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Flexible Electronics Outlook & Lessons Learned

April 2019

Peter Yu

Agenda

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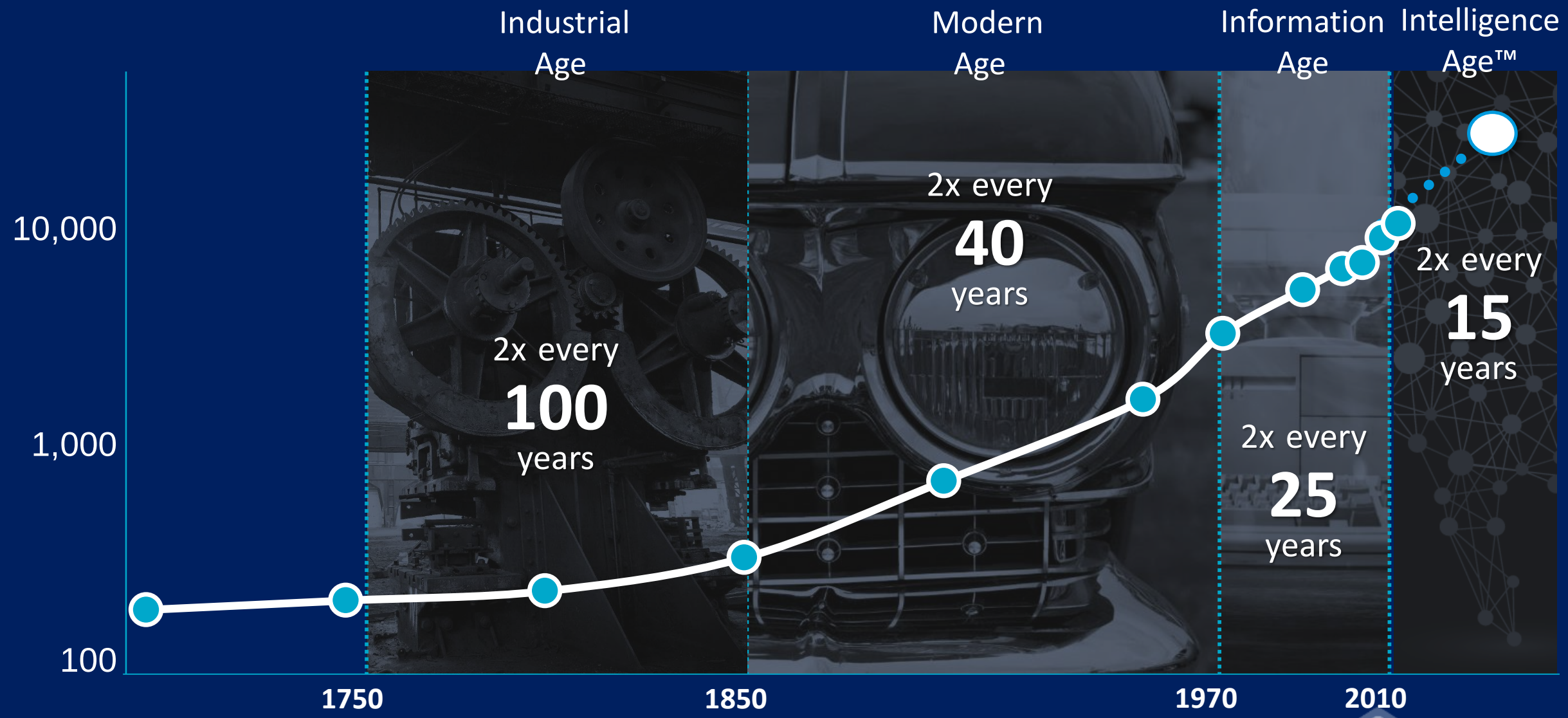
Average World GDP per Capita

($ USD)



Source: World Bank, Maddison Project, De Long- UC Berkeley ("Intelligence Age" TM by Flex)

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Opportunity is Literally All Around Us

…simply connect the dots

By 2020, the **Intelligence of Things™** will bring 50 billion connected devices to market, creating US$7.1T in total addressable market value.

IDC

TM: Flex

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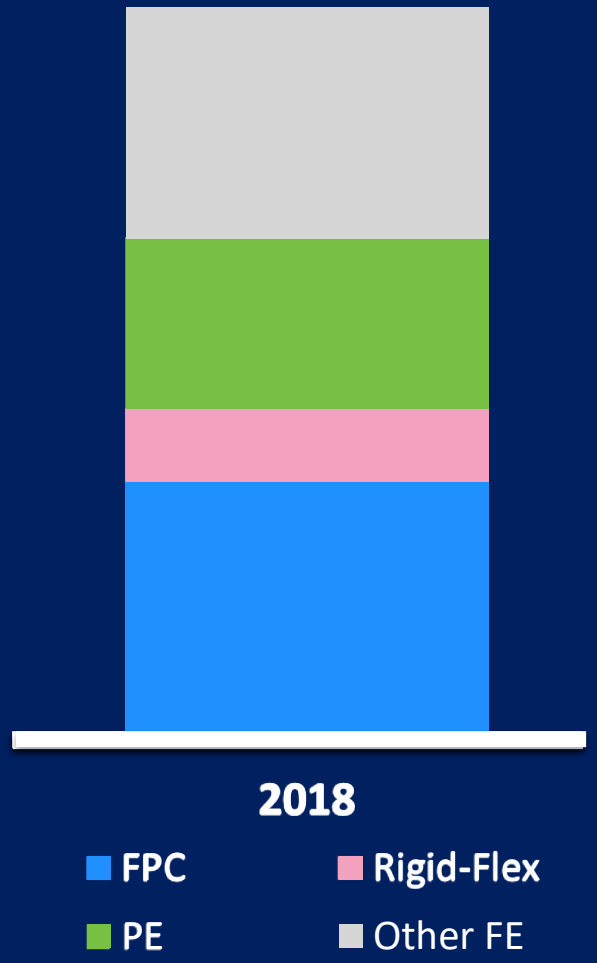
Printed & Flexible Electronics was a $30B Market in 2018



- Flexible Printed Circuits market size estimated to be US$10.3B
- Rigid-Flex PCB estimated to be worth $3B
- Printed Electronics estimated to be worth $7B
- Other “Flexible Electronics” market estimated to be $9.5B

Sources:
FPC & Rigid-Flex: Prismark Research & NTI
Printed Electronics: MarketsandMarkets
Other FE: Zion Research (http://pcb.iconnect007.com/index.php/article/104477/?skin=pcb&p=1)

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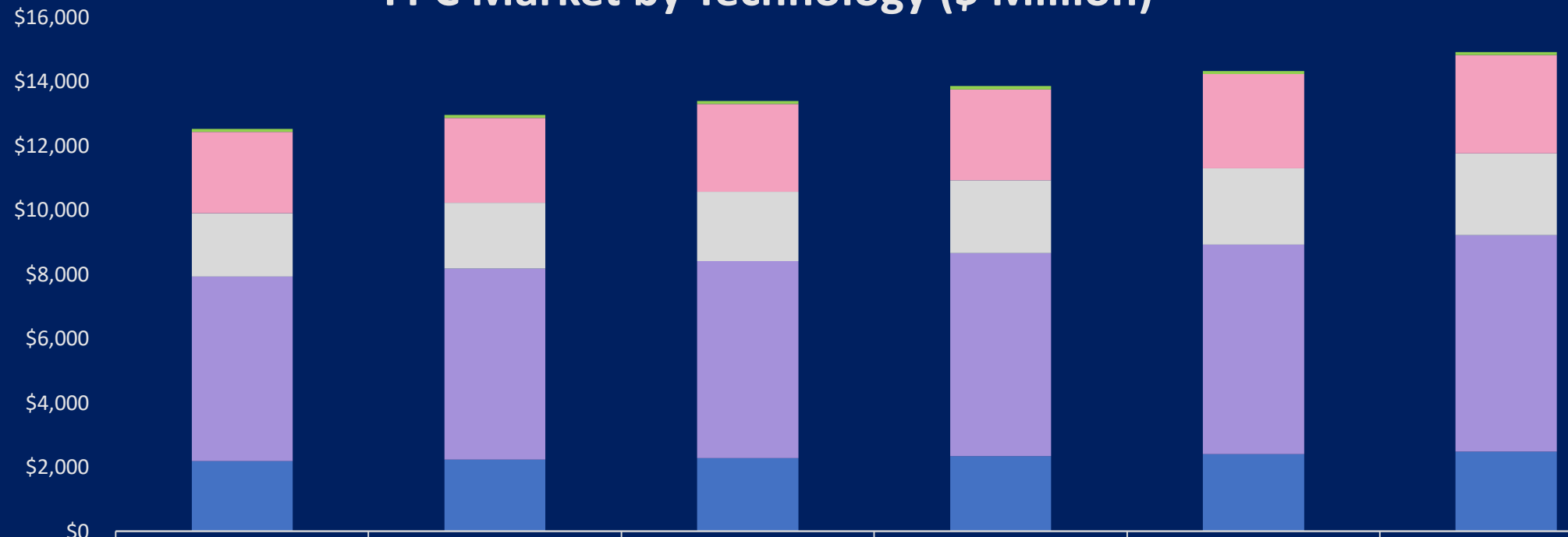
Flexible Printed Circuits: Largest but Slowest Growth at 3.5%

FPC Market by Technology ($ Million)



	2017	2018	2019	2020	2021	2022
Other (PET/PEN)	$92	$94	$97	$100	$102	$104
Rigid Flex	$2,542	$2,634	$2,728	$2,827	$2,928	$3,054
Multilayer Flex	$1,961	$2,057	$2,158	$2,264	$2,375	$2,541
Double Sided-Flex	$5,755	$5,939	$6,129	$6,325	$6,528	$6,737
Single-Sided Flex	$2,173	$2,225	$2,279	$2,333	$2,389	$2,477
Total FPC	$ 9,986	$ 10,315	$ 10,662	$ 11,022	$ 11,894	$ 11,859

Source: Prismark Research & NTI

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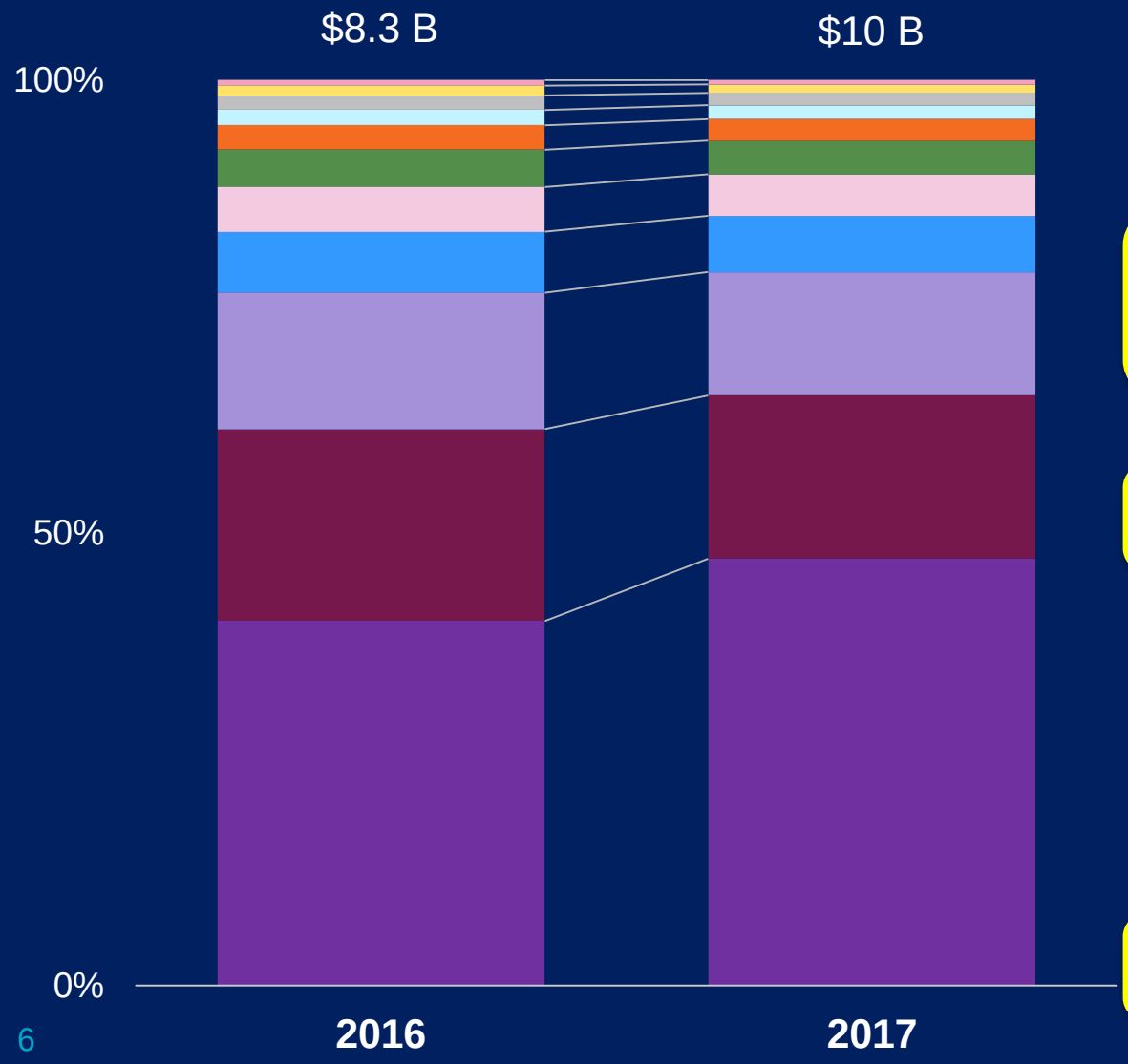
FPC Growth Driven by Certain Applications



	2017 Growth	2017-'22 CAGR
Mobile Phones	41%	2.2%
PCs	2%	0.7%
Consumer	9%	6.4%
Automotive	11%	6.6%
Other Computer	11%	1.6%
Server/Data Storage	9%	5.9%
Military/Aerospace	7%	4.2%
Industrial	6%	3%
Medical	5%	3.4%
Wired Infrastucture	-1%	3.7%
Wireless Infrastructure	0%	4.5%

Source: Prismark Research

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Wearables to Grow in High Teens by Unit Volume

…but price erosion / commoditization will stunt FPC value growth

Worldwide Wearable Devices by Product Category, Shipment Volume, Market Share, and 5-Year CAGR(shipments are in millions)

Product	2017 Volumes	2017 Market Share	2021 Volumes	2021 Market Share	2017 - 2021 CAGR
Clothing	2.8	2.30%	11.6	5.10%	42.80%
Earwear	1.8	1.50%	10.5	4.60%	54.40%
Modular	1.6	1.30%	1.5	0.60%	-2.80%
Other	0.4	0.30%	0.2	0.10%	-10.50%
Watch	67.4	55.40%	154.4	67.30%	23.00%
Wrist Band	47.6	39.10%	51.3	22.40%	1.90%
TOTAL	121.7	100.00%	229.5	100.00%	17.20%

Source: IDC Worldwide Quarterly Wearable Device Tracker, September 14, 2017

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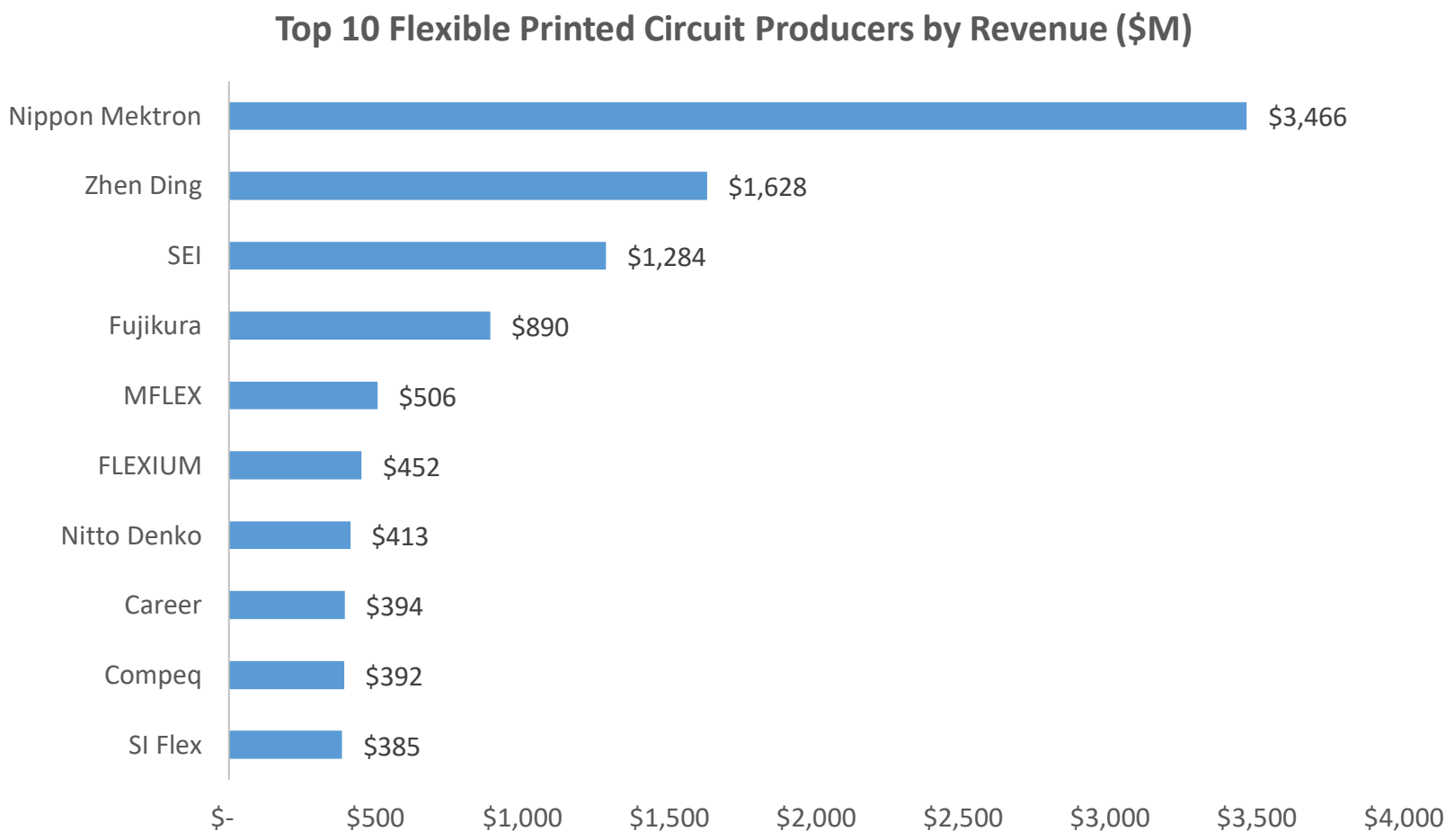
Rigid-Flex Follows Closely FPC's Growth

Rigid Flex Market Size by Application ($ Million)

	2017	2018	2019	2020	2021	2022
Industrial/ Medical	$127	$130	$133	$136	$139	$142
Auto	$186	$196	$207	$218	$230	$243
Military	$203	$204	$204	$202	$200	$217
Consumer Devices	$344	$365	$387	$411	$436	$463
Display	$455	$461	$468	$475	$482	$490
Communication	$1,227	$1,277	$1,330	$1,384	$1,441	$1,500
Total	$2,542	$2,634	$2,728	$2,827	$2,928	$3,054

Source: Prismark Research & NTI

But Leading Players Differ Between Rigid-Flex vs. FPC Makers

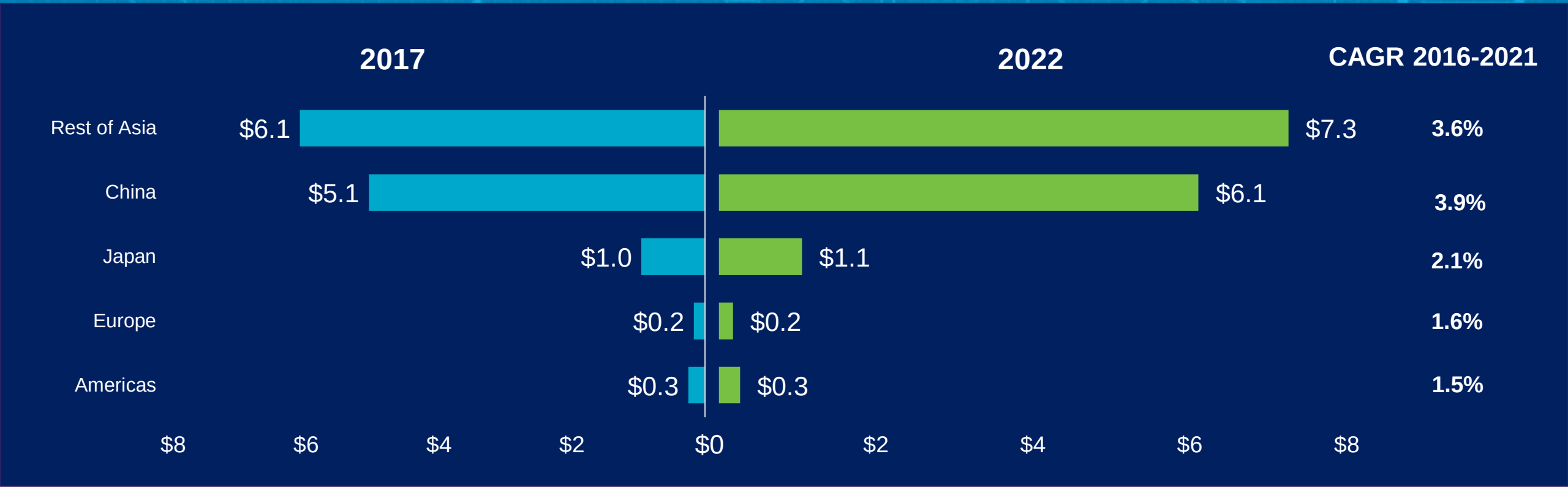


Source: Prismark Research, NTI, Digital Journal, thetacticalbusiness.com

Top Rigid-Flex Producers

- TTM Technologies
- AT & S
- Multek
- Schoeller-Electronics
- Royal Circuits
- Flexible Circuit
- All Flex Inc.
- San Francisco Circuits
- NCAB Group
- Tech-Etch
- Molex
- Cirexx
- Pioneer Circuits
- Micro Systems Technologies
- CONTAG AG
- Samsung Electro-Mechanics
- Rigid-Flex International
- EPEC
- PCB Solutions
- Flexible Circuit Technologies (FCT)

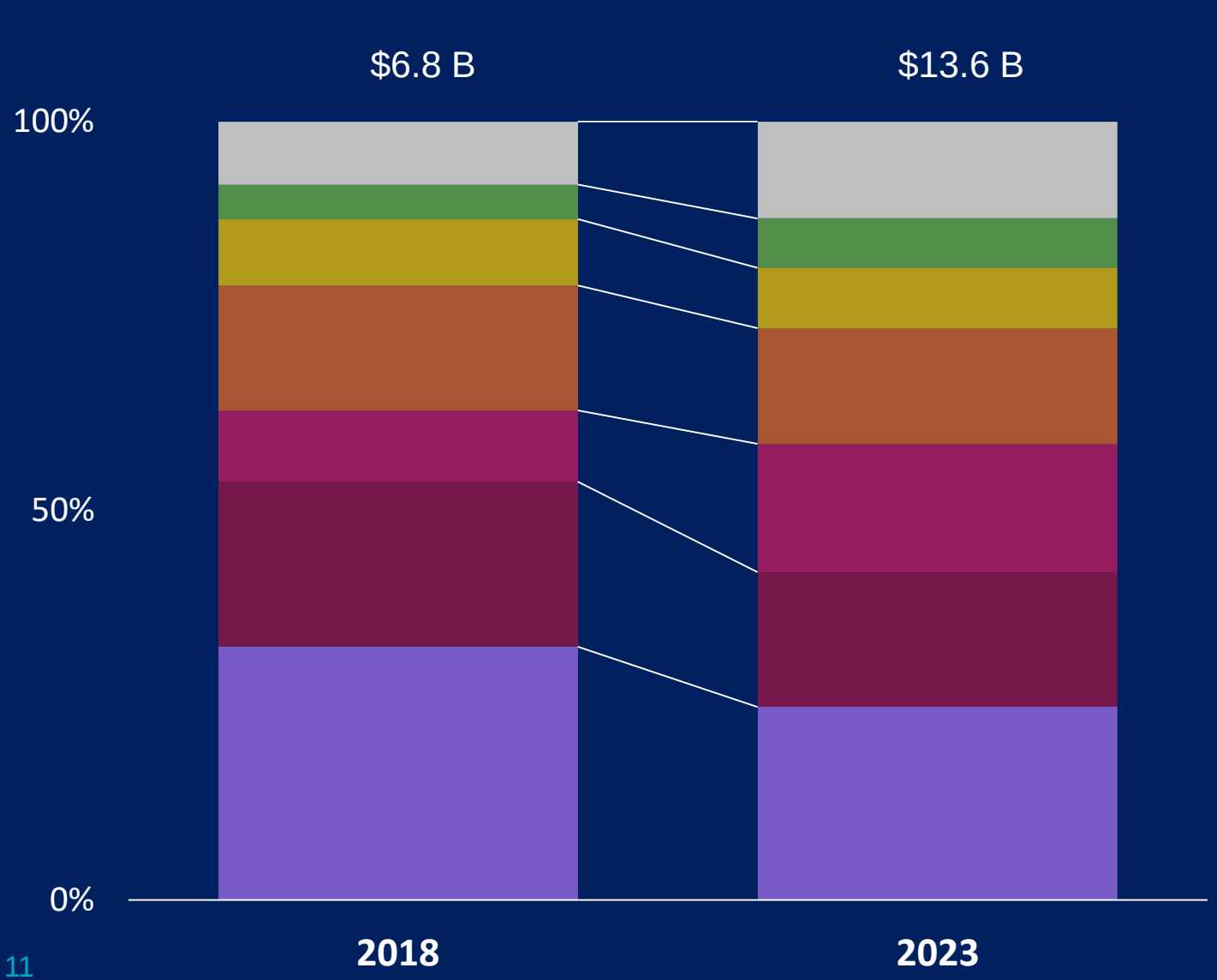
Total Combined FPC & Rigid-Flex Growth by Region



- China has become the largest manufacturer of FPC - China, accounting for 40% of the total FPC market in 2017, will be continue to be the market leader through 2022 growing at a CAGR of 3.6% between 2017 and 2022
- Americas will report lower FPC growth between 2017 and 2022 at CAGR 1.5%

Source: Prismark Research & NTI

Printed Electronics is Growing Fast, Surpassing FPCs by 2022



	2018 - 2023 CAGR
Displays	8.8%
PV Cells	10.4%
Lighting Panels/Solutions	29.2%
RFID Tags	13.1%
Sensors	13.1%
Batteries	23.6%
Others	25.3%

Combined CAGR of 15%

Source: Prismark Research & NTI

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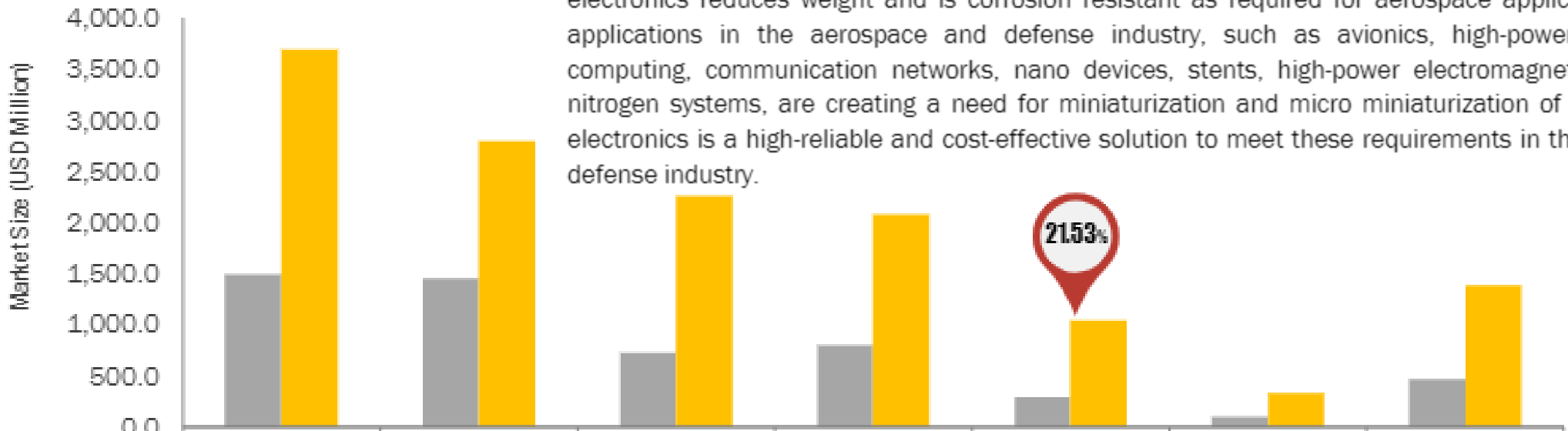
Aerospace & Defense Will Lead Printed Electronics Growth

The printed electronics market for the aerospace & defense industry is likely to grow at the highest CAGR in the coming years. This technology is used in an unmanned aerial vehicle (UAV) owing to its advantages such as lightweight, less complexity, and high reliability, which ultimately results in low maintenance requirements. Further, printed electronics technology reduces wiring in several aircraft solutions such as in-flight entertainment systems and aircraft structural health monitoring systems. Similarly, printed electronics reduces weight and is corrosion resistant as required for aerospace applications. Emerging applications in the aerospace and defense industry, such as avionics, high-power lasers, radars, computing, communication networks, nano devices, stents, high-power electromagnetic systems, and nitrogen systems, are creating a need for miniaturization and micro miniaturization of systems. Printed electronics is a high-reliable and cost-effective solution to meet these requirements in the aerospace and defense industry.

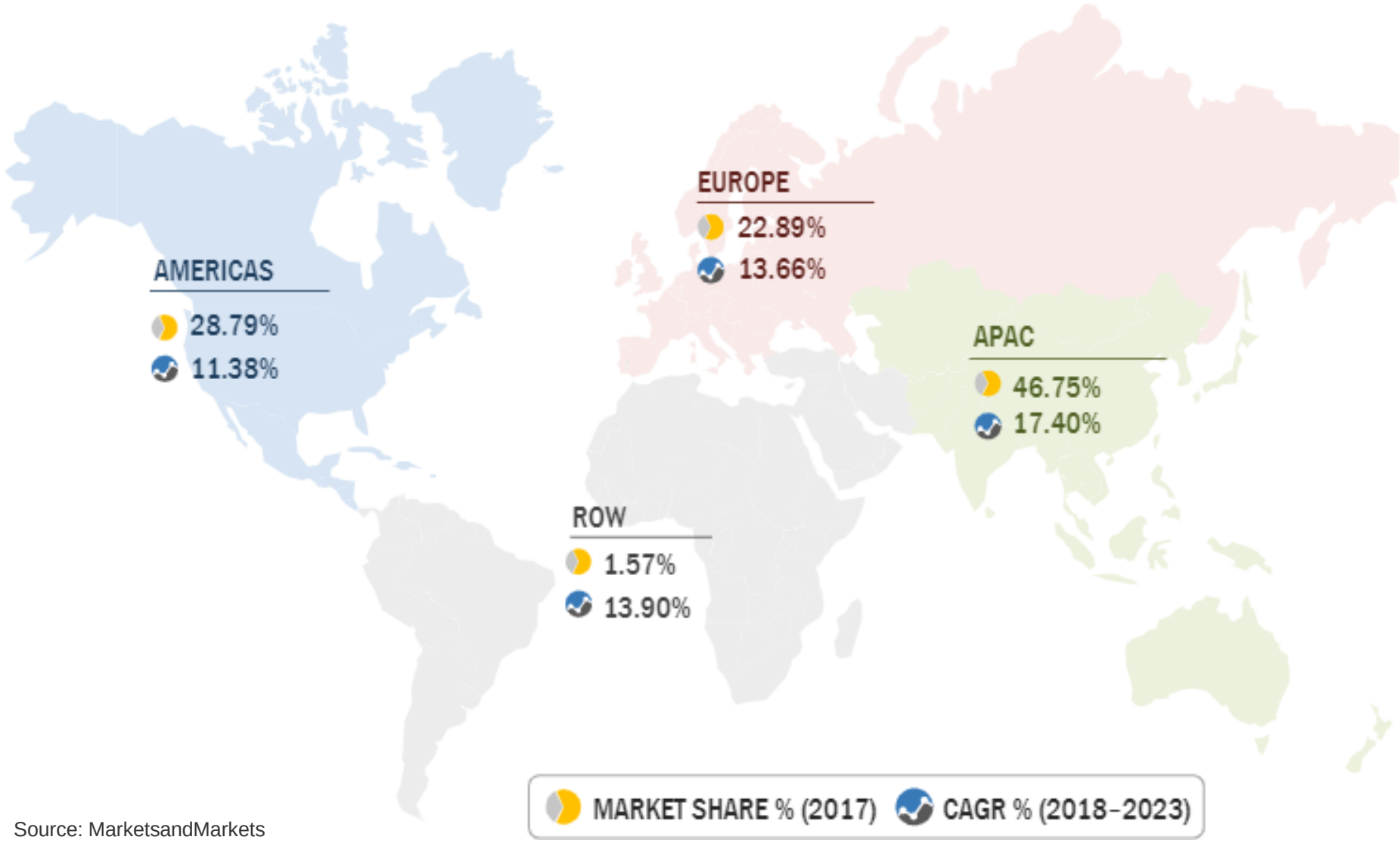


	Automotive & Transportation	Consumer Electronics	Retail & Packaging	Medical	Aerospace & Defense	Construction & Architecture	Others
2017	1,501.3	1,457.8	723.3	799.3	290.5	104.6	467.0
2023	3,701.2	2,796.1	2,259.6	2,081.9	1,041.6	331.9	1,391.2
CAGR (2016–2023)	14.34%	9.50%	18.87%	15.28%	21.53%	19.13%	17.93%

Note: "Others" includes advertising & media, textiles, and semiconductor industries.

Source: Secondary Literature, Expert Interviews, Hellenic Organic and Printed Electronics Association (HOPE-A), Organic and Printed Electronics Association (OE-A), Canadian Printable Electronics Industry Association (CPES), Korea Printed Electronics Association (KoPEA), and MarketsandMarkets Analysis

APAC: Largest & Fastest-Growing Printed Electronics Region



Source: MarketsandMarkets

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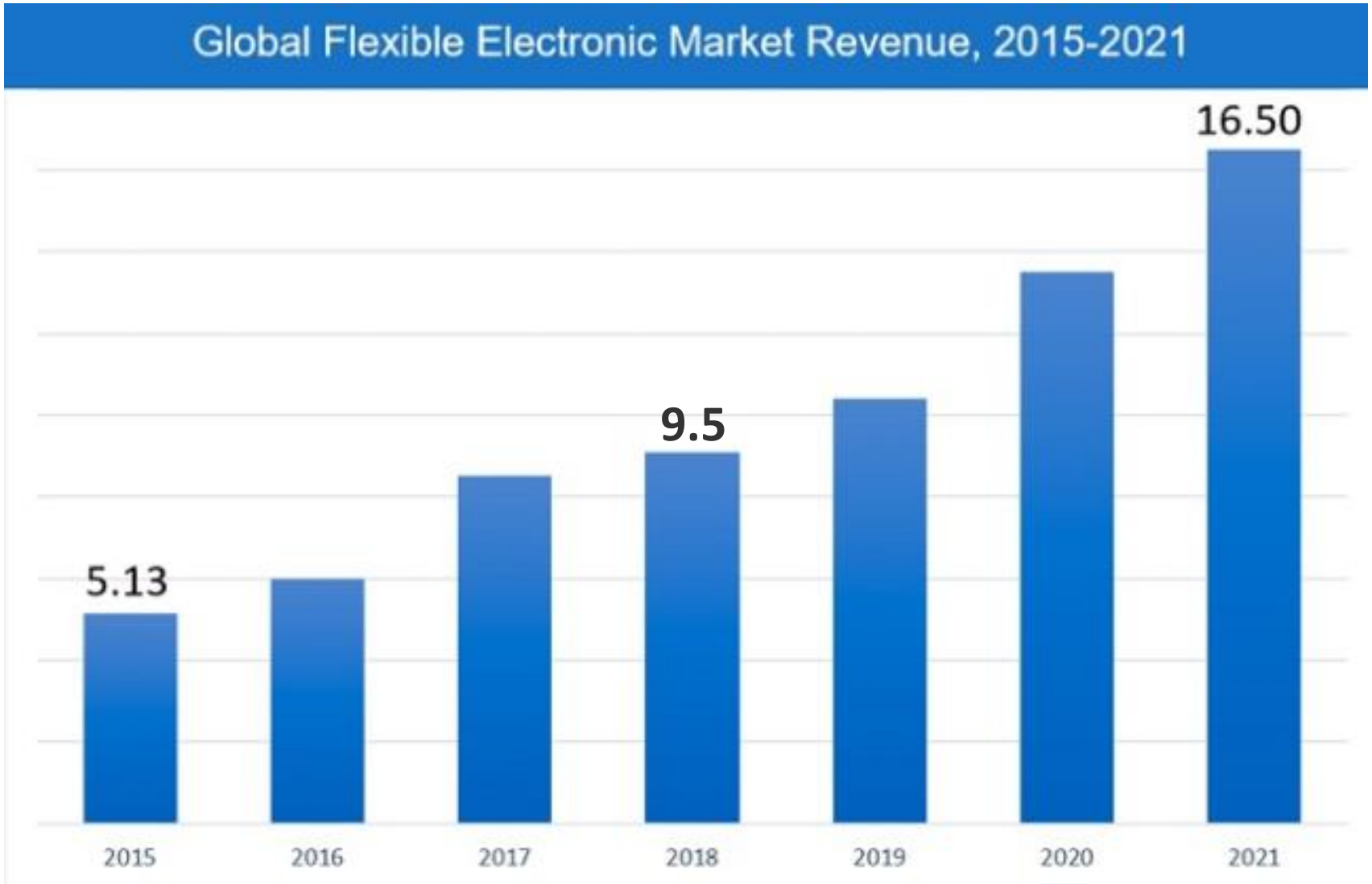
Flexible Electronics is the Fastest-Growing of all Segments



- Global demand for the flexible electronics market was valued at $9.5B in 2018 and is expected to generate revenue of $16.5B by 2021, growing at a CAGR of slightly above 21% between 2016 and 2021
- Key elements of the market, in the view of most analysts, include flex displays, sensors, batteries, and memory
- IDTechEx Research finds that the total market for printed, flexible and organic electronics will grow from $31.7 Billion in 2018 (of which the $9.5B opportunity for Printed Electronics is a subset) to $77.3B in 2029

Source: Zion Research, iConnect 007, IDTechEx Research

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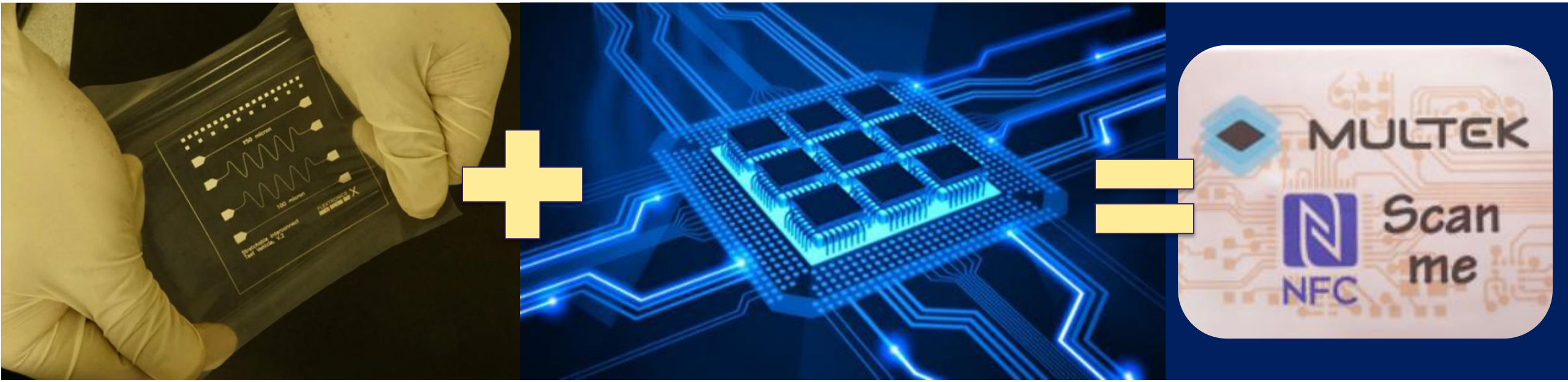
Flexible Hybrid Electronics (FHE)

FHE is an emerging form of Flexible Electronics enabled by the advances made in the FPC, Rigid-Flex, Printed Electronics, Semiconductors and Roll-to-Roll Assembly technologies



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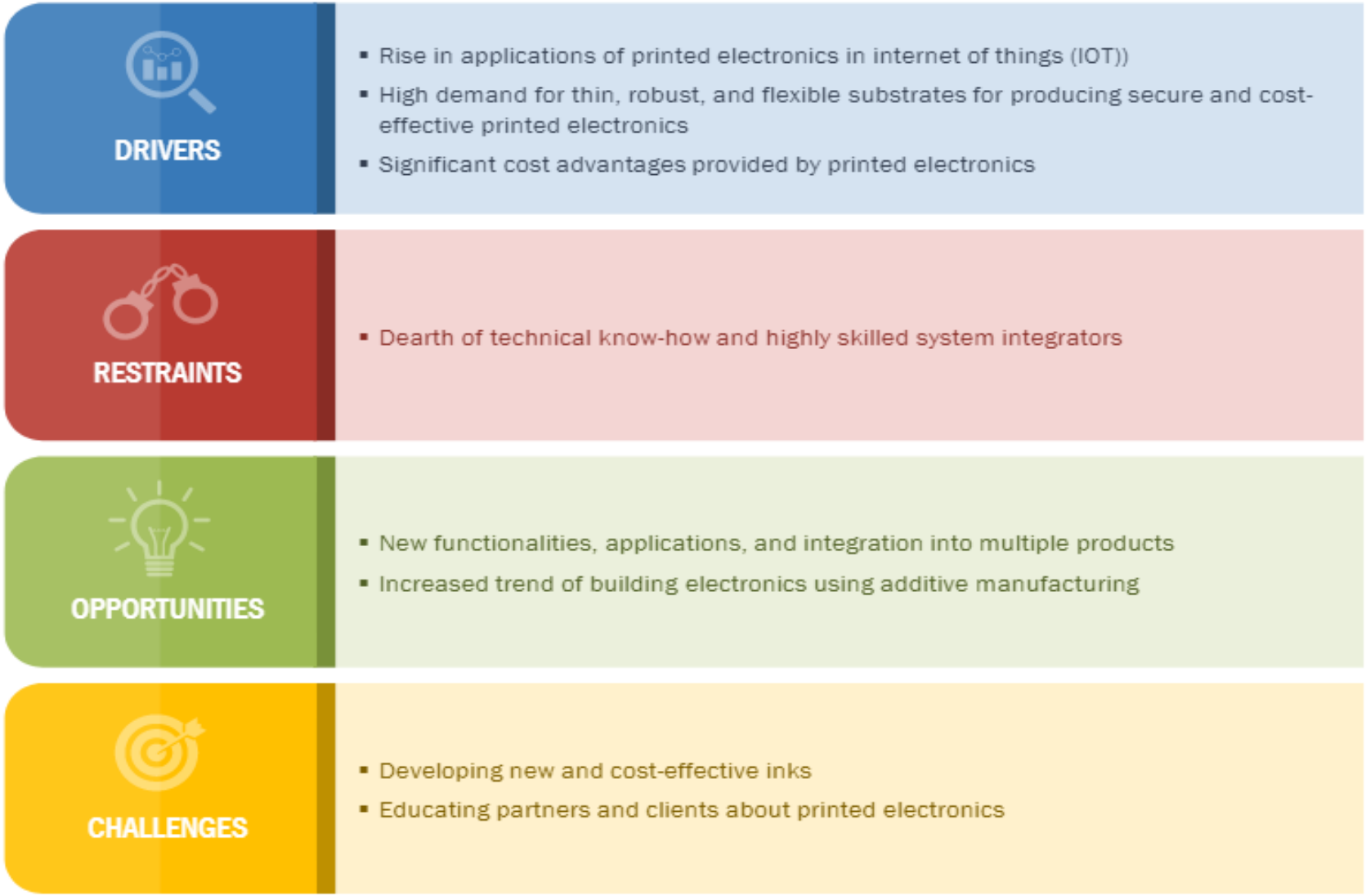
Printed and Flexible Electronics Market Dynamics

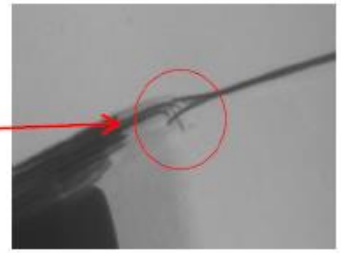


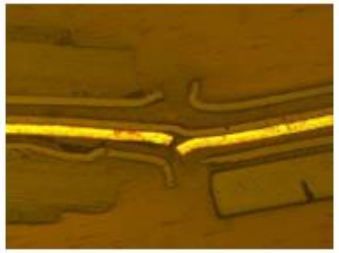
Source: MarketsandMarkets

Lessons Learned: Fitness Bands – Tech & Cost Challenges

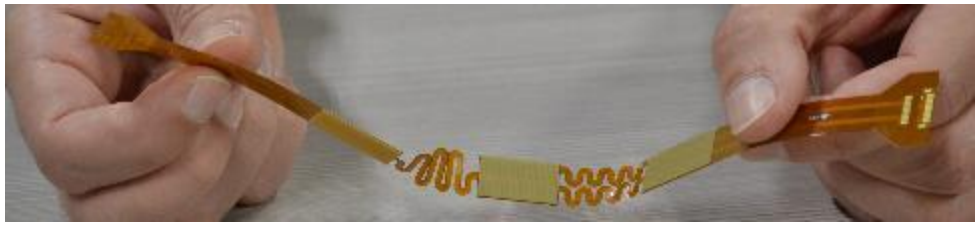
dropping
compression
twisting
flexing

electrical failure





Stretchable/Twist Circuit



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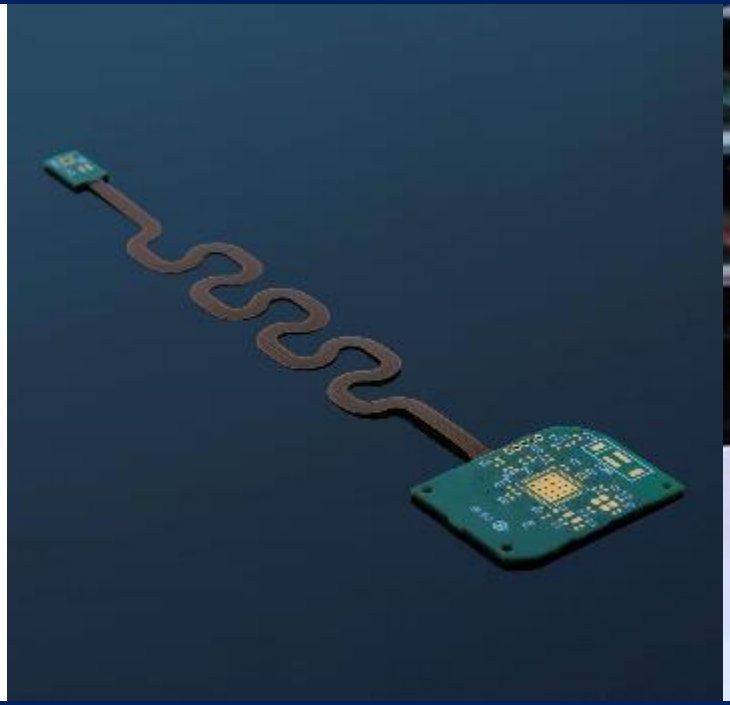
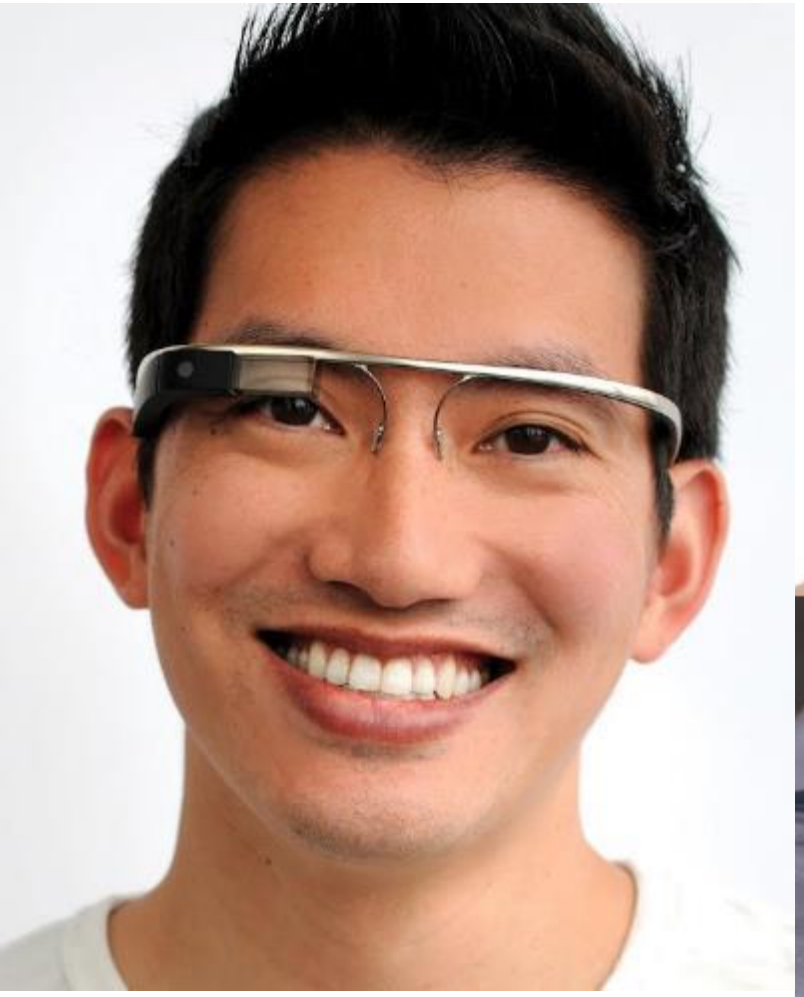
Lessons Learned: Running Shoes – Software Drives Success



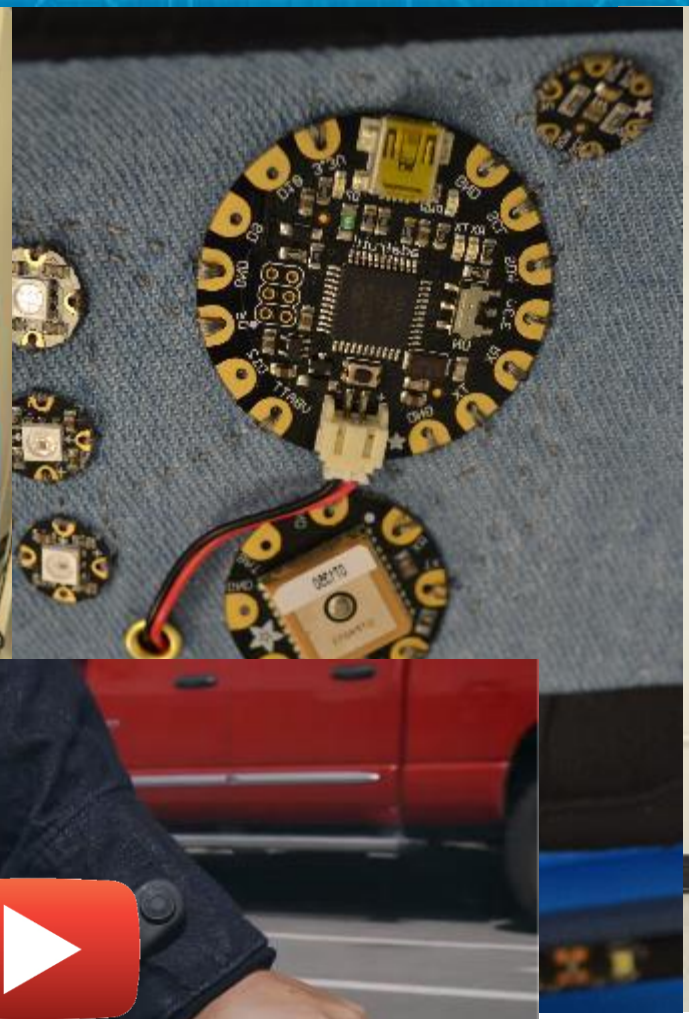
Source: Mensjournal.com, Multek, running.pocketoutdoormedia.com

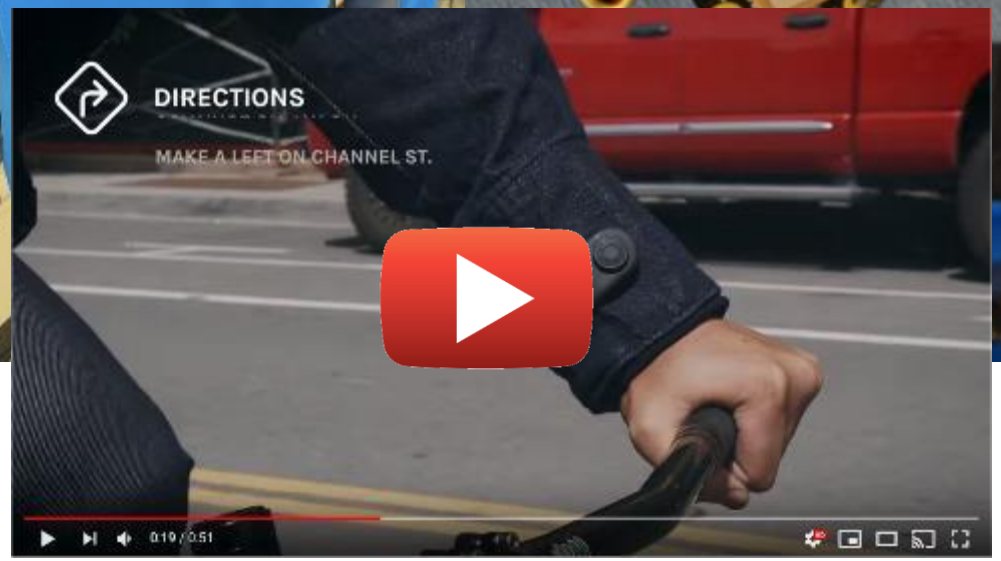
Lessons Learned: Smart Glasses – Market May Not Materialize



Source: Google, Snap, Magic Leap

Lessons Learned: Smart Clothing – Simpler is Better





Source: Flex, Youtube

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Typical Technology Outlook for Flexible Circuits (Panel)

		2019	2020	2021	2022
Layer Count:	max	14	14	16	16
Maximum Board Thickness:	mm	1.8	1.8	2	2
Minimum Board Thickness:	µm	50	50	45	40
BGA Pitch:	µm	350	350	300	250
Inner Layer Line/Space:	µm	50 / 50	50 / 50	45 / 45	40 / 40
Outer Layer Line/Space:	µm	50 / 50	50 / 50	45 / 45	40 / 40
Minimum Substrate Thickness:	µm	12.5	12.5	9	9
Laser µVia Diameter:	µm	75	75	50	50
µVia Aspect Ratio:	µm	0.8:1	0.8:1	0.9:1	0.9:1
Minimum Mechanical Drill Via Diameter:	µm	150	150	100	100
Minimum Punched Via Diameter:	µm	500	500	500	500
Minimum µVia Pad Size:	µm	µVia Dia + 120	µVia Dia + 100	µVia Dia + 75	µVia Dia + 50
Minimum Mechanical Drilled Via Pad Size:	µm	TH Via Dia + 150	TH Via Dia + 150	TH Via Dia + 150	TH Via Dia + 150
Layer to Layer Registration (ELIC):	µm	+/- 50	+/- 50	+/- 40	+/- 40
Front to Back Same Core Registration:	µm	+/- 50	+/- 50	+/- 40	+/- 25
Solder Mask Registration:	µm	+/- 25	+/- 25	+/- 20	+/- 15

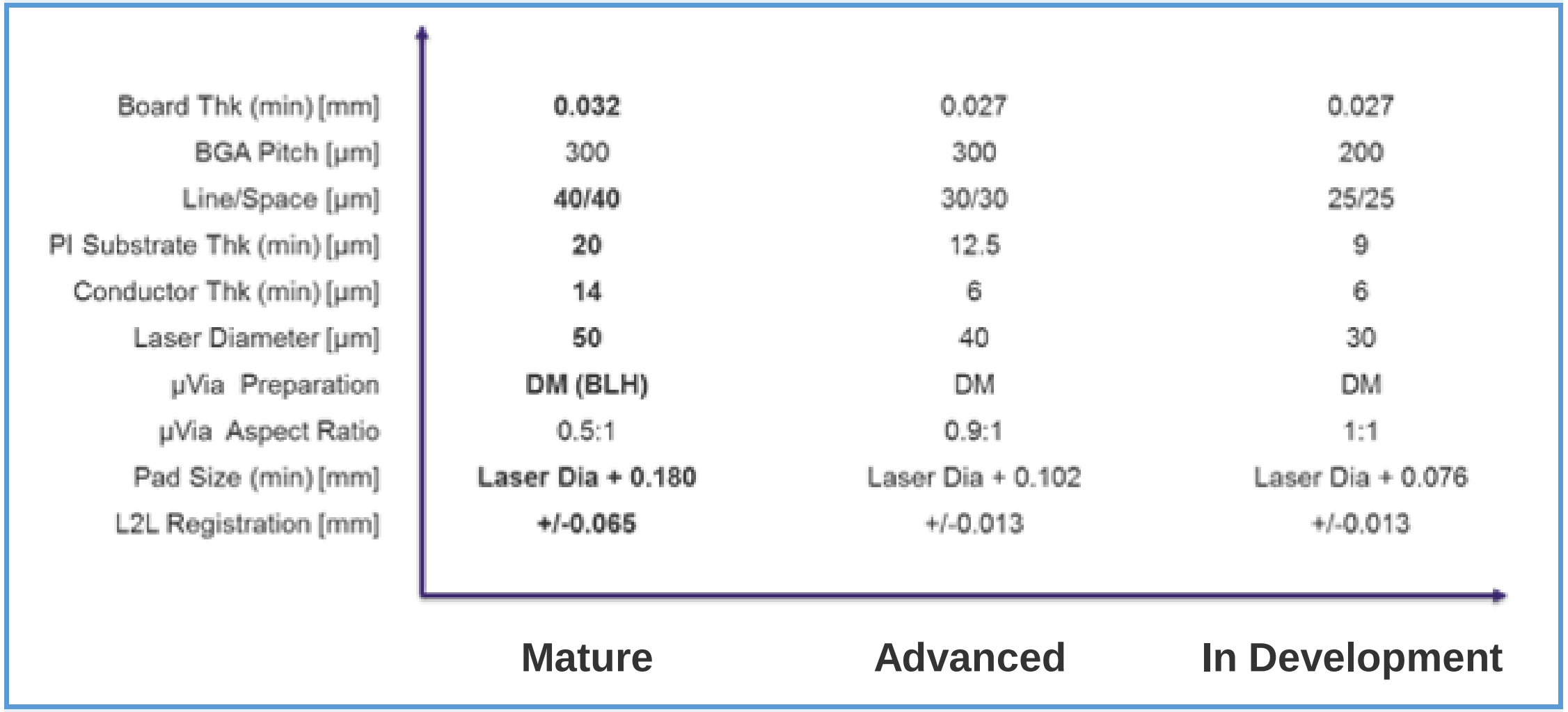
Typical Technology Outlook for Flexible Circuits (Roll-to-Roll)

		2019	2020	2021	2022
Maximum Board Thickness:	mm	0.090	0.105	0.105	0.105
Minimum Board Thickness:	µm	35	25	25	25
BGA Pitch:	µm	350	300	250	200
Line/Space:	µm	50 / 50	30 / 30	25 / 25	20 / 20
Minimum Substrate Thickness:	µm	25	12.5	10	10
Minimum Conductor Thickness:	µm	12	10	5	5
Laser µVia Diameter:	µm	75	50	40	30
µVia Aspect Ratio	µm	1:1	1:1.2	1:1.4	1:1.4
Minimum µVia Pad Size:	µm	µVia Dia + 150	µVia Dia + 120	µVia Dia + 50	µVia Dia + 50
Minimum Mechanical Drilled Via Pad Size:	µm	TH Via Dia + 200	TH Via Dia + 150	TH Via Dia + 150	TH Via Dia + 150
Front to Back Layer to Layer Registration:	µm	+/- 50	+/- 50	+/- 13	+/- 13
Solder Mask Registration:	µm	+/- 25	+/- 25	+/- 25	+/- 25

Typical Technology Outlook for Rigid-Flex Printed Circuits

		2019	2020	2021	2022
Maximum Rigid Layer Count:	max	12	14	16	18
Maximum FPC Layer Count:	max	6	6	8	8
Maximum Board Thickness:	mm	1.6	1.6	2.8	3
Rigid BGA Pitch:	µm	350	350	200	150
Inner Layer Line / Space:	µm	30 / 40	30 / 40	30 / 30	25 / 30
Conductor Thickness:	µm	12	12	9	7
µVia Diameter:	µm	65	65	50	40
µVia Aspect Ratio:	ratio	0.8:1	0.8:1	0.9:1	0.9:1
Minimum Mechanical Drilled Via Diameter:	µm	150	150	100	100
Minimum µVia Pad Size:	µm	µVia Dia + 120	µVia Dia + 100	µVia Dia + 75	µVia Dia + 50
Minimum Mechanical Via Pad Size:	µm	TH Via Dia + 150	TH Via Dia + 150	TH Via Dia + 150	TH Via Dia + 150
Minimum Core Thickness:	µm	40	40	25	25
Minimum Prepreg Thickness:	µm	35	35	25	25
Layer to Layer Registration (ELIC):	µm	+/- 50 (ELIC)	+/- 50 (ELIC)	+/- 40 (RDL)	+/- 35 (RDL)
Layer to Layer Registration (HDI):	µm	+/- 50 (HDI)	+/- 50 (HDI)	+/- 50 (HDI)	+/- 40 (HDI)
Same Core Front-Back Registration:	µm	+/- 12	+/- 10	+/- 10	+/- 10
Solder Mask Registration:	µm	+/- 25	+/- 25	+/- 25	+/- 25

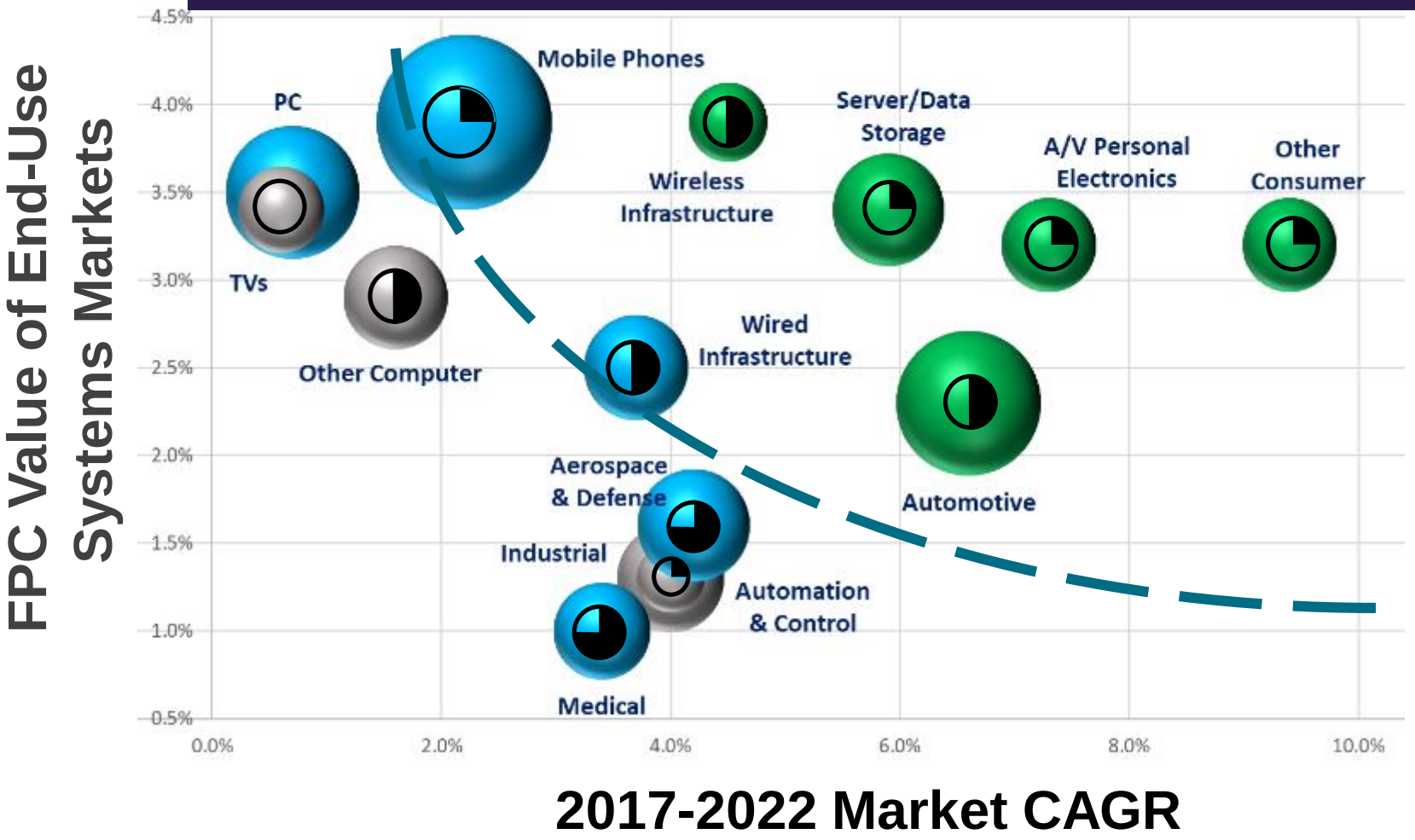
Technology Outlook for Roll-to-Roll (Flexible) Assembly



	Mature	Advanced	In Development
Board Thk (min) [mm]	**0.032**	0.027	0.027
BGA Pitch [µm]	300	300	200
Line/Space [µm]	**40/40**	30/30	25/25
PI Substrate Thk (min) [µm]	**20**	12.5	9
Conductor Thk (min) [µm]	**14**	6	6
Laser Diameter [µm]	**50**	40	30
µVia Preparation	**DM (BLH)**	DM	DM
µVia Aspect Ratio	0.5:1	0.9:1	1:1
Pad Size (min) [mm]	**Laser Dia + 0.180**	Laser Dia + 0.102	Laser Dia + 0.076
L2L Registration [mm]	**+/-0.065**	+/-0.013	+/-0.013

Conclusion: Focus on the Right Markets

End-Use Systems Markets ($B) in 2022



Focus on Faster Growth

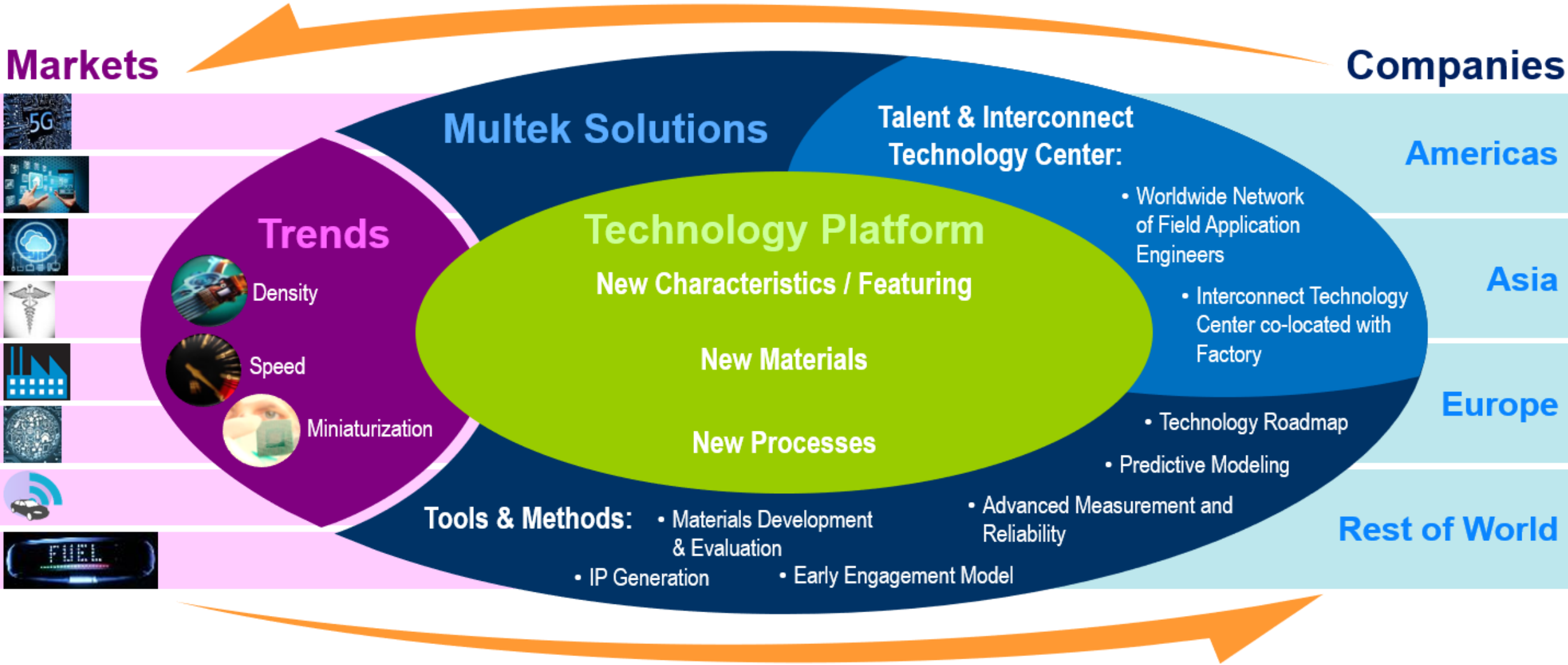
- Other Consumer
- A/V Personal Electronics
- Automotive
- Server/Data Storage
- Wireless Infrastructure

Larger or Niche Segments

- Mobile Phones
- PCs
- Wired Infrastructure
- Aerospace & Defense
- Medical

Source: Prismark & Multek

And Leverage Partners who Understand Technology Across Verticals



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Thank You!

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