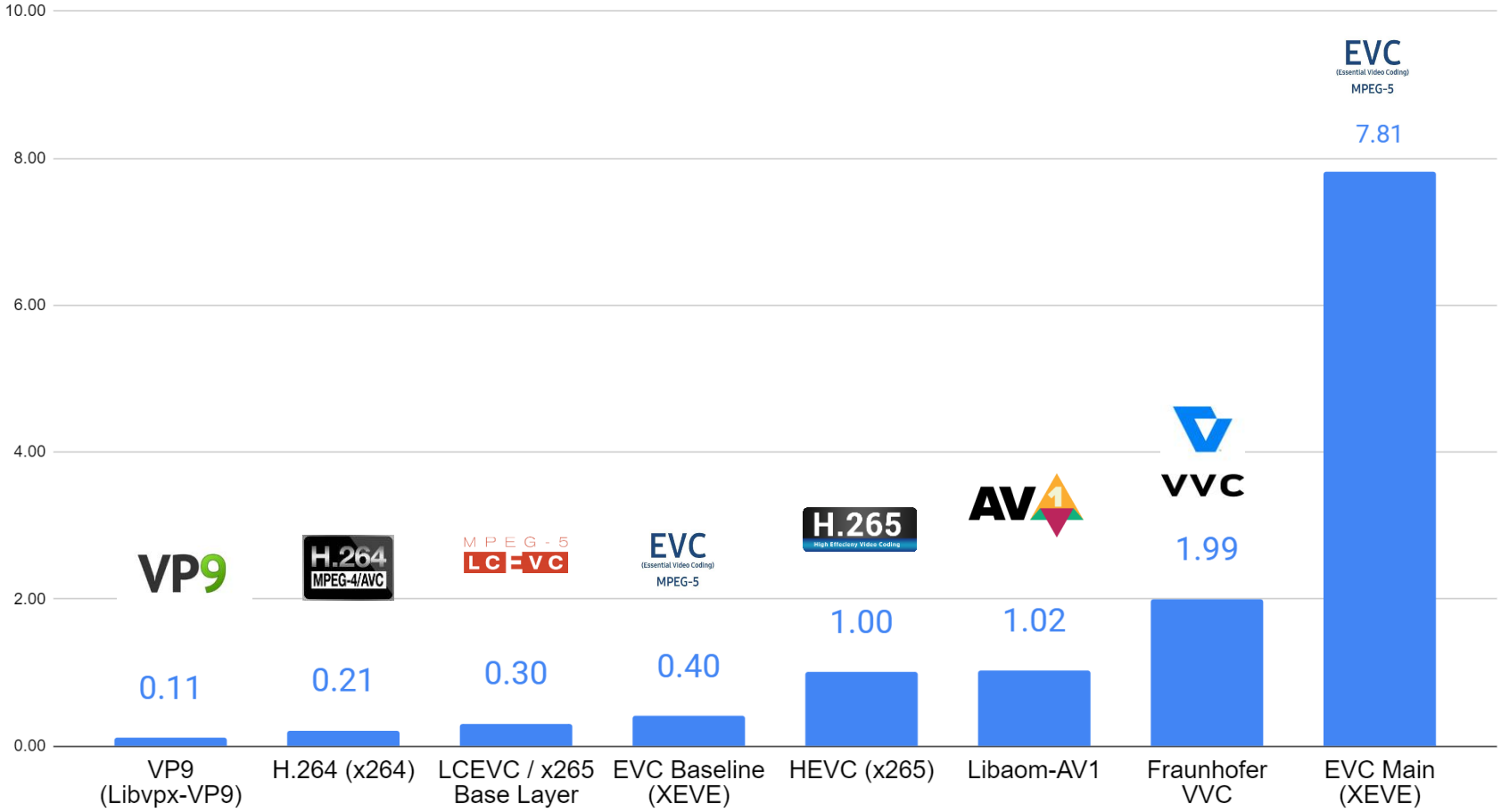
Should be 11:50

							
Publishers not currently using	Now	Never (AV1)	HDR/DRM – now Living room – now Browser focus – AV1	HDR/DRM – H.265 Living room – H.265 Browser focus – Now	Very high volume – Now Low volume - never	Patent owner – now Other – check back in 2024	Unknown
Service providers (encode/player)	Now	Now	Now	Now	2023? (needs adoption)	2023?	Unknown

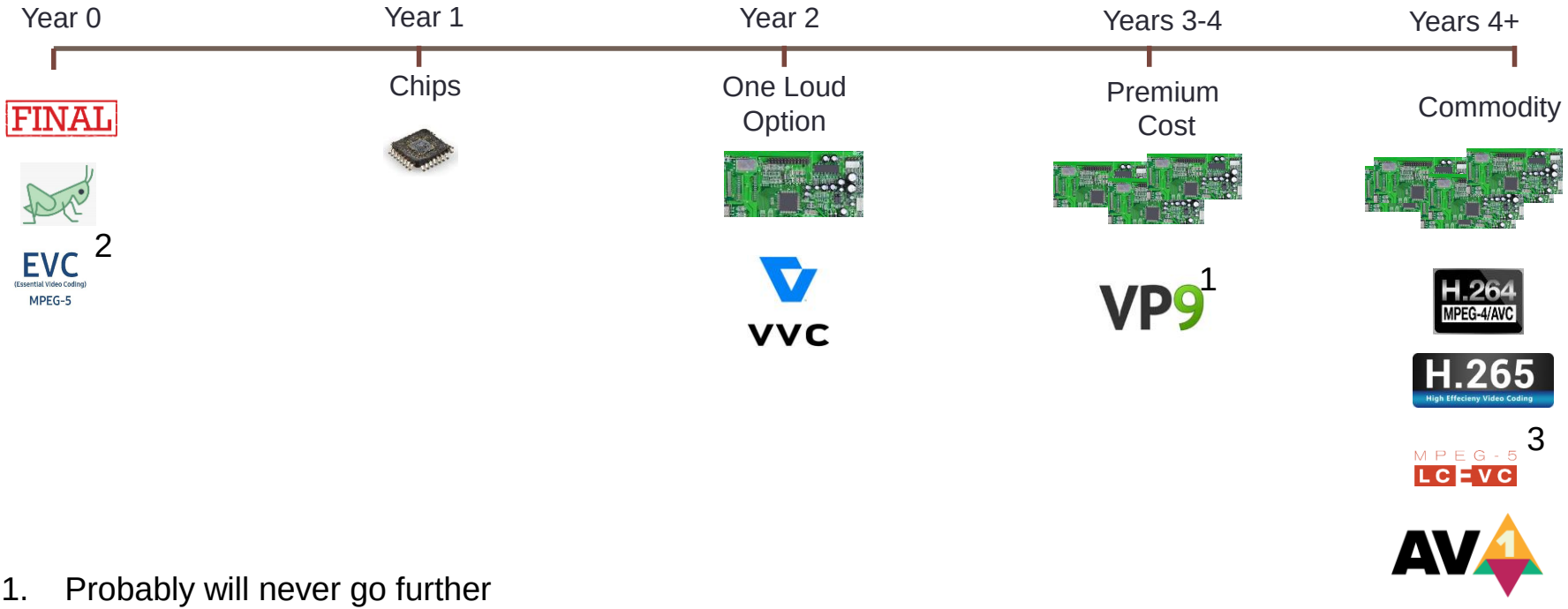
Relative Codec Efficiency to x265/VP9



Encoding Time vs x265 Very Slow (Single Pass PQ/CRF)

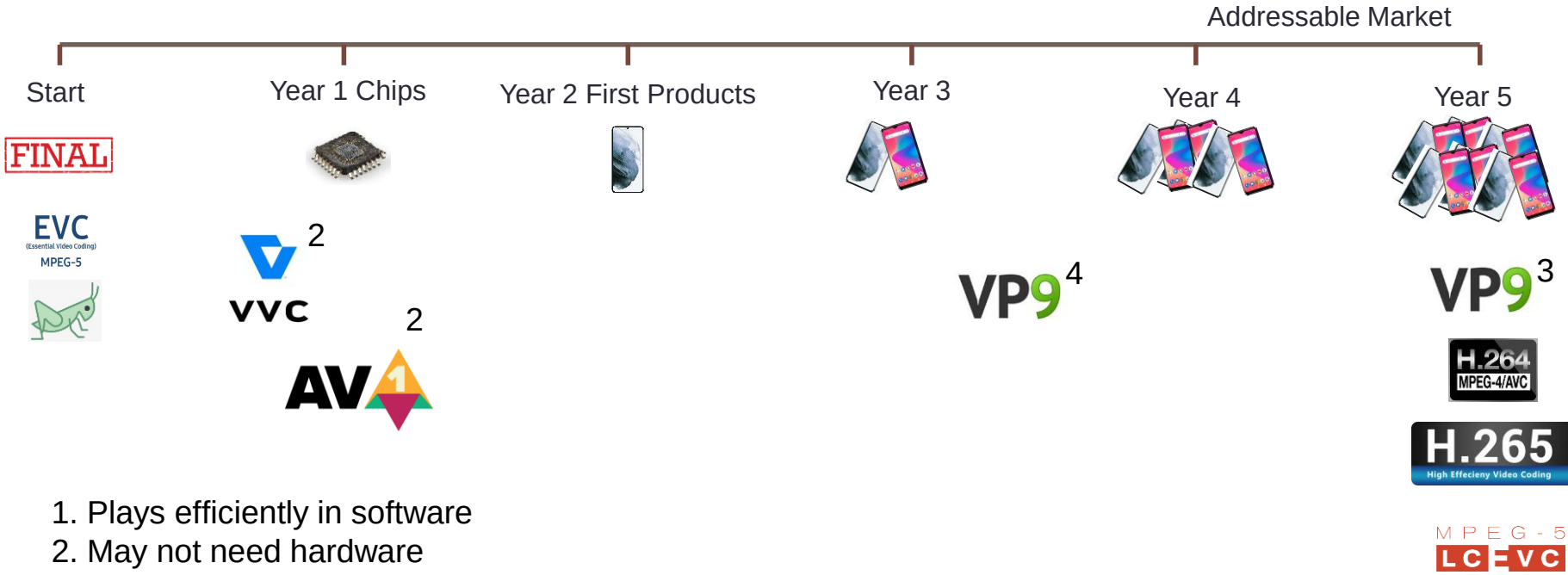


Live Encode/Transcode



1. Probably will never go further
2. May never get started
3. Can operate efficiently in software or on top of existing encoders

Codec Deployment – Mobile



1. Plays efficiently in software
2. May not need hardware
3. Android
4. iPhones

Codec Deployment – Living Room

Addressable Market

Start

FINAL

EVC
(Essential Video Coding)
MPEG-5

Year 1 Chips

Year 2 First Products

VVC

Year 3

AV1 [1]

Year 4

Year 5

VP9 [1]

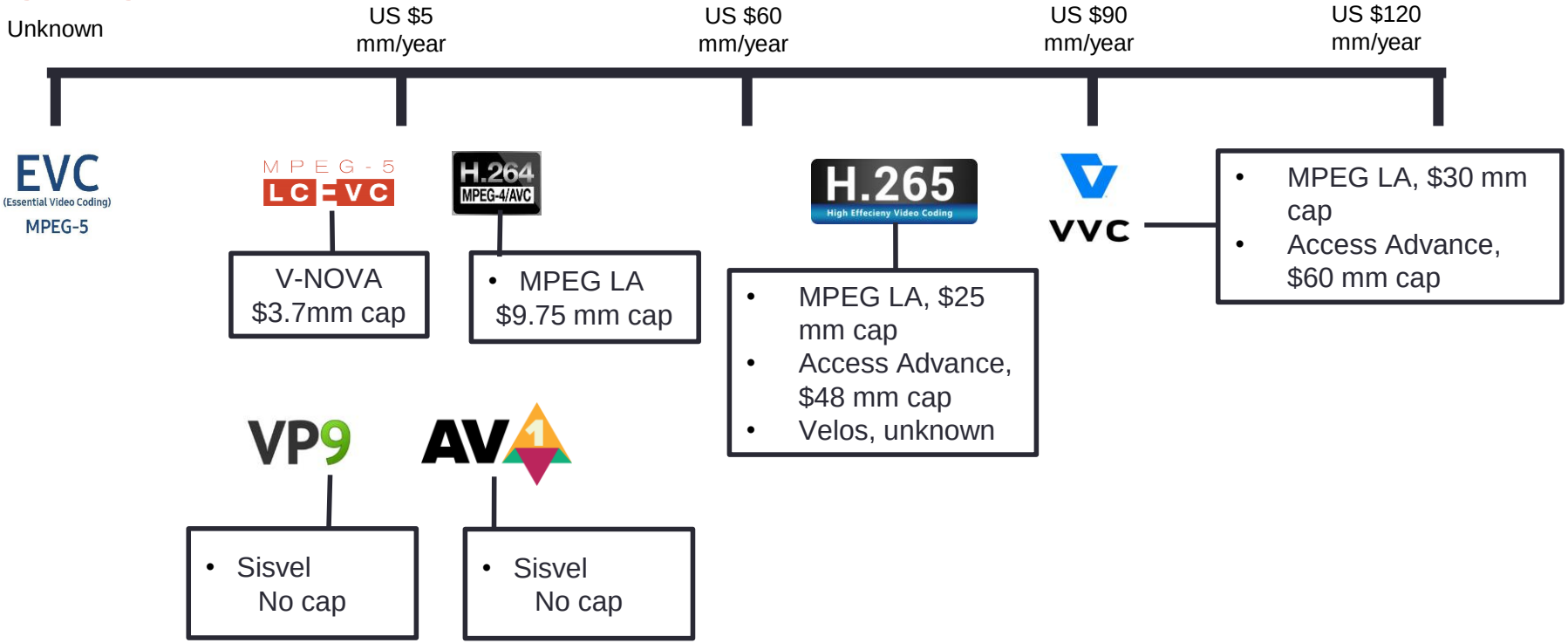
H.264 MPEG-4/AVC [1]

H.265
High Effecieny Video Coding

MPEG-5 LCEVC [2]

1. No Dolby Vision
2. May not need hardware

Royalty Status



Known Royalty Cost

	H.264	HEVC	VP9	AV1	VVC	LCEVC	EVC
Patent pools	1 (MPEG LA)	2 (MPEG LA/Access Advance)	1 - Sisvel (disputed by Google)	1 - Sisvel (disputed by AO Media)	2 (MPEG LA/Access Advance)	0 (V-Nova)	?
Schema	- mostly encoder/ decoder - per-unit royalty - annual cap ($9.75 million)	- encoder/ decoder - per-unit royalty - annual cap (~$75 million)	- decoder - per-unit royalty	- decoder - per-unit royalty	- encoder/ decoder - per-unit royalty - annual cap (~$90 million)	- Content royalty (publisher pays) - cap $3.7 million	- Unknown - 2-year window
Content	- Small content royalty / subs/PPV	- Video on physical media	None	None	- Video on physical media	Yes	Unknown
Learn more:	bit.ly/h264_license	bit.ly/hevc_3	bit.ly/vp9_pool	bit.ly/av1_pool	bit.ly/vvc_pools	bit.ly/lcevc_royalty	