



Chiplet Market Forecast

Custom Intelligence for the Open Compute Project -
Open Domain-Specific Architecture Workgroup

December 25th, 2019 Update

The Chiplet Market Ecosystem

A summary of vertical markets, their typical workloads and suitability for chiplet development

Chiplet market ecosystem		
Market	Typical Workloads	Opportunity
Data Center Compute and Storage	Heavy workloads demand raw processing performance. MPUs dominate. There is a trend toward coprocessors such as GPUs and AI accelerators for machine learning training and inferencing applications.	<i>Early Proprietary Large</i>
Wireless Communications	Split into nodes (devices) and infrastructure (mobile and fixed). Nodes prioritize power efficient application processing through low-power media optimized heterogeneous SoCs. Infrastructure prioritizes packet processing and efficient network management and secure connectivity. This is accomplished with small scale MPUs with high penetration of RF signal processing.	<i>Long-term Large Diverse</i>
Wired Communications	Infrastructure prioritizes extremely high bandwidth for packet processing and efficient network management and security. This is accomplished with large scale MPUs for virtualization and high penetration of packet forwarding logic coprocessors.	<i>Early Moderate</i>
Industrial Electronics	Industrial is a mix of highly diverse applications. Many of the workloads are data access and control functions gathering sensor data and driving machinery. There is also a high volume of human machine interface requiring graphics. The environment can be harsh and work periods long so controllers and more robust SoCs are typical. AI and embedded vision are poised to have a greater impact.	<i>Late Moderate to Large Diverse</i>
Consumer Electronics	Price sensitivity and time-to-market are crucial traits. Low-cost controllers and SoCs are common. Too much engineering or development times can be costly in terms of lost opportunity. Most innovation is iterative with the exception of transformative technologies such as the latest trend in natural speech interfaces.	<i>Late Moderate to Large Diverse</i>
Automotive Electronics	Automotive is split between mission critical (e.g. ADAS) and human machine comfort (e.g. infotainment). This ecosystem values long term relationships and durability due to the reliability and safety constraints. Once dominated by MCUs, vision processing, multimedia subsystems have enabled some SoC vendors to penetrate this high barrier market.	<i>Very Late Small to Moderate</i>

Heterogeneous System on Chip (SoC)

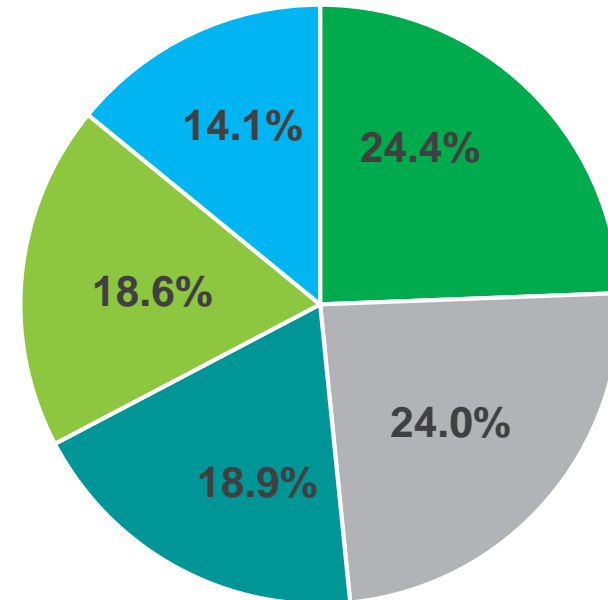
The serviceable market for Chiplets

Multicore System on Chip (SoC)

SoCs represent the largest overall opportunity to target for chiplets given the variety of integrated packages of differing intellectual properties.

- Like MPUs, performance increases can be gained through symmetric multicore packaging.
- Multicore applications processor configurations are already heavily affected by standardized IP. Arm, x86, MIPS Power, Risc V, and other core architectures are likely candidates for chiplets.
- A packaging technique that could accommodate a variety of core configurations could enable a larger product portfolio with fewer specific SKUs.
- Having standard interfaces could also accommodate multiple styles of configurations such as big.LITTLE or Automotive grade vs. non-automotive grade.
- Even application cores from different IP vendors could be simplified through standard packaging interfaces for differing core architectures adhering to a common interface.

SoC revenue based on core count



Percentage of market in 2018

■ Octa ■ Quad ■ Single ■ Dual ■ Other (mostly > 8)

Notes: Excludes embedded x86 MPUs marketed as SoCs. Includes Configurable SoCs from PLD Vendors.

Source: IHS Markit

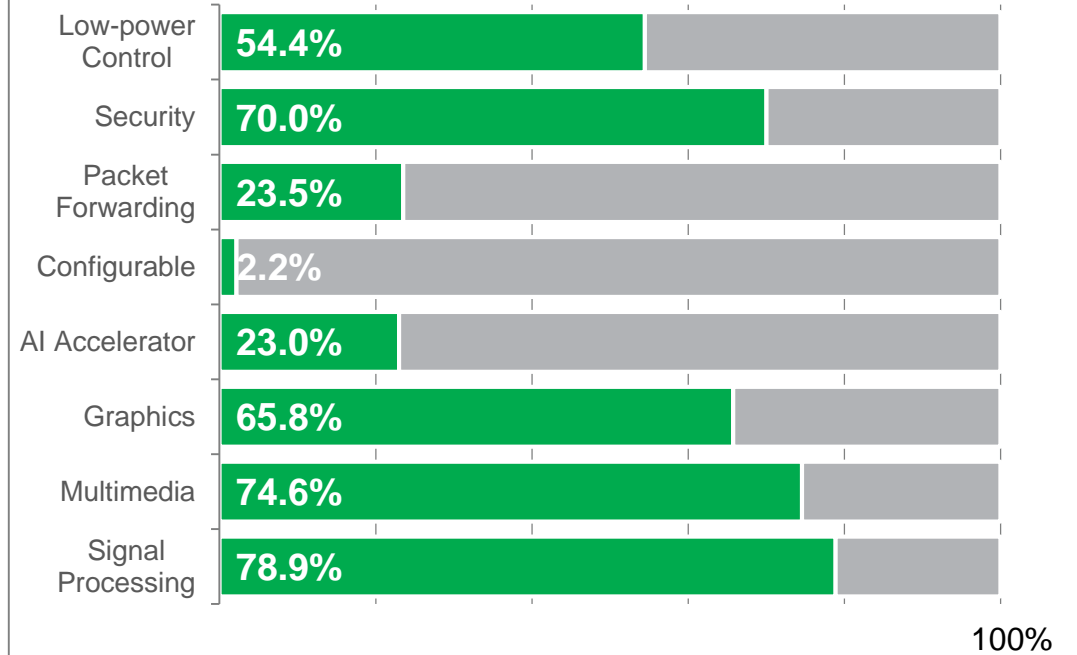
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System on Chip Integration

Many of these processors incorporate IP in the form of subsystems from several unique vendors. This includes just the study of the many subsystems present. SoCs also frequently integrate on-chip memory, specialized I/O such as analog, optical or radio transceivers. The strong push toward integration on-chip extends value propositions well beyond the limits of miniaturization.

- A single processor could have a proprietary DSP or IP from Arm, CEVA, DSP Group, Synopsis or other supplier.
- It could have a proprietary graphics core, or IP from Imagination, Arm, or another graphics IP vendor.
- Similarly, all other subsystems could be a proprietary solution or a chiplet from a supplier specializing in that subsystem technology.
- Each of these IP chiplets could progress generations at a different pace driving innovation.
- Manufacturing the IP separately theoretically increases yield to help offset the costs associated with advanced packaging.

SoC revenue based on integrated subsystem



Percentage of integrated subsystems per SoC as part of market in 2018

Notes: Excludes embedded x86 MPUs marketed as SoCs. Includes Configurable SoCs from PLD Vendors.

Source: IHS Markit

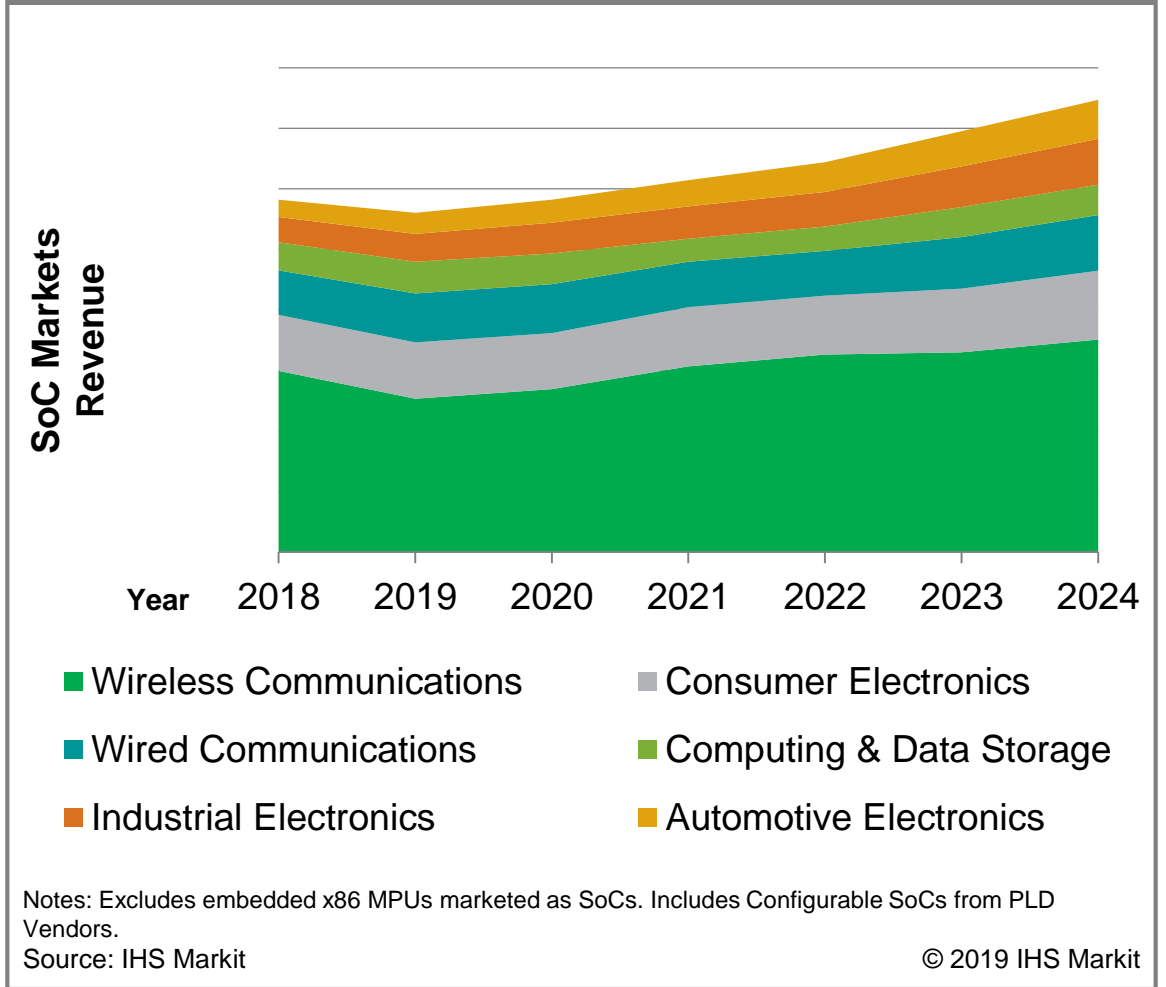
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System on Chip Market Forecast

SoCs are expected to be a prime candidate for chiplets due to their subsystem proliferation, interface diversity and market size demands. The diversity of this market is both driver and barrier. The cutting edge solutions are prime candidates for early adopters, but there are also many cost constrained providers with little R&D for new manufacturing development.

- The Wireless market is the largest and is driven primarily by smartphones. This market has begun to plateau. Other markets, especially Industrial and Automotive are prime for growth.
- Key Applications:
 - > Wireless – Smartphones, Tablets.
 - > Consumer – Set-top Boxes, Smart TVs, Smart Speakers & Digital Assistants.
 - > Wired Communications – Threat Mitigation, Enterprise Ethernet Switches and Routers, Optical Data Transport
 - > Computing and Data Storage – Data Center Servers
 - > Industrial – Automation, Medical, Security & Surveillance
 - > Automotive – Infotainment & Telematics, ADAS

SoC TAM by Market Segment



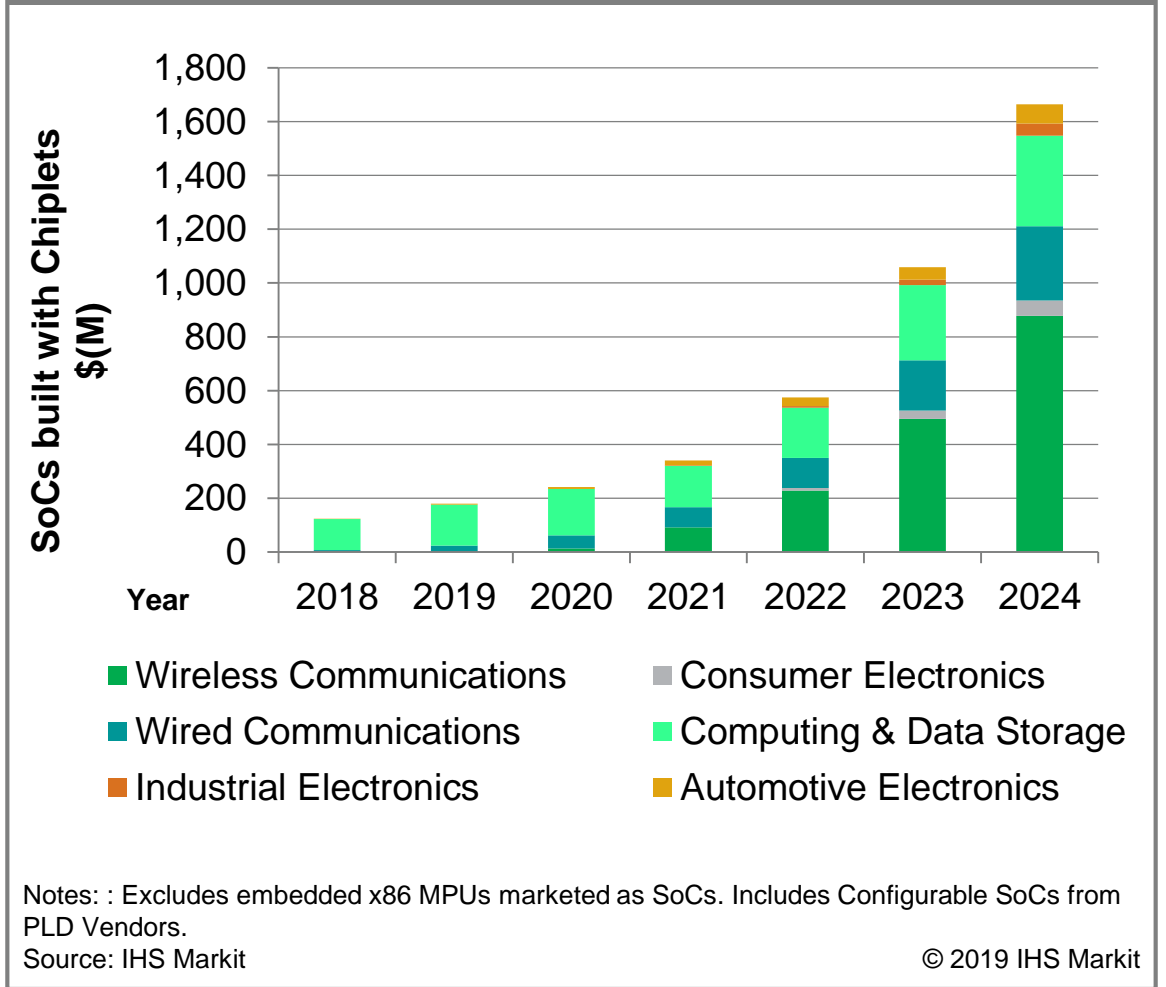
System on Chip Chiplet Forecast

The Chiplet Serviceable Available Market (SAM) slice

Assumptions applied to derive the SAM for chiplets to capture SoC revenue.

- Heterogenous processors are a key target for long-term chiplet growth.
- Current advances in processor packaging have targeted performance applications such as data center and adjacent applications such as communications equipment, networking, and industrial applications.
- Early solutions will continue to be driven by larger processor suppliers working in cutting edge process nodes who have the most at stake as miniaturization fails to sustain Moore’s Law.
- Superscalars and service providers will drive early innovation in datacenter and communications including edge devices to support their own ‘MPU plus custom accelerator’ strategies.
- Low-power Wireless and Consumer markets may be slow to adopt, but it is inevitable as miniaturization becomes costlier and chiplets become more economical, these markets will benefit greatly. This diverse competitive landscape will rapidly invest in chiplet technologies due to the prevalence of integration.
- Automotive and Industrial are even slow adopters due to high reliability and liability constraints. These constraints create strong barriers to entry.

SoC SAM by Market Segment



Microprocessor (MPU and CPU)

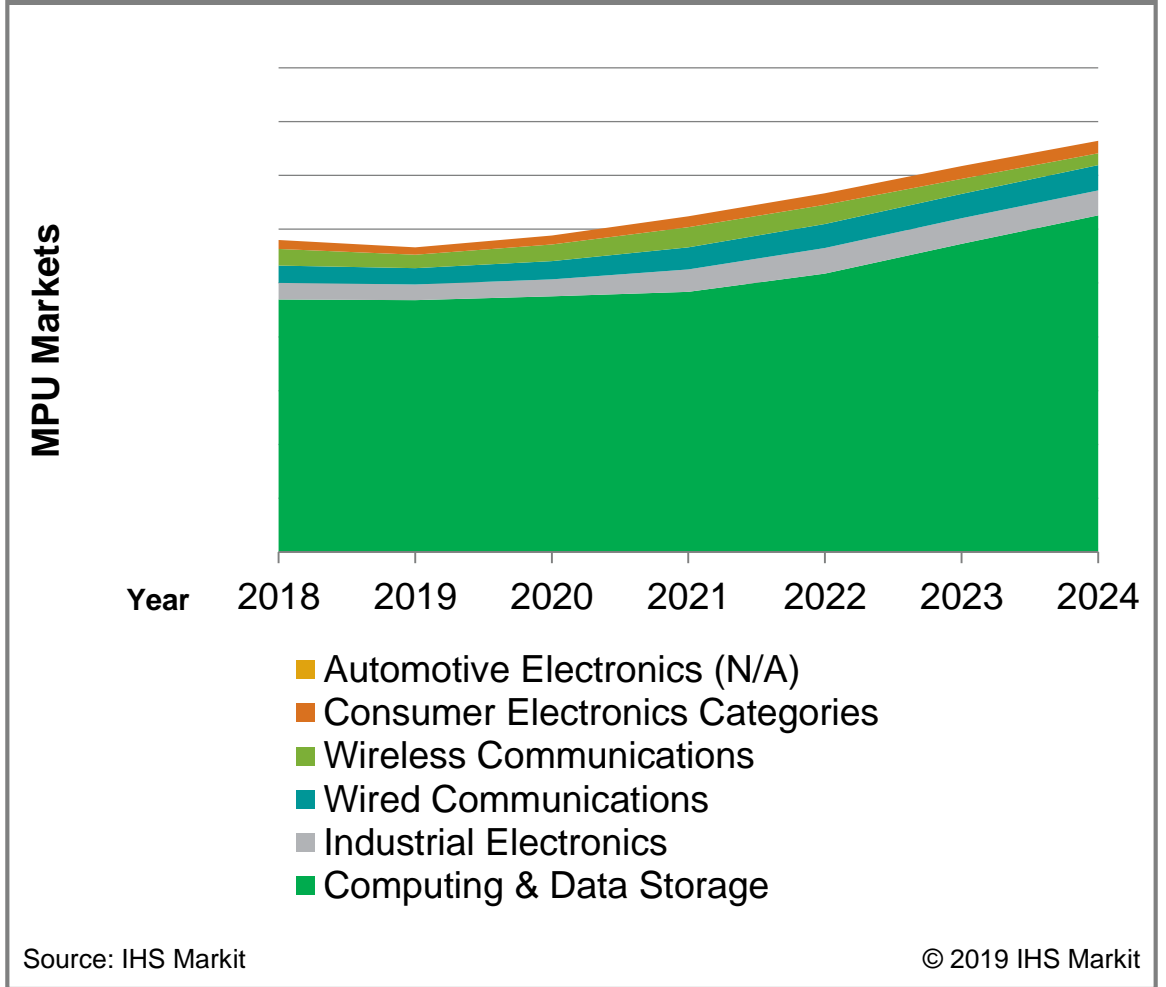
The serviceable market for Chiplets

Microprocessor Forecast

MPU revenue contributes to the chiplet TAM based on subsystem and market size demands. The cutting edge process nodes used make it one of the first impacted by Moore’s Law financial barriers making it a prime and early adopter for chiplets including development by Intel and AMD.

- The Computing & Data Storage market is the largest market for MPUs, more commonly referred to as a Compute Processing Unit (CPU) in a computer. Historically, volume was driven primarily by PCs, which are plateauing, but the high growth in Data Center MPU revenue is predicted to overtake that of PC MPUs by 2024. Industrial & Communications are smaller but prime for growth.
- Key Applications:
 - > Computing and Data Storage – Data Center Servers, Notebook PCs and Desktop PCs.
 - > Industrial Electronics – Automation, Medical, Military & Aerospace
 - > Wired Communications – Threat Mitigation, Enterprise Ethernet Switches and Routers
 - > Wireless Communications – Wireless Infrastructure
 - > Consumer Electronics – Video Gaming Consoles

MPU TAM by market segment



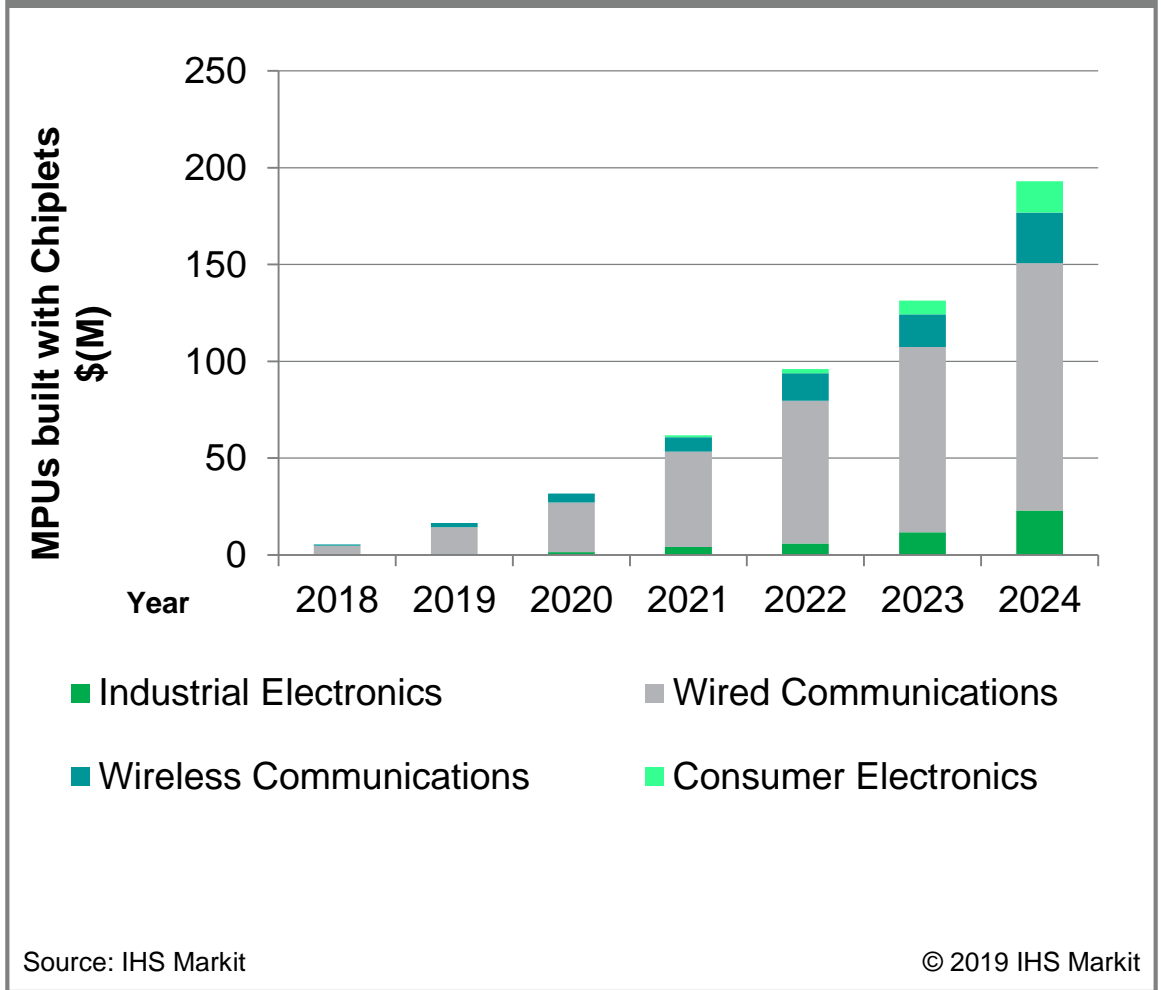
Microprocessor Chiplet Forecast

The Chiplet Serviceable Available Market (SAM) slice

Here is another view of the same MPU data with the overwhelming CPU market removed to compare scale

- Intel and AMD have very little competition for CPUs, but outside of Computers & Data Storage, there is some diversity that includes non-x86 core architectures marketed as MPUs.
- Outside of CPUs, MPU solutions are not dissimilar from SoCs and the distinction from SoCs has more alignment with performance targeting support for advanced applications with human-machine interfacing than any clear chip-level core technology differences.
- Wired and Wireless communications infrastructure relies heavily on advanced interfaces including SERDES, RF, Optical and other integration to optimize processors. This is the assumption that makes these markets early and fast adopters of chiplet technologies despite being much smaller than the CPU market.
- The consumer market for chiplets are almost exclusively dependent upon AMD and Nvidia supporting game platforms. Currently game consoles are dominated by AMD which is an early adopter but has yet to use chiplets outside CPUs. Nvidia supports Switch, Shield and smaller handheld solutions and has been seriously considering chiplet designs.

MPU SAM by market segment



Aggregated Chiplet Forecast

The serviceable market for Chiplets

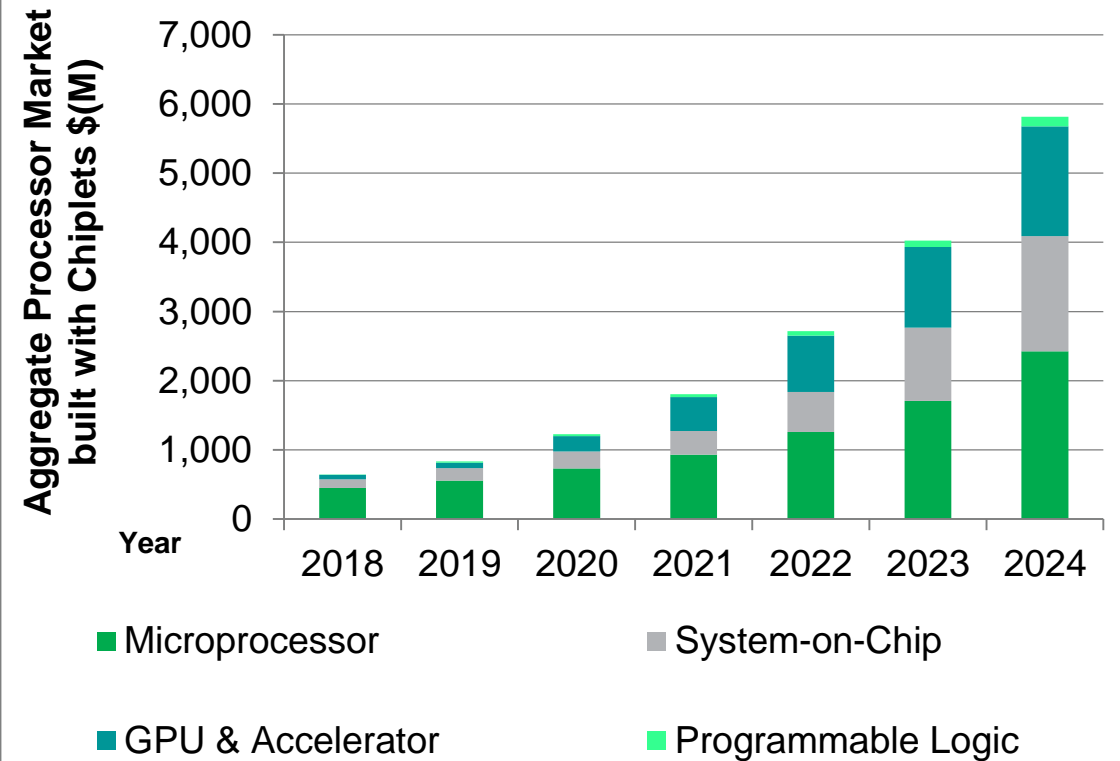
Processor Revenue Splits by Class

The Chiplet Serviceable Available Market (SAM) slice

Aggregated market for processors using chiplets by class

- MPUs – The large and concentrated revenue of the few MPU suppliers is highly dependent upon being at the cutting edge of manufacturing technologies. They have the most to lose from the practical end of Moore’s Law and large R&D budgets to prevent that from happening. As such, they are early adopters of proprietary solutions and are also likely contributors to support standardization to grow the overall market for chiplets.
- SoCs – These are slower to start than MPUs, but the diversity of I/O including analog, RF, optical; memory; coprocessing subsystems make this ultimately the greater long-term target market and beneficiary of advancing chiplet technologies.
- GPUs & Accelerators – Similar to MPUs in competitive landscape, there are few suppliers of GPUs. This market is likely to diverge between ever more powerful data center systems vs. highly optimized SoCs with graphics and AI. early development will favor proprietary solutions but expand toward standardization.
- PLDs – The bulk of PLDs are mature FPGA strategies, but new configurable SoCs and advanced compute platforms are a small but very likely adopter of standardized chiplet technologies.

Overall Chiplet SAM by Processor Type



Source: IHS Markit

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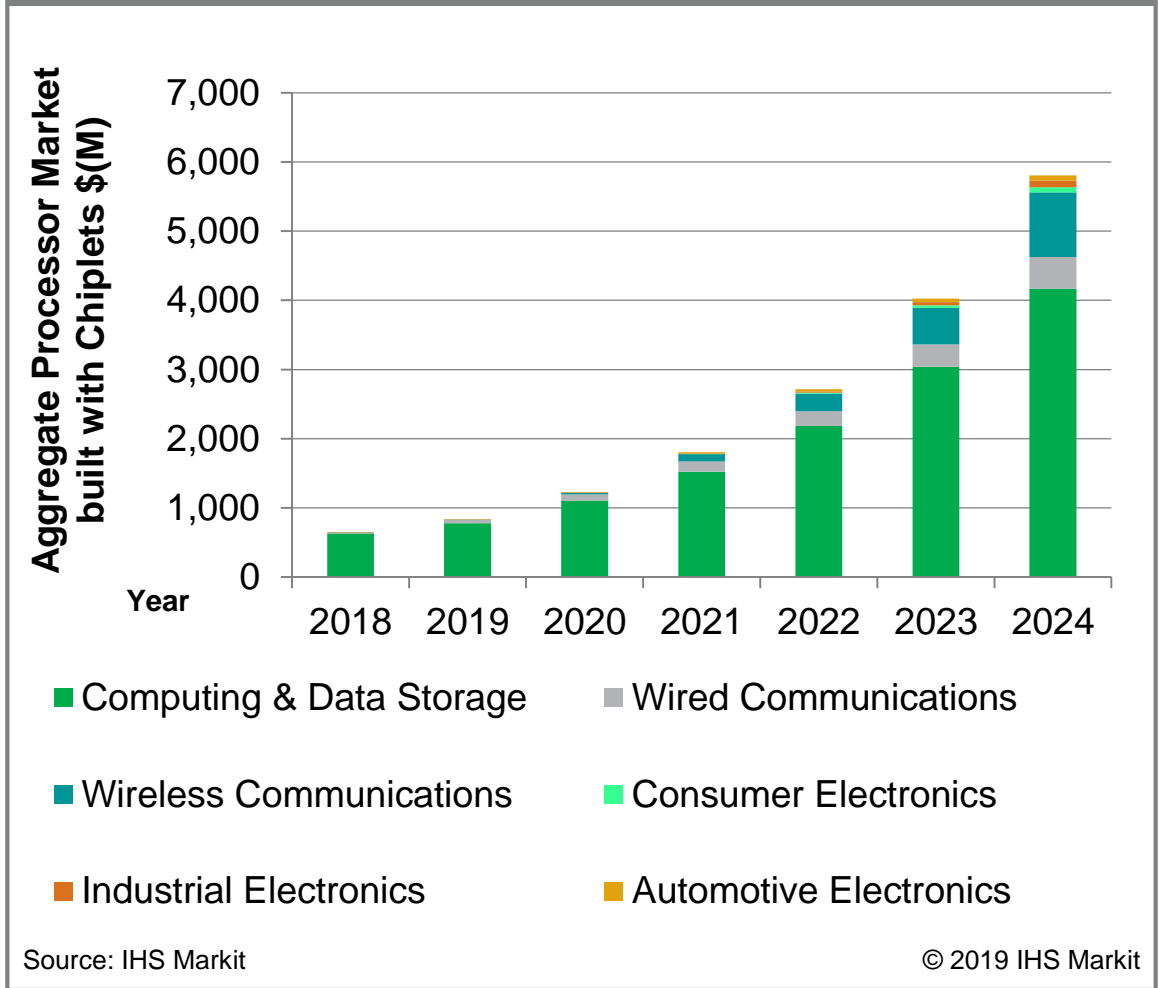
Aggregated Chiplet Forecast

The Chiplet Serviceable Available Market (SAM) slice

Aggregated market for processors using chiplets by market

- Because of early proprietary MPU and GPU solutions, Compute & Storage Space dominates early growth. There is already significant chiplet technologies developed as proprietary solutions.
- Hyperscalers, cloud and communications service providers all have incentives to see the computing and data storage market become more resistant to the eminently increasing expense associated with the end of Moore's Law.
- While this trend is apparent for the short term forecast, it should be made clear that new edge applications and the rapid adoption of heterogeneous solutions in deeply embedded applications will drive a later wave of faster adoption rates in other markets that may in some instances, such as wireless device SoCs, overtake the computing and data center adoption rates in the long term.
- The key takeaway here is that early adoption of chiplets is happening because the eventual demise of Moore's Law makes it essential for cutting edge processor suppliers. At some point, diversity in processor design will make it even more economical for the wider market to adopt at their typical adaptation pace.

Overall Chiplet SAM by Market Segment



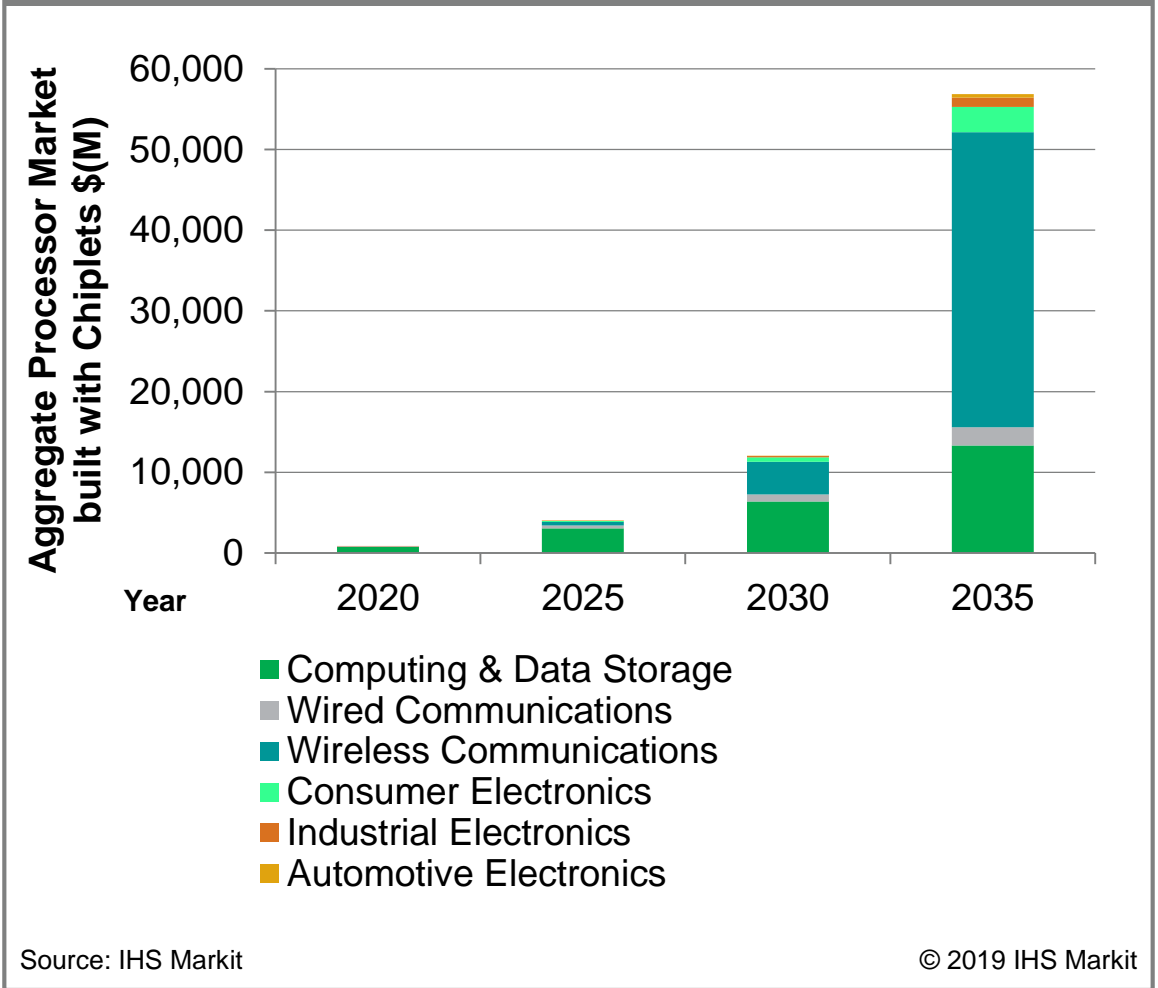
Long Range Chiplet Forecast

The Chiplet Serviceable Available Market (SAM) slice

Wireless to overtake Compute & Data Storage long-term

- While the short term forecast was tied to a very detailed market processor tracking database, it is worth noting that it does not quite do justice to the long term opportunity for chiplets.
- As barriers to miniaturization continue to drive the cost of transistor density, the overall cost of chiplets will inevitably shrink with economies of scale increasing its viability in the long term.
- This graph extends the pattern of adoption to highlight how the market is expected to change dynamics over the more mature market. Heterogeneous processors will play a critical role in chiplet growth and the Wireless market is predicted to become a substantial source of innovation and market growth over the long term, exceeding \$50 in the next 15 years. This is mainly due to the processor market size and its faster replacement cycle that favor fast transition rates. Compared this to the slow and lengthy adoption rates of Industrial and Automotive where OEMs prefer mature and tested solutions with long lifecycles.
- This long term forecast is subject to unforeseen barriers or competition, but serves as a reasonable strategic roadmap.

Extended Chiplet SAM by market segment



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