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RISC-V Market Report: Application Forecasts in a Heterogeneous World

(abridged version)

January 2024
SHD101A.b-24

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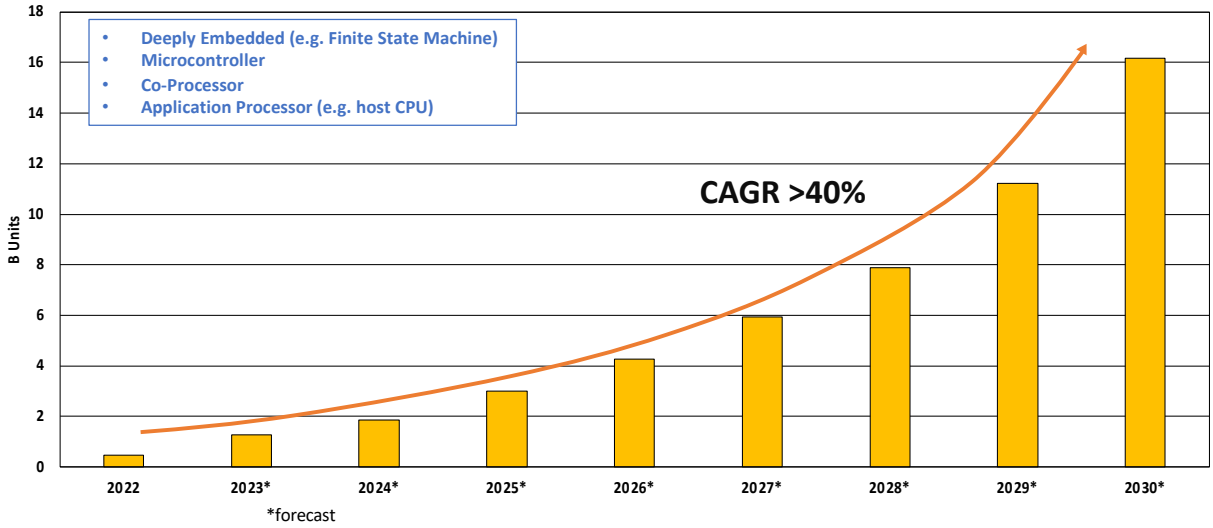
Executive Summary

The following document is an abridged version of our more comprehensive RISC-V report, published by The SHD Group. This abridged version summarizes the analysis of the market for the RISC-V ISA architecture and its impact on the rapidly changing semiconductor industry. It focuses on RISC-V SoC market penetration and corresponding IP products that support this growth. The complete report is 225 pages in length with 107 tables and 89 figures. A list of the additional items included can be found in section XVI at the end of this report. To obtain information about receiving the full report version, please contact m.kinman@theshdgroup.com.

This a report provides an examination of the rapidly evolving semiconductor market, with a specific focus on the RISC-V architecture's influence in the post-COVID era. As the global recovery from the COVID-19 pandemic fuels growth in the semiconductor intellectual property (IP) and system-on-chip (SoC) markets, the introduction of the RISC-V instruction set architecture (ISA) has profoundly impacted SoC design strategies across various sectors.

The introduction of RISC-V has fueled extensive CPU architectural exploration, visibly impacting device revenues, unit shipments, design starts, and IP licensing revenues on a global basis. The pervasive integration of AI across applications is a primary catalyst in today's semiconductor market. The RISC-V architecture has notably influenced SoC designers and architects and is poised to drive a substantial share of designs, revenues, and unit shipments in the coming years.

Figure 1 RISC-V SoC Unit Shipments



Key Highlights:

RISC-V SoC Market Growth:

- RISC-V-based SoC unit shipments are forecast to surge to 16.2B units, with revenues reaching $92B by 2030, boasting CAGRs of 44% and 47%, respectively.

SoC Market Growth:

- SoC architectures utilizing 3rd party IP exhibit substantial growth in units and revenues across Industrial, Automotive, Networking, computer, Consumer, and Other categories, notably driven by the burgeoning AI market.
- Projections indicate SoC unit shipments reaching 69B units and revenues hitting $416B by 2030, showcasing CAGRs of 12.5% and 8.7%, respectively.

SoC Design Starts:

- SoC design starts for SoCs using RISC-V CPU cores are forecast to reach 1,371 designs by 2030, a 15.7% CAGR.
- Design starts for Consumer applications are expected to show the largest number of designs by 2030, with Computer and Networking applications following closely behind.

3rd Party IP Market:

- In 2022, the worldwide IP market reached $7.9B, marking an 8.4% growth from 2021. Forecasts predict a 5.3% increase to $8.3B in 2023, projecting a potential $15B market by 2030, with a CAGR of 9%.
- The Central Processing Unit (CPU) IP market soared by 22.4% in 2022 to $2.7B and is anticipated to hit $5.8B by 2030, demonstrating a robust 10.4% CAGR.
- RISC-V IP revenues surged to $156M in 2023, with an estimated CAGR of 39.5% through 2030.

While this analysis excludes the impact of the emerging chiplet market, expectations lean toward increased utilization of the RISC-V architecture in future SoC designs, further bolstering IP and SoC revenues. We will continue to monitor this area.

Specification vs. implementation

In researching and writing this report, our approach remains non-biased, steering clear of the geopolitical controversies prevalent in the high-tech world. Our focus instead is to bring insight to growth opportunities for hardware, software, and systems using the RISC-V architecture.

However, it's important to remember that RISC-V, at its core, is a *specification* – a blueprint designed to foster compatibility among hardware and software developers. This open specification democratizes innovation, allowing anyone with the necessary technical expertise and funding to design their own *implementation*. It's imperative to distinguish between the RISC-V *specification*, which is open and accessible, and these individual *implementations*, which are proprietary endeavors. Each implementation, developed by various groups, constitutes its own IP, complete with unique designs, innovations, or patents – and regulatory restrictions.

The technological landscape is influenced not only by innovation but also by regulatory frameworks governing aspects like funding sources, export controls, and more. These regulations are important for maintaining a balance between open innovation and national security priorities. However, the idea of restricting the RISC-V *specification* counters the very benefits that openness brings, encouraging fragmentation, which could have economic repercussions across the supply chain.

Economically, a unified specification like RISC-V enables economies of scale, reducing development costs and accelerating time-to-market for companies. We commend the collaborative efforts to evolve the RISC-V specifications, which benefit a diverse array of companies and individuals. This progress exemplifies the strength of open standards in fostering technological advancement. We also emphasize the importance of adhering to regulatory frameworks, ensuring that implementations of RISC-V respect the necessary legal boundaries. It is this equilibrium between open innovation, economic pragmatism, and regulatory compliance that will propel the technological advancements we all aspire to achieve. The bottom line is that we all benefit from openly collaborating on *specifications* while the *implementations* remain company-specific intellectual property subject to regulation.

The SHD Group

Introduction

The title of this report, **RISC-V Market Analysis: Application Forecasts in a Heterogeneous World,** was chosen because the semiconductor market today has changed from what it was 12-15 years ago. In that previous era, SoC designs had transitioned to multicore and away from single-core implementations due to the end of Dennard scaling and the fact that SoC speeds were topping out.

The time-honored solution of moving a design down the process geometry curve to gain faster device speeds, lower power consumption and higher performance no longer delivered the gains previous generations of silicon enjoyed. The only way forward was to adopt a multi-core approach where clock speeds would remain mostly static, but more work could be performed by splitting the workload between many cores instead of just one core.

While SoC designs remained monolithic, they now implemented many CPU cores, whereas before, there had only been one core to perform the work. In the SoC market, CPU architectures from Arm Holdings and the Intel x86 reigned supreme in most markets and applications. There were other competitive CPU architectures available from Synopsys (ARC), MIPS, Cadence (Tensilica), Andes Technology and others. However, they never quite had the support of the market and were not major factors in the SoC design landscape.

This has now changed with the emergence of the RISC-V ISA and the RISC-V International organization, which is dedicated to the establishment and growth of a robust, comprehensive ecosystem designed to support the increase in adoption of the RISC-V CPU core.

With this emergence of a competitive 3rd party CPU core, a new trend has taken hold of the SoC market, that of heterogeneous SoC designs, where not all the CPU cores used in the design must derive from the same CPU vendor. Now, while multiple CPU cores are still being used, with the number of cores steadily increasing, they are no longer all coming from a single CPU IP vendor.

Today, it is possible to encounter many SoC designs that use Arm cores alongside RISC-V and other cores, all performing different tasks as dictated by the SoC architect.

Due to the rising complexity levels in response to increasing market requirements for more functionality and richer feature sets, SoC designers have adopted the practice of using the CPU core that best fits the design requirements. This is done regardless of whether they already use another core from a different vendor.

Designers consider many factors when choosing a CPU core, and longevity in the market and the specific CPU IP supplier's track record are but two of them. However, increasingly today, the right ecosystem support structure, encompassing EDA tools, a rich IP catalog, and designers knowledgeable in the specific CPU cores ISA, have become available from many sources, easing the designer's task in crafting the next amazing silicon solution.

The SHD Group has taken a different approach in compiling this report, keeping in mind the heterogeneous nature of today's market. We have chosen to focus on the functions performed by the

RISC-V CPU cores in the SoC rather than trying to assign the SoCs to separate silos based on the main CPU core integrated into each part.

Using this as the metric to differentiate between parts was valid in a homogeneous world but no longer works in a heterogeneous world. We do not see value to our readers if this report were to say that an SoC falls into an all-Arm or all-x86 bucket when the chip is heterogeneous, has one or more cores, or other architectures on the die. This is even more important when 10, 100, or even 1000 RISC-V CPUs are also on the part performing functions alongside an x86 or Arm CPU.

We think there is a better way to look at things. The market has evolved, and we believe the research needs to evolve along with it.

With that thought in mind, we have segmented a portion of this report into looking at what functions the RISC-V CPU cores are being tasked to perform.

These functions are:

- Deeply embedded (e.g., programmable replacement to a Finite State Machine)
- MCU
- Co-processor (e.g. DSP, Vector or AI Accelerator)
- Applications Processor

We believe this gives a better perspective on the uses the RISC-V cores are being put to and where the opportunities lie for RISC-V CPU IP vendors, software developers, and SoC designers.

As we step into the third decade of the 21st century, the semiconductor and computer industries have witnessed significant progress, leading to a surge in exploration and breakthroughs in computational and silicon architecture. These advancements encompass the integration of artificial intelligence (AI), Large Language Models (LLMs), accelerated communication through 5G, the burgeoning chiplet market, and widespread deployment of sensors across various applications, generating vast amounts of data. This surge is contributing to a notable increase in the complexity of devices and systems, accompanied by a corresponding rise in design intricacy.

In tandem with these strides, the RISC-V ISA emerged at the University of California, Berkeley, in 2010. Subsequently, the RISC-V Foundation was established in 2015 to foster industry adoption and encourage collaboration within the RISC-V ecosystem. The business model associated with this open architecture IP eschews upfront licensing fees, empowering users to tailor and adapt cores to their specific applications and fostering opportunities for distinctive differentiation.

Initially embraced within academic circles to educate students about IP and intricate SoC silicon design, the RISC-V IP movement has transcended academia. It is now embraced by the broader SoC design community, with many companies incorporating it as an alternative to more traditional CPU IP types. The hallmark of the RISC-V architecture lies in its ability to be customized to align precisely with the requirements of the application.

Large companies such as Qualcomm, Samsung, AMD, Nvidia, Amazon, Google, Microsoft and Intel have disclosed that they are working with RISC-V in some way. Others, like Apple, are well-rumored to have

projects underway. Google and Qualcomm have made notable announcements about their development of a RISC-V-based platform for wearables. Meta has disclosed a RISC-V project which uses the Andes AX25 in a Training and Inference Accelerator for data center applications.

Figure 2: RISC-V Momentum Continues to Build, Courtesy Andes Technology

Many may rely on their internal designers to create specific RISC-V point solutions they need in their systems' businesses and semiconductors for their own product portfolios. However, as the market for RISC-V parts becomes established and more semiconductor companies offer competitive products, this will change. Even Tier 1 companies source semiconductor solutions from the general market as needed. We expect this to increase the overall adoption of RISC-V, whether based on home-grown licensed IP, and expand the volume of RISC-V based devices globally.

For companies venturing into creating licensable CPU cores based on the RISC-V ISA, upfront fees become pertinent once these cores are licensed into the 3rd party IP market. This allows other entities to integrate them into their own silicon solutions, contributing to the continued growth and adoption of RISC-V in the semiconductor landscape.

For the IP companies that intend to take the RISC-V ISA and create their own licensable CPU core, there will be up-front fees associated with their cores once they are licensed into the 3rd party IP market for others to incorporate into their silicon solutions.

This report looks at the existing SoC markets for Industrial, Automotive, Computer, Consumer, Networking, and other applications. It analyzes the potential impact RISC-V is having today and will have in the future regarding the following areas:

- The SHD Group is profiling 53 end applications where RISC-V is being used and segmenting these applications by the function the RISC-V CPU cores are being asked to perform.

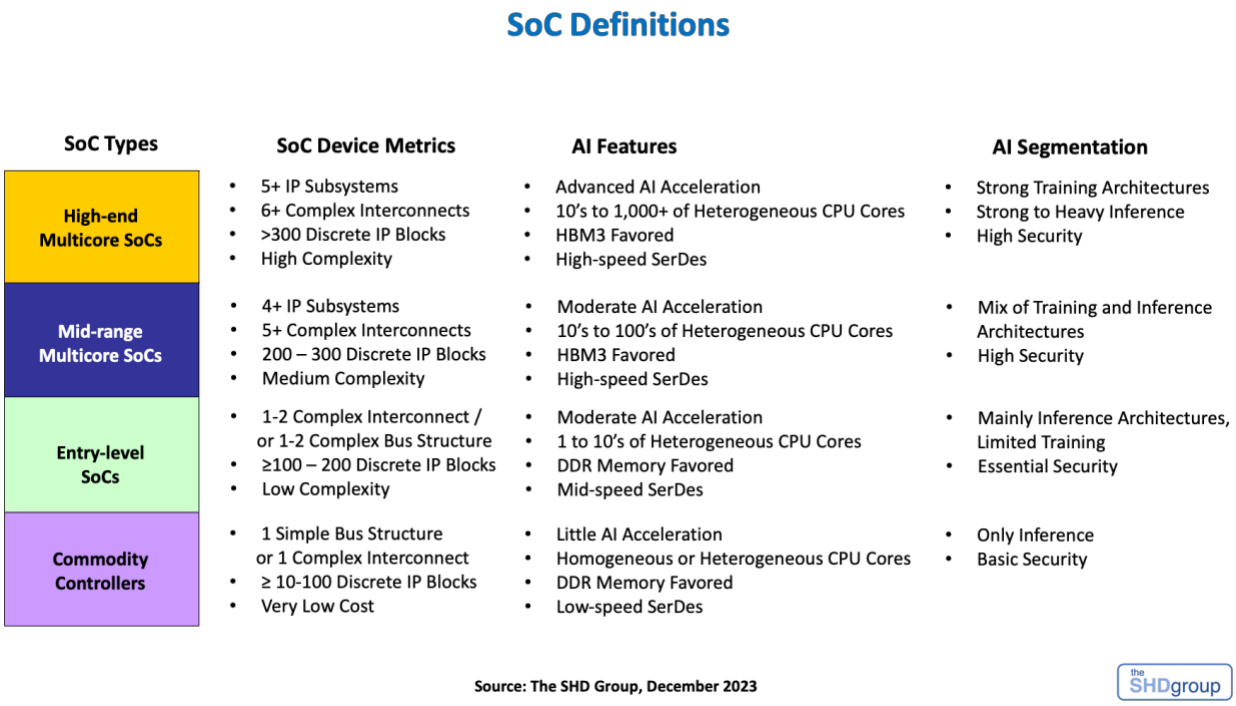
    - The list of functions includes deeply embedded, for example Finite State Machine, MCU, co-processor, and a host CPU.
- Revenues for the RISC-V SoC market for Industrial, Automotive, Computer, Consumer, and Networking applications, split by high-end multicore SoCs, mid-range multicore SoCs and entry-level SoCs.
- Unit shipments for the RISC-V SoC market for Industrial, Automotive, Computer, Consumer, Networking, and other applications.
- The market revenues for 3rd party semiconductor IP, CPU IP and RISC-V IP for royalties, licensing, and services.
- An analysis of the revenues of the different CPU IP architectures currently in the market.
- SoC design starts for the three application categories and the 10 RISC-V SoC device types.
- Regional splits for the Americas, EMEA, Japan, China, and Asia Pacific.

I. Architectural Definition for an SoC

The SHD Group has compiled an architectural definition of the three SoC types we collect data for:

- High-end multicore SoC – silicon that functions with the most complexity, representing the highest cost range.
- Mid-range multicore SoC – silicon that represents the mid-range in device complexity and has a more moderate cost range.
- Entry-level SoC – silicon that operates with the least device complexity and occupies the lowest cost structure.

Figure 3: SoC Defined by IP Content



As this diagram in Figure 2 shows, we consider SoC architecture to be more about how the design is created than about the silicon itself. Contemporary SoCs today rely heavily on the use of 3rd party IP and realistically cannot be crafted any other way. With this thought in mind, we created this diagram to give some granularity to these three silicon solutions to better understand the design and market dynamics that impact each type. We have extended these definitions to include device features and segmentation of the emerging AI market solutions since this new development in the semiconductor marketplace is going to be a main driver of applications, revenues, and unit volumes for many years to come.

We expect to amend this diagram as evolving market requirements provoke responses from silicon architects and designers alike.

Chiplets

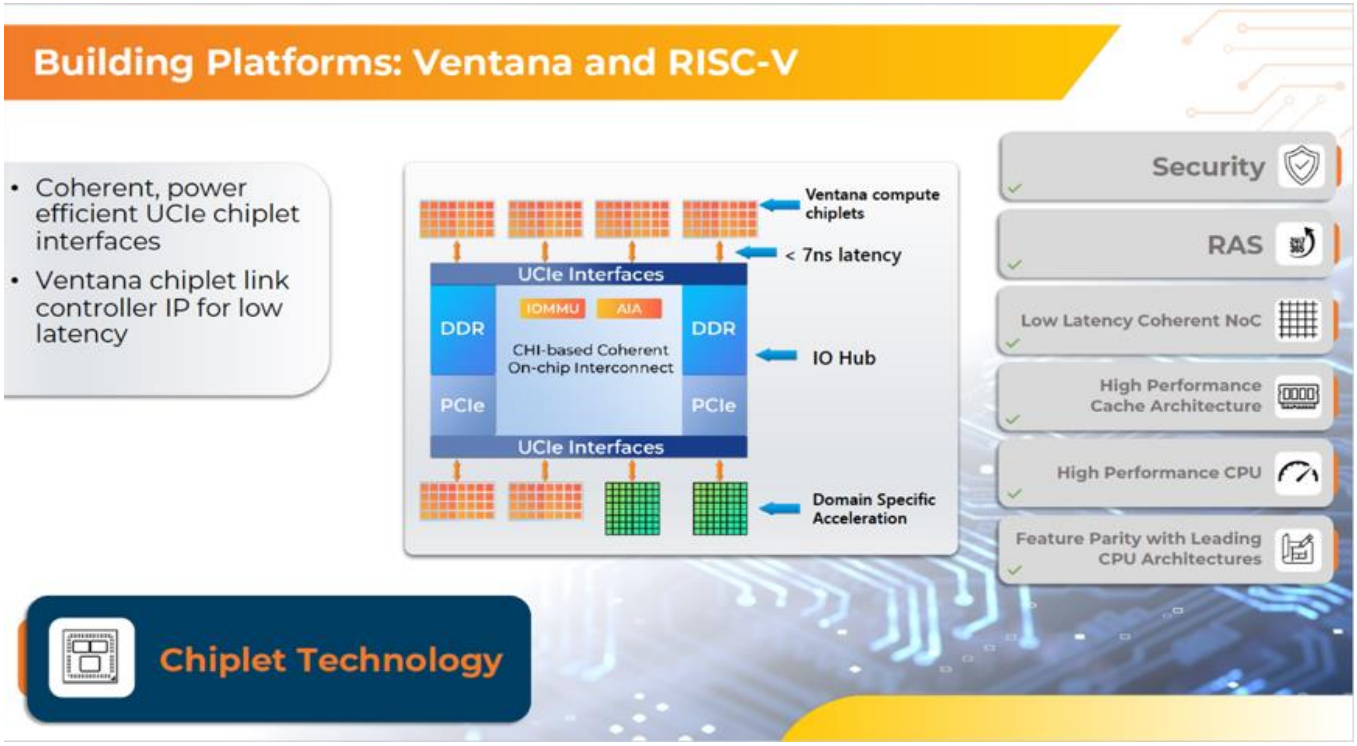
As this report is being written, the semiconductor industry is actively embracing chiplet technology as a strategic approach to mitigate the substantial design costs associated with newer, smaller process geometries and to address the challenges linked to large, monolithic die sizes of 300mm² and above that often result in poor yields. Major players in the industry, such as Intel, AMD, Nvidia and many others, are dedicating significant efforts to refine and optimize the chiplet approach. While several obstacles need addressing, the potential for reduced design costs and improved device yields is compelling, especially for companies dealing with large and expensive monolithic designs.

The mention of chiplets is pertinent for two key reasons:

1. Designers will require new silicon and innovative designs to complete their chiplet products.
2. AI acceleration is poised to play a significant role in many chiplet designs, presenting an ideal opportunity for the adoption of RISC-V-enabled solutions.

Illustrated in Figure 3 is a depiction of a chiplet implementation from Ventana Micro Systems, intended for a data center-class applications. Constructing such a solution would be very difficult if the industry was not collaborating on creating standards for die-to-die interconnects, packaging, testing, etc. The process of working through all the potential design, manufacturing, packaging, and testing issues is well underway, and the first examples of products from major semiconductor companies are now entering the market. This example of a chiplet architecture serves to highlight potential areas where RISC-V solutions could find application in a diverse range of implementations, presenting a promising opportunity for the adoption of RISC-V in the near future.

Figure 4: Chiplet Example, Provided by Ventana Micro Systems



II. RISC-V Market Drivers and Challenges

This section looks at the trends and drivers powering the semiconductor and SoC market in the near term. Correspondingly, there are also many challenges that these markets face that could put a damper on growth going forward.

General Market Drivers and Trends

- Pervasive deployment of sensors, notably in IoT applications
- Ongoing expansion of wireless connectivity
- Enhanced feedback and control over Industrial processes via embedded vision solutions
- Persistent demand for increased mobile device bandwidth and requisite infrastructure
- Growing use of FPGA solutions as accelerators in data centers alongside main CPU functions
- Renewed focus on factory floor revitalization with connectivity and IIoT solutions
- Electrification of automotive vehicles and the adoption of driver-assist systems
- Extensive deployment of AI in various applications
- Development and refinement of semiconductor architectures tailored for AI inference operations
    - Increasing incorporation of AI in endpoint devices and applications
    - Growing significance of voice recognition across various applications
    - Initiatives by tech giants like Microsoft and Google to integrate user-accessible AI assistance into search engines and business applications
- Introduction and rapid adoption of OpenAI's ChatGPT application signifying a substantial impact on the economy and society, thereby influencing the IP, SoC and EDA markets
    - Declarations by Qualcomm and Intel to enable running ChatGPT applications on their respective smartphone and desktop PC, laptop and tablet silicon, potentially rejuvenating these markets
    - Efforts by Microsoft to infuse AI functionality into the Windows OS and Office suite of business applications
    - Introduction of Microsoft’s own LLM models with considerably reduced parameter counts
- Implementation of new transistor architectures at 5nm and 3nm extending Moore's Law
- Accelerating momentum of chiplets with standardization in interconnects efforts underway for packaging
- Significant increase in reticle size by TSMC: 4X current reticle size in 2023 and 6X increase in reticle size by 2025
    - The introduction of Alibaba’s 60B transistor data accelerator and Apple’s MI Ultra, featuring 114B transistors in a two-die package, are likely examples of this.
    - IMEC proposed a new process technology roadmap extending beyond 2036 that reaches 0.2nm (200 pico meters), reaching a potential 1 trillion transistors per square mm.
- Integration of AI functionality into EDA design tools to enhance designer efficiency
- Ongoing rollout of 5G infrastructure worldwide
- Renewed interest in older process geometries due to advancements in EDA toolsets accommodating higher complexity
- Convergence of 5G, AI, IoT, and 3D Printing fostering new market demands and business models

- Emergence of Silicon Lifecycle Management IP facilitating powerful analytics embedded into various SoCs, available from three vendors today
- Multiple FPGA vendors transitioning their portions of their product lines or segments to incorporate RISC-V CPU cores, boosting the momentum of RISC-V
    - Lattice Semiconductor, Microchip, QuickLogic, Efinix
- Substantial announcements for new fab capacity from various industry leaders to address potential capacity shortfalls in the near future
    - New capacity by Intel, Samsung, TSMC, GlobalFoundries and Micron promises to alleviate capacity shortfalls in 2-3 years.
    - Intel has re-entered the silicon foundry market and introduced an aggressive geometry development roadmap through 2025.
- Legislative actions, such as the CHIPS and Science Act, designed to incentivize semiconductor manufacturers to build new fab capacity in the US
    - President Biden signed the $52B CHIPS Act legislation to build new fab capacity in the US and establish new learning centers in support of the U.S. semiconductor market.

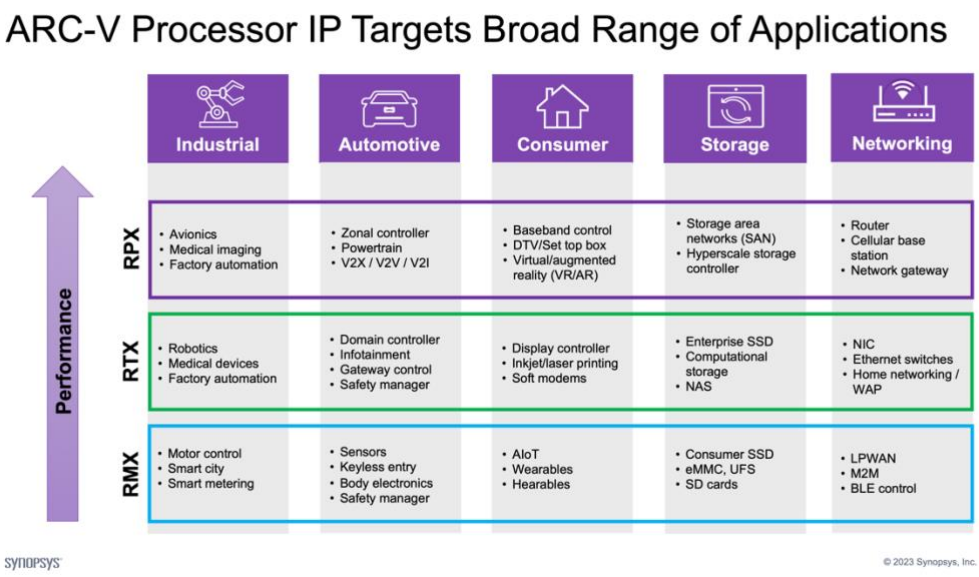
  The final reading of the U.S. 3Q23 GDP came in at 4.9%, signaling a growing economy compared to 1H23.

RISC-V-Specific Drivers

Positive developments specific to RISC-V in the market and ecosystem include:

- Introduction of the RISC-V Software Ecosystem (RISE) aimed at accelerating the development of open-source software for RISC-V architecture
- Embracing RISC-V ISA by well-known CPU IP vendors like Andes, MIPS, SiFive, Imagination Technologies and Synopsys, expanding the list of IP vendors supporting RISC-V
- Intel also joined RISC-V International, signaling support for the ISA adding momentum to the evolution of its ecosystem
- Collaborative efforts by Qualcomm and Google to develop a RISC-V-based platform for wearables
- Increasing availability of EDA tool vendors offering design tools tailored to RISC-V designs
- Ongoing enhancements in higher-performing RISC-V CPU cores offered by RISC-V CPU IP vendors
- Qualcomm Technologies, NXP Semiconductors, Infineon Technologies AG, Nordic Semiconductor ASA and Robert Bosch GmbH form a new company named Quintauris, based in Munich, Germany to be a single source to enable compatible RISC-V-based products, provide reference architectures, and help establish solutions widely used in the industry
- Renesas introduces families of 32bit and 64bit MCUs and MPUs based on the Andes RISC-V D25F
- Meta introduces a training and inference accelerator SoC for data center applications based on the Andes RISC-V AX25
- Alibaba introduced a new data center accelerator SoC based on a RISC-V CPU core from a Chinese company, SophGo

Figure 5: RISC-V Momentum Continues to Build, Courtesy of Synopsys



Another indicator of the momentum building around the RISC-V ecosystem is the entrance of Synopsys into the community. Synopsys will transition their existing ARC CPU IP cores over to the RISC-V ISA and plan to have products available by mid-2024.

Synopsys, as the second largest IP provider behind Arm, brings an extensive product portfolio of IP blocks to the RISC-V community, which can be used to flesh out design using RISC-V CPU cores. As Figure 8 shows, Synopsys is targeting a wide range of applications with the three ARC-V CPU cores they are introducing to the market. This not only adds to the list of available CPU cores designers can take advantage of but also builds confidence in those designers that if they choose a RISC-V CPU core, the company they pick will also be around for the long haul. Synopsys has an extensive track record in the industry as both the leader in the EDA Tools market and the #2 IP provider in the IP market. Their expertise on the tools side of SoC design will be a valuable resource for designers of all types in the years to come.

Effects of AI on RISC-V SoC Designs

While this report does not specifically center on the AI market, it is essential to briefly address this burgeoning technology within the semiconductor industry. The SHD Group underscores the significance of AI as a compelling opportunity for RISC-V-based designs in the foreseeable future, anticipating it to be a primary driving force, not just for RISC-V-based SoCs but for all SoCs in the market for an extended period.

The advent of AI is reshaping the landscape of contemporary silicon design and the utilization of AI functionalities in various applications. A noteworthy aspect of this evolution is the current classification of any chip featuring AI capabilities as an AI device. The SHD Group observed that this categorization stems from the early stages of the market development. As device complexity continues to escalate, architectural definitions become more precise and AI algorithms become more sophisticated, our perceptions of these devices will evolve over time.

Presently, low-complexity devices executing only a limited set of AI functions are deemed cutting-edge. However, as performance enhancements unfold in the coming years, even budget-friendly devices are anticipated to incorporate a diverse array of AI functionalities while maintaining cost-effectiveness. Instances already exist where devices can concurrently perform multiple AI functions at Levels 1 and 2, and this trend is poised to expand in the future.

Figure 6: Different Levels of AI Functionality

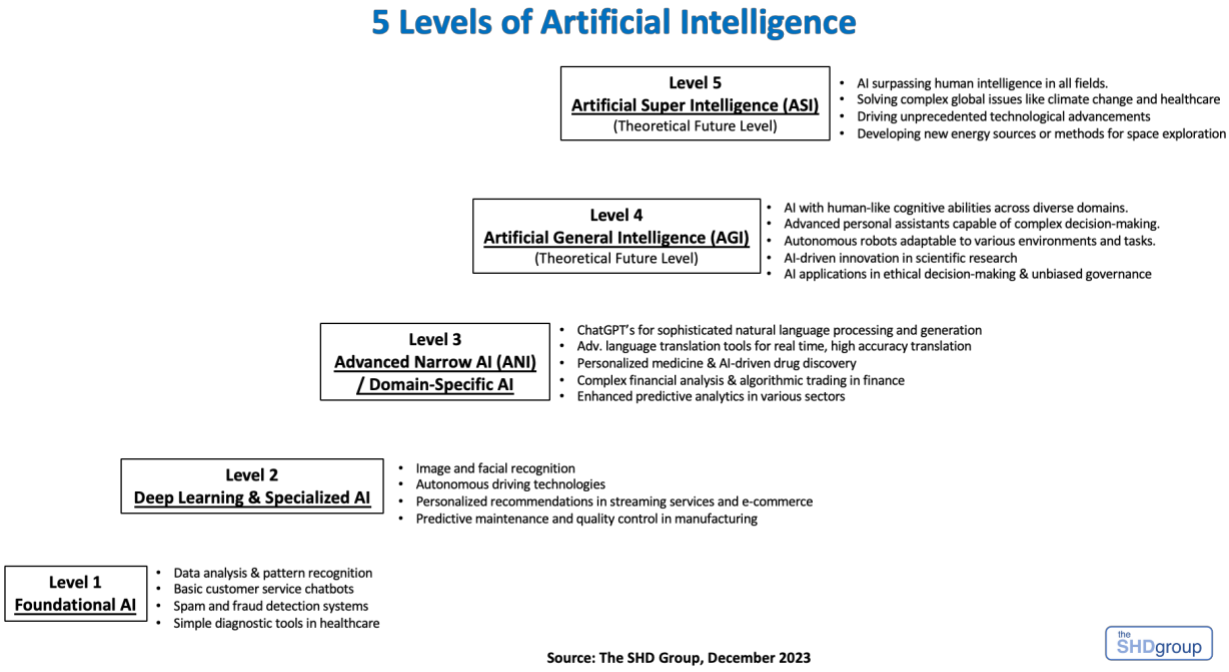


Figure 5 represents The SHD Group's perspective on the potential evolution of AI anticipated over the next several years as a series of levels. In it, we outline existing functions achievable from Level 1 "Foundational" capabilities and project movement towards Artificial Super Intelligence (ASI) at Level 5. There are many ways to try and illustrate the levels in the evolution of AI, but we have created the

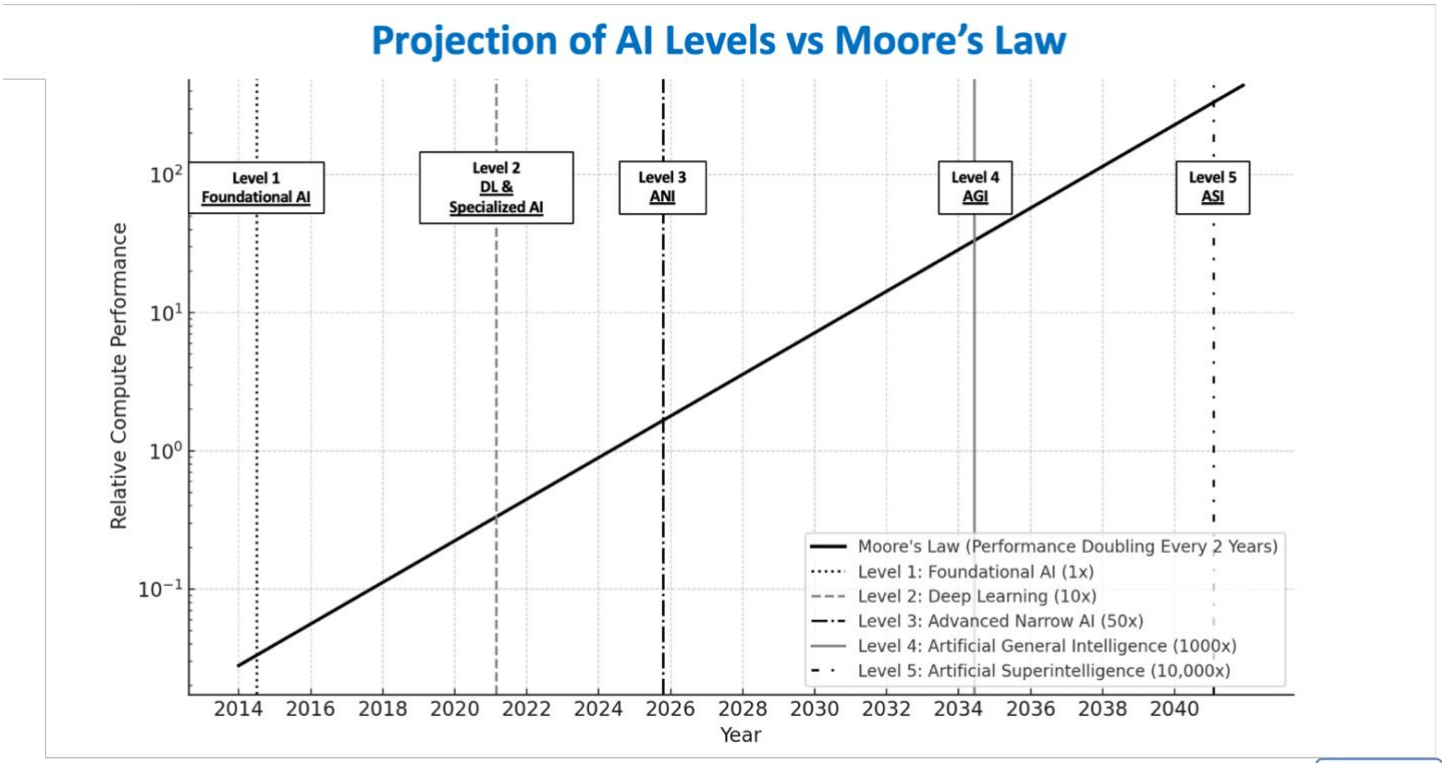
above approach as a somewhat simple way to look at progress – and consider the impact on SoCs in general and RISC-V in particular.

It is at this point the evolution of the technology takes over and helps produce something compelling and potentially extremely useful to people. The largest LLMs today have something approaching 1 trillion parameters in order to accomplish and conduct human-like conversations and responses. This is truly amazing but does not satisfy the market need to be able to run these applications on our personal or mobile devices where the real demand resides.

If these applications can only ever run while connected to the Cloud due to the enormous number of parameters to be executed, the potential benefits of LLMs will be limited – and volumes of SoCs needed constrained.

However, many companies are attempting to pare down the number of parameters needed for their LLM to not be dependent on connection back to the Cloud for execution. If connection to the Cloud becomes unnecessary, this becomes a massive market driver for future SoC devices with AI capabilities integrated into everything from cell phones to appliances.

Figure 7: AI Processing vs. Moore's Law 2014 - 2040



Source: The SHD Group, December 2023

As depicted in Figure 6, an evolutionary trajectory exists, leading to increased complexity and functionality. The SHD Group anticipates that silicon solutions introduced to the market will generally align with this trend, adapting to evolving market demands for AI capabilities. We believe the industry is hovering between Levels 2 and 3 today and can project forward to AGI in the middle of the next decade.

With the introduction of ChatGPT tools by OpenAI in December 2022, AI started becoming a household word. It is estimated that 180M people are utilizing AI through ChatGPT and thus becoming familiar with AI-enabled tools and applications by leveraging the benefits of Generative AI and Large Language Models. This rapid rate at which AI functions like ChatGPT is being integrated into new applications is dramatic and changing the way we use computers as tools. Moreover, this is just the tip of the iceberg – driven by essentially one "product" - ChatGPT. As more and more different types of AI products come to market, we can anticipate new AI-enabled applications that could result in millions more customers using AI. When taken all together, this presents a great incentive for the semiconductor industry to respond with diverse solutions including Domain-Specific AI capabilities.

Qualcomm has already stated they intend to enable their smartphones to run ChatGPT applications. Intel has introduced a new AI processor, Meteor Lake, which incorporates a Neural Processing Unit (NPU) intended to be included in PCs and other computer systems. Microsoft is adding AI functionality, including the ability to run LLMs to their Windows OS and Office applications. At the time of this writing, they have introduced their own LLM, Orca 2, a pair of small language models at 7 billion and 13 billion parameters that hypothetically outperform larger competing alternatives.

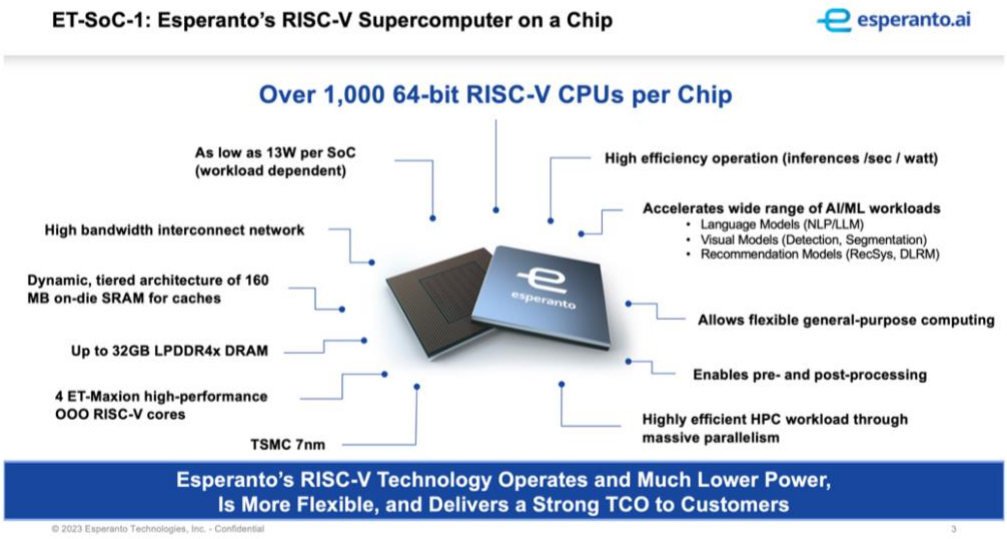
However, no one has yet said what performance level is necessary to run these applications on any device. It is a reasonable assumption that the processing power needed is going to be high. Many new designs and new architectures will also be required to accomplish this.

This is the real reason we have commented on the AI market and the emergence of technologies such as LLMs in this report. These developments represent a great opportunity for RISC-V designs and designers going forward in both market revenues and unit volumes. This is especially true because there are no real "legacy constraints" for AI-enabled applications; it is still an evolving field.

It is likely that new, high-performance silicon will be necessary to enable AI applications in PCs, laptops, tablets, and other computer systems, whether those are based on LLMs or another form of AI. In addition, it is also likely to be deployed into the Industrial, Consumer, and Automotive markets, which are all growth areas for RISC-V.

In keeping with the premise laid out in Figure 10 above, data appliances created specifically for the execution of AI-driven applications are starting to enter the market. We note that Esperanto Technologies is the first company shipping a RISC-V system designed to run many of these Generative AI use cases, LLMs being one of them.

Figure 8: RISC-V Performance Increases with Innovative Architectures, Esperanto Technologies



Esperanto's system is based on their own ET-SoC-1 silicon with 1088 64-bit RISC-V CPU cores. It is targeted at information summarization use cases such as Vicuna LLM, as well as text-to-image OpenJourney and code generation/translation applications such as StarCoder. These systems are scalable up to hosting 16 of their accelerator chips, giving more than 16,000 RISC-V CPU cores per appliance. These systems are targeted at data center and heavy edge opportunities and are a prime example of current RISC-V-based silicon entering the high-performance computing (HPC) market.

Market Challenges and Issues

- Escalating design costs leading to exploration of alternative product development approaches such as chiplets
- Smartphone market challenges with unit shipment decline due to supply chain disruptions and parts shortages, albeit with positive reception for 5G-enabled phones
- Continued consolidation in the semiconductor and systems markets, potentially influencing further acquisitions and market shifts.
- Slowdown in the PC market, post-pandemic work-at-home upgrades, particularly impacting desktop sales.
- Challenges in the Automotive sector due to higher prices, parts shortages and extended lead times, with potential for of sustained shortages.
- Evolving business guidelines and restrictions for doing business in China imposed by the Department of Commerce may add further complications to supply chain dynamics.
- Concerns over regional conflicts potentially impacting broader economies and supply chains.

The SHD Group believes the positive drivers outweigh the negative drivers in the semiconductor market today and signal continued growth in the years ahead. Assuming regional conflicts remain manageable and energy prices stay consistent with the world economy relatively stable, and inflation does not reignite, the semiconductor market should see a reasonable growth year in 2024 and beyond.

III. SoC Market Analysis

General Assumptions

1. The RISC-V ecosystem continues to grow and be fleshed out with additional software support and EDA tool support.
2. SoC designers continue to gain confidence that if they adopt RISC-V as part of their design solution, the requisite software, tools, and IP block will be available.
3. RISC-V CPU cores will share space with other competing CPU cores on the same die.
4. Slowly, as more powerful RISC-V cores become available, they will be adopted to perform higher complexity tasks on contemporary SoCs.
5. Currently, RISC-V will be tasked with providing the following functionality: deeply embedded Finite State Machine, MCU functions, co-processor functions, and applications processor functions – a truly heterogeneous mixture.

Table 1: Market Revenues for all RISC-V SoCs by Application 2021–2030

											CAGR %
B Dollars	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Industrial	$0.0	$0.0	$0.2	$0.3	$0.5	$0.7	$1.0	$1.3	$1.8	$2.5	47.9%
Automotive	$0.1	$0.1	$0.5	$0.9	$1.6	$2.3	$2.9	$3.7	$4.9	$8.7	52.5%
Networking	$0.0	$0.1	$0.4	$1.3	$2.4	$3.2	$4.4	$6.0	$8.4	$12.7	62.1%
Computer	$0.3	$0.5	$2.1	$4.1	$7.4	$9.8	$13.0	$16.7	$22.4	$33.5	48.8%
Consumer	$0.3	$0.8	$2.8	$4.4	$7.2	$10.0	$13.2	$17.1	$23.2	$32.9	42.3%
Other	$0.0	$0.1	$0.2	$0.3	$0.4	$0.7	$0.9	$1.2	$1.8	$2.4	40.4%
Total	$0.7	$1.6	$6.1	$11.3	$19.5	$26.6	$35.5	$46.1	$62.5	$92.7	47.4%
Percent Growth		126.8%	276.8%	84.0%	72.4%	36.7%	33.4%	29.9%	35.7%	48.2%	

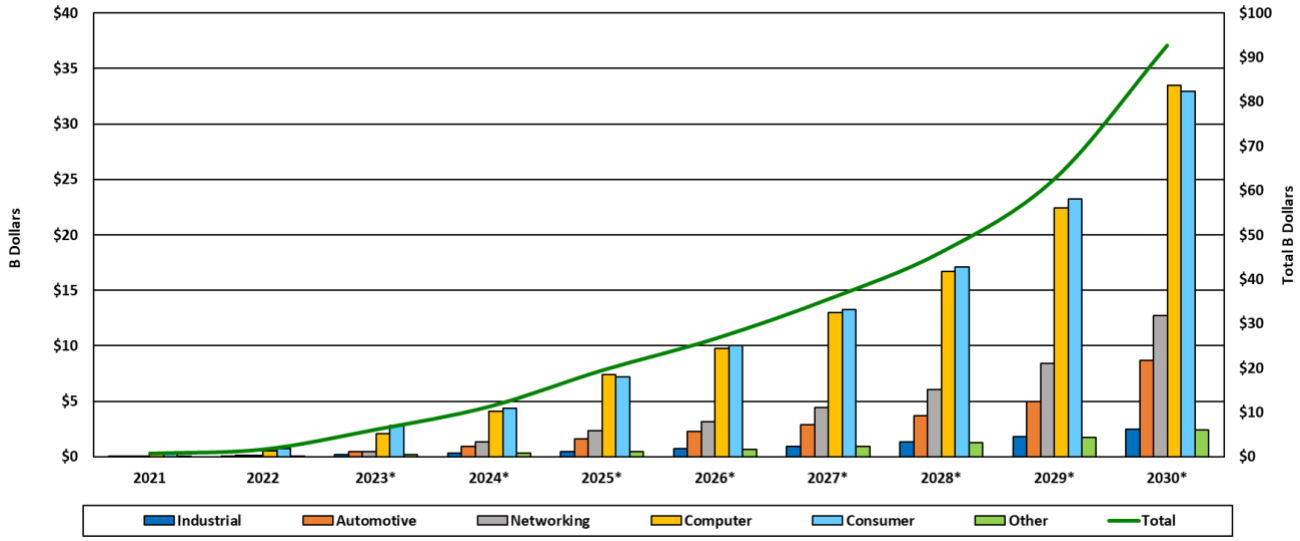
***Forecast** **Source: The SHD Group, January 2024**

Total RISC-V SoC market revenues reached $6.1B in 2023, a growth of 276.8% over 2022 and is forecast to grow to $92.7B by 2030, a CAGR of 47.4%. The RISC-V SoC market, in general, is characterized by the adoption of RISC-V CPU cores into many already-existing SoCs, so the ecosystem needed to use these devices is already built out and aiding in a fast adoption rate. It is also important to remember that all of these markets are coming from very small base years, resulting in very high CAGRs.

- The Consumer segment is the largest category at $2.8B in 2023, a growth of 268.5% over 2022. It is forecast to reach $32.9B by 2030, a CAGR of 42.3%, and driven by all cell phones, UHDTVs, game consoles, and other high-value consumer systems.
- The Computer segment is the second highest category, reaching $2.1B in 2023, a growth of 281.4% over 2022. It is forecast to grow to $33.5B by 2030, a CAGR of 48.8% over the forecast period of the identified applications.

- The Automotive segment is undergoing a complete transformation as ADAS and other AI functionality is being added along with the electrification of vehicles in general. This market was $0.45B in 2023 and grew 294.1% over 2022. It is forecast to reach $8.7B by 2030, a CAGR of 52.5%
- The Networking market represents the 4th largest category and reached $0.43B in 2023, growing 308.3% over 2022. It is forecast to reach $12.7B by 2030, driven by networking switches and infrastructure build-out, with a CAGR of 62.1%.
- The Other category has the 5th lowest growth rate and is projected to reach $2.4B by 2030, a CAGR of 40.4%.
- The Industrial segment is the smallest market, reaching $0.2B in 2023, a growth of 227.9% over 2022 and is forecast to reach $2.5B by 2030, a CAGR of 47.9%.

Figure 9: Market Revenues for All RISC-V SoCs by Application 2021–2030



***Forecast**

Source: The SHD Group, January 2024

Table 2: Market Unit Shipments for all RISC-V SoCs by Application 2021–2030

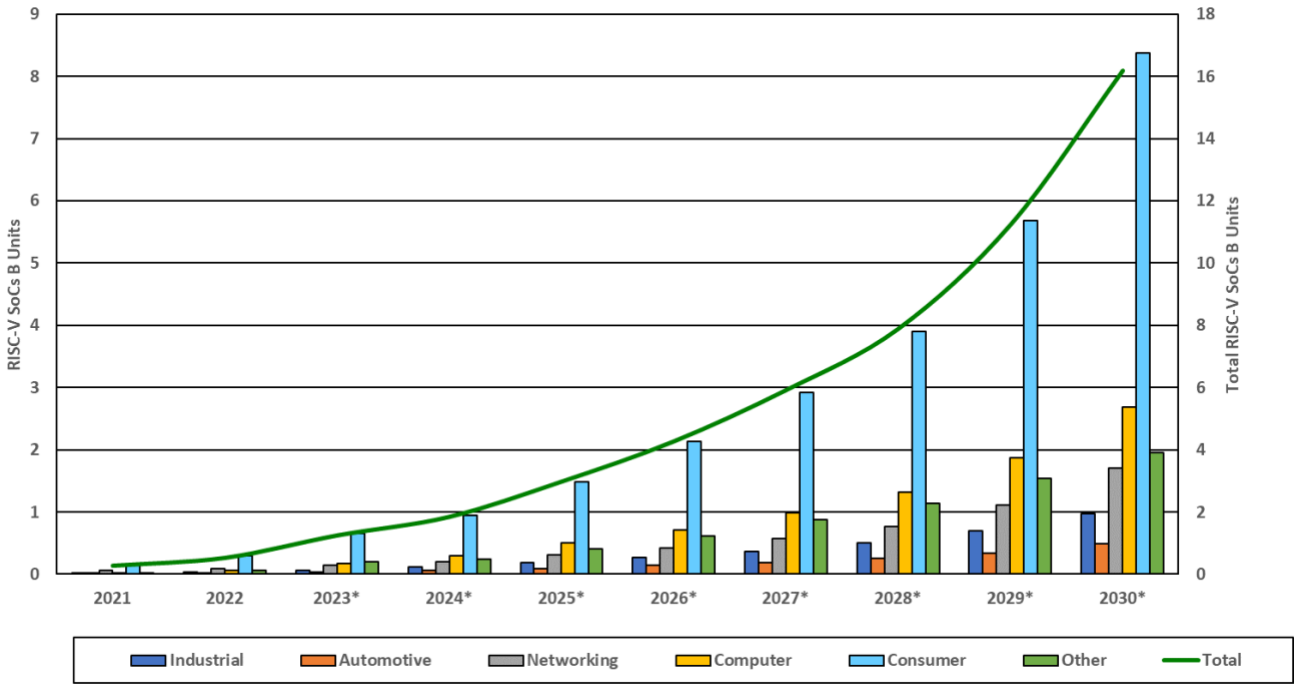
											CAGR %
M Units	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Industrial	16.7	31.8	64.0	118.9	186.4	268.3	368.7	510.0	693.5	969.9	47.5%
Automotive	2.2	4.9	29.3	55.2	92.2	139.4	193.0	257.6	345.6	489.2	49.5%
Networking	68.0	89.1	137.9	197.3	312.7	420.2	577.9	771.2	1,104.6	1,705.1	43.2%
Computer	22.7	55.5	169.1	293.7	510.4	710.5	989.0	1,313.0	1,868.3	2,692.1	48.5%
Consumer	156.7	295.7	659.4	944.0	1,478.5	2,128.3	2,926.1	3,899.2	5,684.9	8,371.1	43.8%
Other	17.9	59.4	201.1	246.5	407.3	612.5	870.9	1,142.9	1,514.9	1,954.0	38.4%
Total	284.3	536.4	1,260.8	1,855.6	2,987.6	4,279.2	5,925.5	7,893.9	11,211.8	16,181.5	44.0%
Percent Growth		88.7%	135.1%	47.2%	61.0%	43.2%	38.5%	33.2%	42.0%	44.3%	

***Forecast** **Source: The SHD Group, January 2024**

Total SoC market unit shipments reached 1.3B units in 2023, a growth of 134.5% over 2022 and is forecast to grow to 16.2B units by 2030, a CAGR of 44%. The SoC market in general is characterized by rising complexity levels driven, in part, by the introduction of AI and continuing increases in connectivity and computing performance requirements. It is also important to remember that all these markets are coming from very small base years, resulting in very high CAGRs.

- The Consumer segment is the largest category at 0.7B in 2023, a growth of 123% over 2022. It is forecast to reach 8.4B units by 2030, a CAGR of 43.8%, and driven by all cell phones, UHDTVs, wearables, and other high-volume consumer systems.
- The Other category has the 2nd largest growth rate and is projected to reach 2.0B units by 2030, a CAGR of 38.7%.
- The Computer segment is the 3rd highest category, reaching 0.2B units in 2023, a growth of 204.8% over 2022. It is forecast to grow to 2.7B units by 2030, a CAGR of 48.5% over the forecast period of the identified applications.
- The Networking market represents the 3rd smallest category and reached 0.1B units in 2023, growing 54.8% over 2022. It is forecast to reach 1.7B units by 2030, driven by networking
- The Industrial segment is the 2nd smallest market, reaching 0.1B units in 2023, a growth of 101.4% over 2022 and is forecast to reach 1.0B units by 2030, a CAGR of 47.5%.
- The Automotive segment is undergoing a complete transformation as ADAS and other AI functionality is being added along with the electrification of vehicles in general. This market was 0.03B units in 2023 and grew 496.6% over 2022 as a great deal of new functionality is being added to vehicles of all types. It is forecast to reach 0.5B units by 2030, a CAGR of 49.4% switches and infrastructure build-out, with a CAGR of 43.2%.

Figure 10: Market Unit Shipments for All RISC-V SoCs by Application 2021–2030

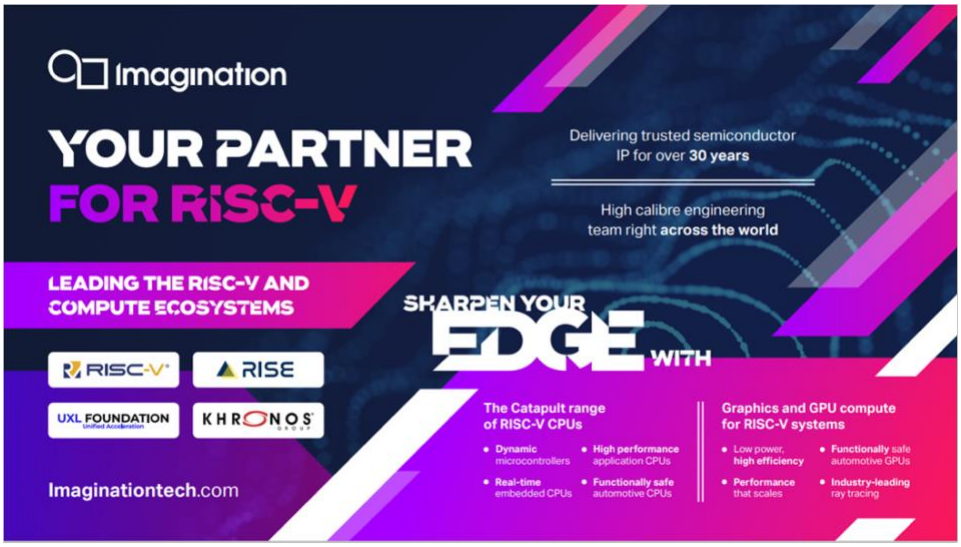


***Forecast** **Source: The SHD Group, January 2024**

As time passes, more IP vendors are joining in support of RISC-V designs, aiding in the growth of the RISC-V ecosystem, a sure sign of industry support for this ISA.

The integration of RISC-V specifications into non-RISC-V specific products represents a significant trend in the tech industry, underscoring the versatile and open-source nature of the RISC-V architecture. This phenomenon is driven by the need for more customizable, efficient, and cost-effective solutions in various technological domains.

Figure 11: Imagination Technologies Enters the RISC-V Arena with Innovative CPUs



Imagination Technologies is a long-established IP vendor in the semiconductor market for GPU IP and has now a force in the RISC-V CPU cores. They have introduced Catapult, a RISC-V CPU product line designed from the ground up for deployment in key applications and configurable for any use. Catapult CPUs are designed for various market applications and next-generation control, compute, and heterogeneous compute needs.

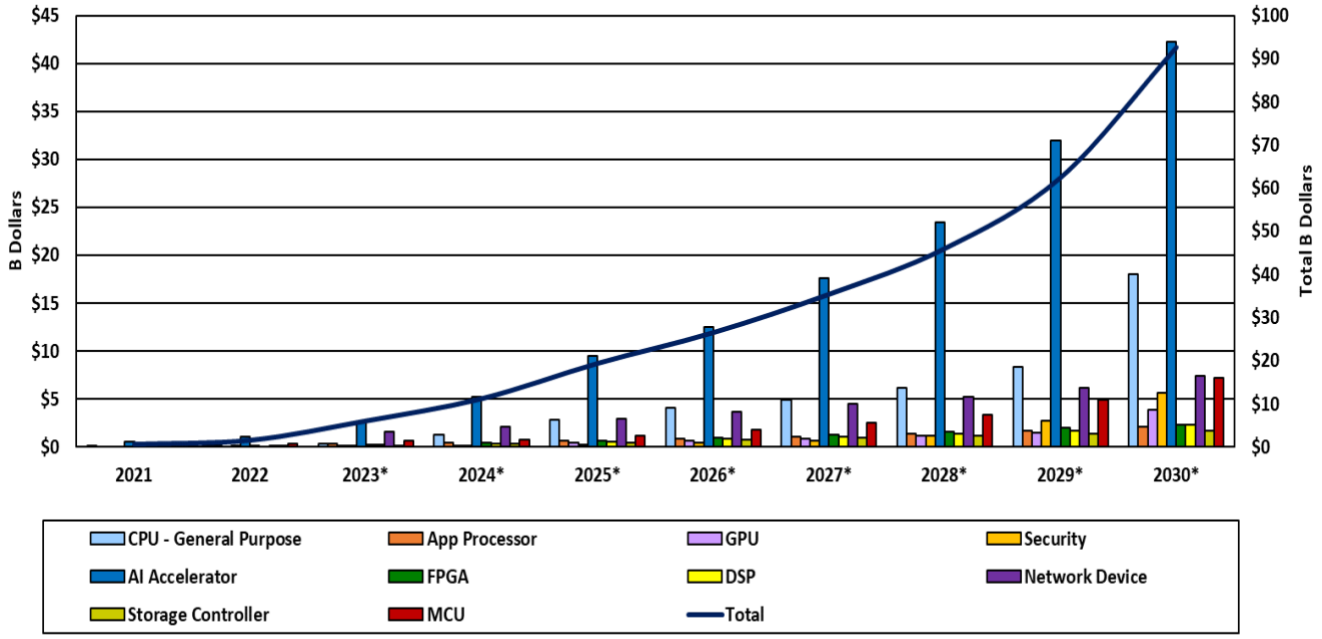
Configurability and customization are key attributes in the emergence of RISC-V CPU cores in the market today. They provide a much-needed series of alternative choices that SoC designers can take advantage of and allow for the creation of domain-specific solutions at most application levels. The introduction of these capabilities also bolsters the trend towards heterogeneity in SoCs across a wide range of end applications.

Total RISC-V SoC Market Metrics and Analysis by Application and Device Type

This section deals with the revenues and shipments for RISC-V-powered SoCs by device type and end application category.

Please Note: Many of the CAGRs for the individual part types and the markets they are targeted for in this section can be very high, driven by the fact that they are all coming from very small base years.

Figure 12: Total RISC-V SoC Market Revenues for all Applications 2021-2030



***Forecast** **Source: The SHD Group, January 2024**

The total market for RISC-V SoCs was $1.63B in 2022 and is forecast to reach $6.1B in 2023, a growth of 276.8% over 2022 and is projected to reach $92.7B by 2030, a CAGR of 47.4%.

- The total penetration of RISC-V SoCs in 2022 was 0.8% and is forecast to reach 2.6% in 2023. By 2030, the penetration is projected to reach 22.3%.

Within the RISC-V SoC market, the top three device types are:

- AI Accelerators were the largest type of RISC-V SoC at $1.07B in 2022 and are forecast to reach $2.6B in 2023, a growth of 136.6%. By 2030, this part type is projected to reach $42.2B, a CAGR of 49.2%.
- The second largest SoC category is MCU SoCs, which reached $0.360B in 2022 and are forecast to grow to $0.615B in 2023, a growth rate of 77.9%. In 2030, this part type is projected to reach $7.2B, a CAGR of 42.0%.

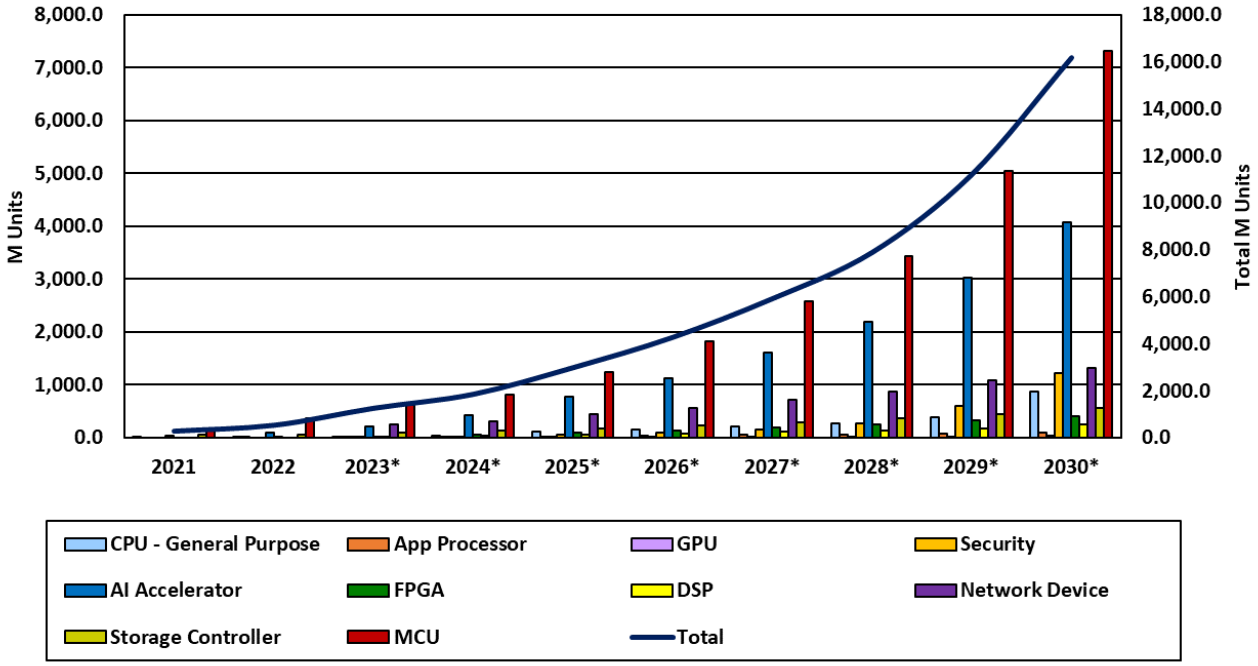
- The third largest SoC category is Application Processors (smartphones) SoCs, which reached $0.148B in 2022 and are forecast to grow to $0.344B in 2023, a growth rate of 132.3%. In 2030, this part type is projected to reach $2.1B, a CAGR of 29.3%.

Figure 13: Security Solutions for RISC-V Software, Emproof Embedded Security

Emproof specializes in security solutions for embedded systems. The Nyx product provides advanced security, to protect algorithms and data across the entire SoC, safeguarding against reverse engineering and exploitation attacks. This makes Emproof Nyx particularly effective for RISC-V systems, addressing the unique challenges of this dynamic landscape. Nyx uses minimal resources and doesn't require access to customer or application source code, making it ideal for protecting RISC-V SoCs from various threats while preserving intellectual property and revenue streams. Emproof's role in the RISC-V community underscores its commitment to robust and adaptable embedded system security.

The always-connected world of our society depends on user systems being secured from outside attacks and bad actors at all levels. This includes incorporating robust security functions on SoCs in the system. Emproof adds another layer of security by protecting the application software being executed on the devices. They are providing a very important additional line of defense against unwanted intrusions.

Figure 14: Total RISC-V SoC Market Unit Shipments for all Applications 2021-2030



***Forecast**

Source: The SHD Group, January 2024

The total market for RISC-V SoCs was 536.4M units in 2022 and is forecast to reach 1,260.8M units in 2023, a growth of 135.0% over 2022 and is projected to reach 16.181B units by 2030, a CAGR of 44.0%.

- The penetration of RISC-V SoCs in 2022 was 1.9% and is forecast to reach 3.9% in 2023. By 2030, the penetration is projected to reach 22.3%.

Within the Other category, the top three device types are:

- The largest SoC category is MCU SoCs which reached 366.5M units in 2022 and are forecast to grow to 617.4M units in 2023, a growth rate of 68.5%. In 2030, this part type is projected to reach 7.3B units, a CAGR of 42.4%.
- AI Accelerators were 95.3M units in 2022 and are forecast to reach 217.8M units in 2023, a growth of 128.6%. By 2030, this part type is projected to reach 4.1B units, a CAGR of 51.9%.
- Storage Controllers are the third largest part type and had shipments of 67.4M units in 2022 but are forecast to grow to 97.5M units in 2023. They are forecast to reach 558.0M units by 2030, a CAGR of 28.3% over the forecast period of the identified applications.

Table 3: Penetration of RISC-V SoCs by Revenue by Device Type 2021–2030

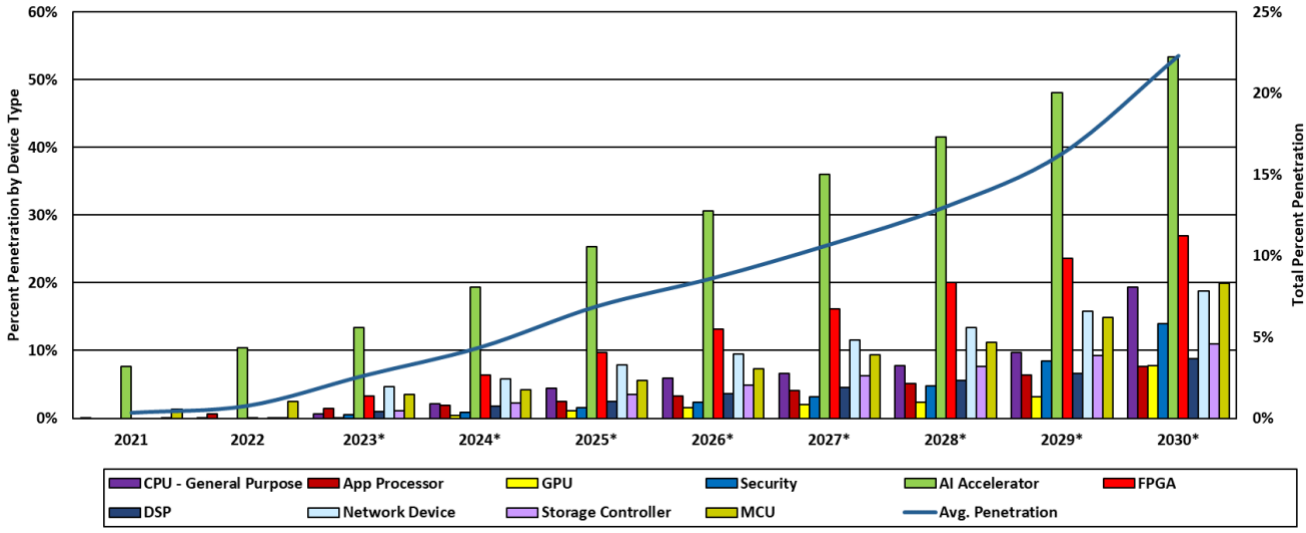
Percentage	2021	2022	2023*	2024*	2025*	2026*	2027*	2028*	2029*	2030*
CPU - General Purpose	0%	0.1%	0.7%	2.2%	4.4%	5.9%	6.6%	7.7%	9.7%	19.3%
App Processor	0%	0.6%	1.5%	1.9%	2.5%	3.2%	4.0%	5.1%	6.3%	7.7%
GPU	0%	0%	0.1%	0.4%	1.0%	1.5%	1.9%	2.3%	3.1%	7.6%
Security	0%	0%	0.6%	0.8%	1.6%	2.3%	3.2%	4.8%	8.4%	13.9%
AI Accelerator	7.6%	10.3%	13.4%	19.4%	25.4%	30.6%	36.0%	41.5%	48.1%	53.4%
FPGA	0%	0.1%	3.3%	6.4%	9.8%	13.2%	16.1%	20.1%	23.6%	26.9%
DSP	0%	0%	1.0%	1.7%	2.4%	3.6%	4.5%	5.6%	6.6%	8.8%
Network Device	0%	0%	4.7%	5.8%	7.9%	9.5%	11.6%	13.4%	15.8%	18.8%
Storage Controller	0%	0%	1.1%	2.2%	3.5%	4.9%	6.2%	7.7%	9.2%	10.9%
MCU	1.3%	2.5%	3.5%	4.2%	5.6%	7.3%	9.3%	11.2%	14.9%	19.9%
Avg. Penetration	**0.4%**	**0.8%**	**2.6%**	**4.4%**	**6.9%**	**8.6%**	**10.7%**	**13.0%**	**16.3%**	**22.3%**

***Forecast** **Source: The SHD Group, January 2024**

Table 3 and Figure 14 show the penetration of RISC-V SoCs by revenue in the device types for all applications profiled in this report. These values are calculated by looking at the revenues for all SoCs and then totaling the revenues for SoCs with RISC-V CPU cores and dividing one group by the other to arrive at the penetration given in percent.

- Overall, The SHD Group projects that SoCs with RISC-V CPU cores will grow to penetrate 22.3% of all SoCs by 2030, powered by several different SoC types.
- AI Accelerators are forecast to reach the highest penetration out of all the device types The SHD Group analyzed. In 2022, the penetration was 10.3% and is forecast to grow to 13.4% in 2023. By 2030, we forecast the penetration of RISC-V into AI Accelerators to be 53.4%
    - This is not hard to understand since AI functionality is being added to almost every application and SoC solution for those applications.
- The device type with the second highest penetration in 2022 was the FPGA, reaching 0.1% and forecast to grow to 3.3% in 2023. By 2030, we expect the penetration of RISC-V into the FPGA market to reach 26.9%.
- There are two reasons for this. FPGAs have a higher ASP than most other SoCs profiled in this report. Also, most of the RISC-V usage in FPGAs will come from soft IP cores, which can be added at any time, even after the device's initial configuration. This is a valued feature of FPGA programmability and re-programmability.
- MCUs with RISC-V CPU cores have the 3rd highest penetration, with 2.5% in 2022, and are forecast to grow to 3.5% in 2023. By 2030, we expect RISC-V cores in MCUs to reach 19.9%.

Figure 15: Penetration of RISC-V SoCs by Revenue by Device Type 2021–2030



*Forecast

Source: The SHD Group, January 2024

Table 4: Penetration of RISC-V SoCs by Unit Shipments by Device Type 2021–2030

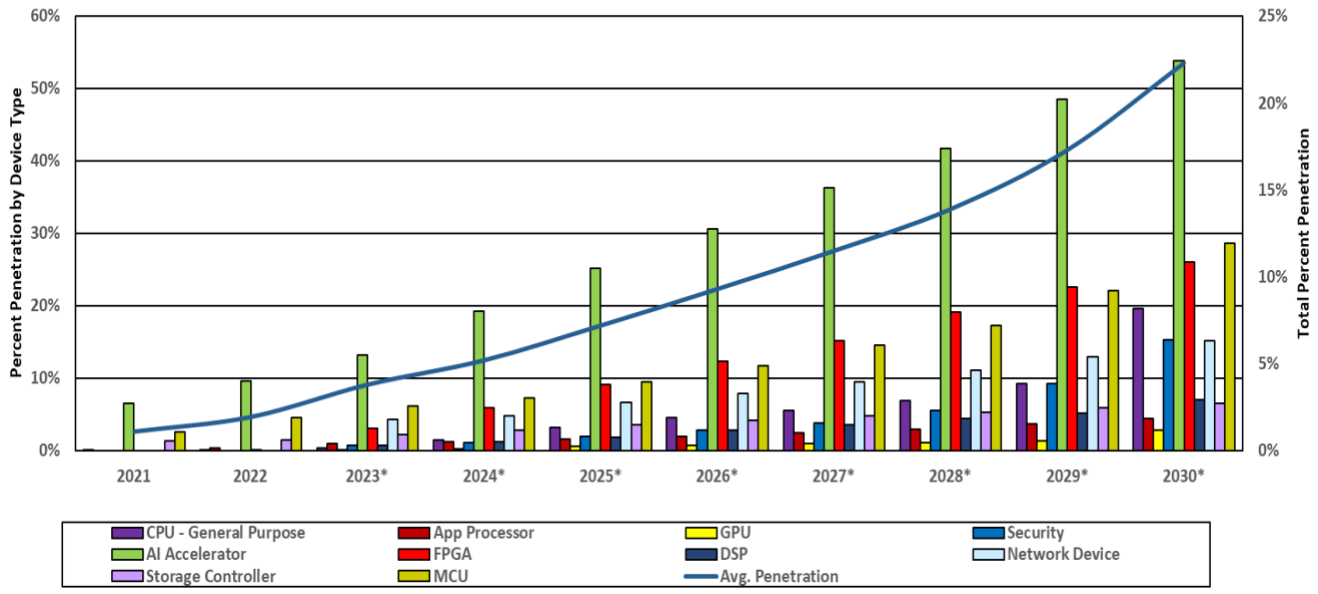
Percentage	2021	2022	2023*	2024*	2025*	2026*	2027*	2028*	2029*	2030*
CPU - General Purpose	0%	0%	0.4%	1.4%	3.1%	4.6%	5.6%	6.9%	9.2%	19.6%
App Processor	0%	0.4%	0.9%	1.2%	1.5%	1.9%	2.4%	3.0%	3.7%	4.4%
GPU	0%	0%	0.1%	0.2%	0.5%	0.8%	0.9%	1.1%	1.3%	2.8%
Security	0%	0%	0.8%	1.1%	2.0%	2.8%	3.8%	5.5%	9.3%	15.2%
AI Accelerator	6.6%	9.6%	13.2%	19.3%	25.2%	30.5%	36.2%	41.7%	48.5%	53.8%
FPGA	0%	0.1%	3.0%	5.9%	9.1%	12.4%	15.2%	19.1%	22.5%	26.0%
DSP	0%	0%	0.7%	1.3%	1.8%	2.7%	3.5%	4.4%	5.2%	7.0%
Network Device	0%	0%	4.2%	4.8%	6.6%	7.8%	9.5%	11.0%	12.9%	15.1%
Storage Controller	1.4%	1.5%	2.2%	2.8%	3.5%	4.1%	4.7%	5.3%	5.8%	6.5%
MCU	2.6%	4.6%	6.1%	7.3%	9.5%	11.7%	14.5%	17.2%	22.1%	28.6%
Avg. Penetration	**1.1%**	**1.9%**	**3.8%**	**5.2%**	**7.2%**	**9.3%**	**11.5%**	**13.9%**	**17.3%**	**22.3%**

***Forecast** **Source: The SHD Group, January 2024**

Table 4 and Figure 15 show the penetration of RISC-V SoCs by revenue in the device types for all applications profiled in this report. These values are calculated by looking at the unit shipments for all SoCs and then totaling the unit shipments for SoCs with RISC-V CPU cores and dividing one group by the other to arrive at the penetration given in percent.

- Overall, The SHD Group projects that SoCs with RISC-V CPU cores will grow to penetrate 22.3% of all SoCs by 2030, powered by several different SoC types.
- AI Accelerators are forecast to reach the highest penetration out of all the device types The SHD Group analyzed. In 2022, the penetration was 9.6% and is forecast to grow to 13.2% in 2023. By 2030, we forecast the penetration of RISC-V into AI Accelerators to be 53.8%
    - This is not hard to understand since AI functionality is being added to almost every application and SoC solution for those applications.
- The device type with the second highest penetration in 2022 was the FPGA, reaching 3.0% and forecast to grow to 5.9% in 2023. By 2030, we expect the penetration of RISC-V into the FPGA market to reach 26.0%.
- There are two reasons for this. Lower-cost FPGAs ship in higher volumes than the higher-cost parts. Even the low-end FPGAs can perform AI Acceleration in the right application. Also, most of the RISC-V usage in FPGAs will come from soft IP cores, which can be added at any time, even after the device's initial configuration. This is a valued feature of FPGA programmability and re-programmability.
- MCUs with RISC-V CPU cores have the 3rd highest penetration, with 4.6% in 2022, and are forecast to grow to 6.1% in 2023. By 2030, we expect RISC-V cores in MCUs to reach 28.6%.

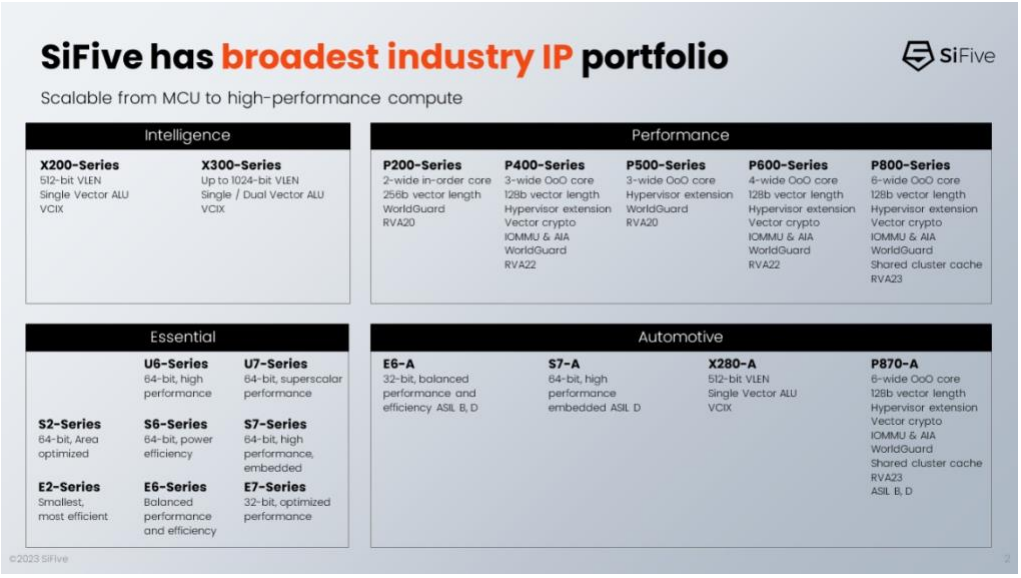
Figure 16: Penetration of RISC-V SoCs by Unit Shipments by Device Type 2021-2030



***Forecast**

Source: The SHD Group, January 2024

Figure 17: Increasing RISC-V Product Options, Courtesy SiFive



SiFive, a leader in the RISC-V revolution, delivers high-performance compute density, crucial for modern workloads, powers advanced consumer devices and wearables. SiFive has contributed significantly to the increasing penetration of RISC-V SoCs as depicted in Figure 15, which illustrates growth in future unit shipments by device type from 2021 to 2030. As a pioneer and leading advocate of the RISC-V architecture, SiFive's role has been pivotal in this expansion. Their influence helps shape the future direction of the RISC-V ecosystem. SiFive continues to increase their product portfolio with new announcements and further expands the adoption of RISC-V into end applications. SiFive is a leading player in the RISC-V market, and we think that the company will continue to have a major impact on overall growth.

IV. RISC-V SoCs by Functionality 2021 - 2030

The next section looks at what functions RISC-V CPU cores will be tasked with performing in RISC-V-powered SoCs. The functions that The SHD Group profiled for this market analysis are:

- Deeply embedded (e.g., Finite State Machine)
- MCU
- Co-processor
- Host Processor

By doing the analysis in this manner, we are no longer trying to place a device in a specific CPU-driven category, reasoning that most, if not all, SoCs going forward will have more than one type of CPU core from multiple vendors. RISC-V International already says that many high-end multicore SoCs can have up to 10-12 different ISAs, indicating the usage of multiple types of CPU cores today. These cores are likely performing the functions we have identified that are relevant to the market now and into the future.

The way to interpret this data is to understand that the part types we have profiled for the report could have one or more of these functions' resident. So, the revenue numbers and the unit volumes are not additive but should be considered as stand-alone data points for each functional type.

Deeply embedded / Finite State Machines (FSM)
Finite State Machines (FSM) are used on every SoC today. In contemporary SoCs, an FSM is a digital circuit designed to execute specific sequences of operations or control the behavior of various parts of the system based on a finite number of defined states. These states can represent different modes of operation or conditions within the chip.

FSMs in SoCs are crucial for managing the complex interactions between different hardware components, facilitating efficient control and coordination within the chip's architecture. They play a fundamental role in controlling the system's behavior, ensuring proper functionality, and optimizing the performance of the SoC.

FSMs can range from the very simple to moderately complex depending on the SoC architecture they are designed into and the task they are performing in the silicon. In addition, there can be many instantiations of an FSM in SoCs today and can number in the hundreds on very complex parts.

In this analysis, we looked at what were likely candidates to use RISC-V-based FSMs. Table 5 and Figure 17 show this data.

SoCs for Consumer applications see the highest concentration of FSMs due to the very large unit volumes of this type of SoC. The Computer and Networking segments see the second and third highest usage of the FSM function.

For this analysis, we counted the device revenues of SoCs where the use of RSIC-V-based FSMs occurred. We counted the entire revenue generated by shipment of the part into the markets, so we are not counting the IP revenue of the RISC-V-based FSM, but the device ASP times the units being shipped as

the determining factor for counting the revenues. In this case, an SoC could have many FSMs on it and was counted the same as if it had only one FSM.

MCU

In the context of SoCs, an MCU function refers to the incorporation of a microcontroller unit (MCU) within the larger integrated circuit design. This involves integrating a microcontroller along with its associated components directly onto the same chip that houses other functionalities. This integration aims to consolidate multiple features into a single chip, reducing the overall size, power consumption, and cost while enhancing efficiency and performance.

This integration is common in a wide range of devices, including IoT (Internet of Things) devices, smart appliances, automotive systems, industrial controllers, and many other embedded systems where compactness, low power consumption, and cost-effectiveness are essential.

The Consumer segment sees the largest use of RISC-V-based MCUs, followed by Networking and Computing. The other segment also has a large usage.

In addition, the Automotive segment is expected to see a large and growing usage of RISC-V-based MCUs.

Co-processor

In SoCs, a co-processor refers to a specialized processing unit that operates alongside the main processor (CPU) within the same integrated circuit. Co-processors are designed to perform specific tasks or computations more efficiently than the main CPU, thereby offloading certain types of processing to improve overall system performance and efficiency.

The integration of co-processors within an SoC architecture contributes to the overall efficiency, performance, and capabilities of the system by distributing workload and utilizing specialized hardware for specific tasks, thus improving the user experience in various applications ranging from mobile devices to high-performance computing systems.

Consumer devices are incorporating AI functionality and are a driver for the use of co-processors. In this segment, their use in high-volume systems like smartphones, UHDTV, and other large-volume systems generates a large portion of the unit shipments.

Host Processor

An applications processor refers to a specific type of processor core within the SoC that is primarily designed to handle general-purpose computing tasks and run various applications and software.

Applications processors are commonly found in a diverse range of devices, including smartphones, tablets, smart TVs, automotive infotainment systems, IoT devices, and other embedded systems where running software applications and handling complex tasks are necessary.

The integration of an applications processor within an SoC allows for a comprehensive solution on a single chip, enabling efficient and streamlined execution of software applications and facilitating seamless user experiences across various devices and platforms.

Many of the systems mentioned above are consumer systems, and their high unit volumes help drive the units in the analysis.

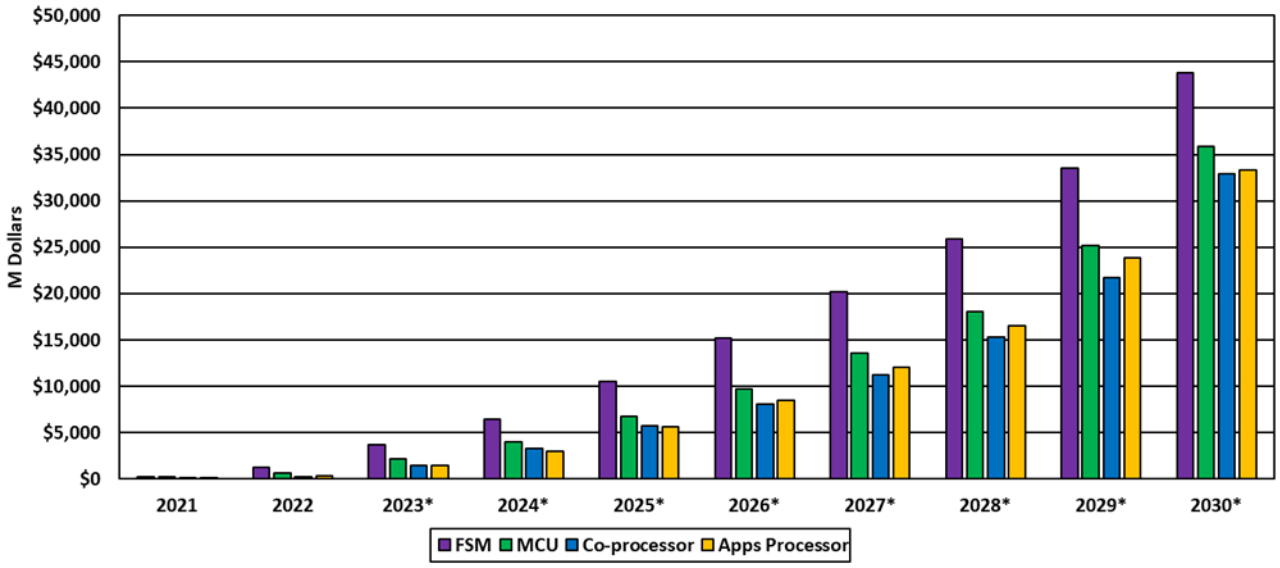
Table 5: RISC-V SoC Revenues by Functionality Category , 2021 - 2030

M Dollars	2021	2022	2023*	2024*	2025*	2026*	2027*	2028*	2029*	2030*
FSM	$213.2	$1,277.6	$3,657.0	$6,456.4	$10,523.6	$15,230.1	$20,180.9	$25,928.0	$33,497.7	$43,763.9
MCU	$258.1	$626.7	$2,195.2	$4,036.5	$6,725.9	$9,718.6	$13,555.4	$18,073.7	$25,150.6	$35,899.5
Co-processor	$166.3	$287.4	$1,499.3	$3,260.3	$5,727.1	$8,045.3	$11,254.0	$15,322.4	$21,731.5	$32,937.7
Host Processor	$167.8	$384.9	$1,453.9	$2,991.9	$5,612.4	$8,483.9	$12,038.5	$16,508.0	$23,830.4	$33,320.0

Forecast* **Source: The SHD Group, January 2024**

In terms of revenue, the FSM function is the largest category in 2023, followed by the MCU function. By 2030, FSM is still the largest functional category followed more closely by the other three functional categories. The gap between them closes as more higher-complexity SoCs ship into the market.

Figure 18: RISC-V SoC Revenues by Functionality Category, 2021-2030



Forecast* **Source: The SHD Group, January 2024**

V. RISC-V SoC Design Starts

The SHD Group has analyzed RISC-V design starts in two ways – by process geometry, from 40nm to 2nm, and by device type for the SoCs profiled in this report. We have also consolidated the design starts by application category: Industrial, Automotive, Networking, Computer, Consumer, and Other.

Given the heterogeneous nature of the SoC market today, we are listing any SoC design with any RISC-V element. So, there will be designs here where the CPU cores would primarily be non-RISC-V in nature or solely RISC-V in nature. We are attempting to capture the uptake and usage of RISC-V in SoCs of all types from any vendor and in any of the profiled applications in this report.

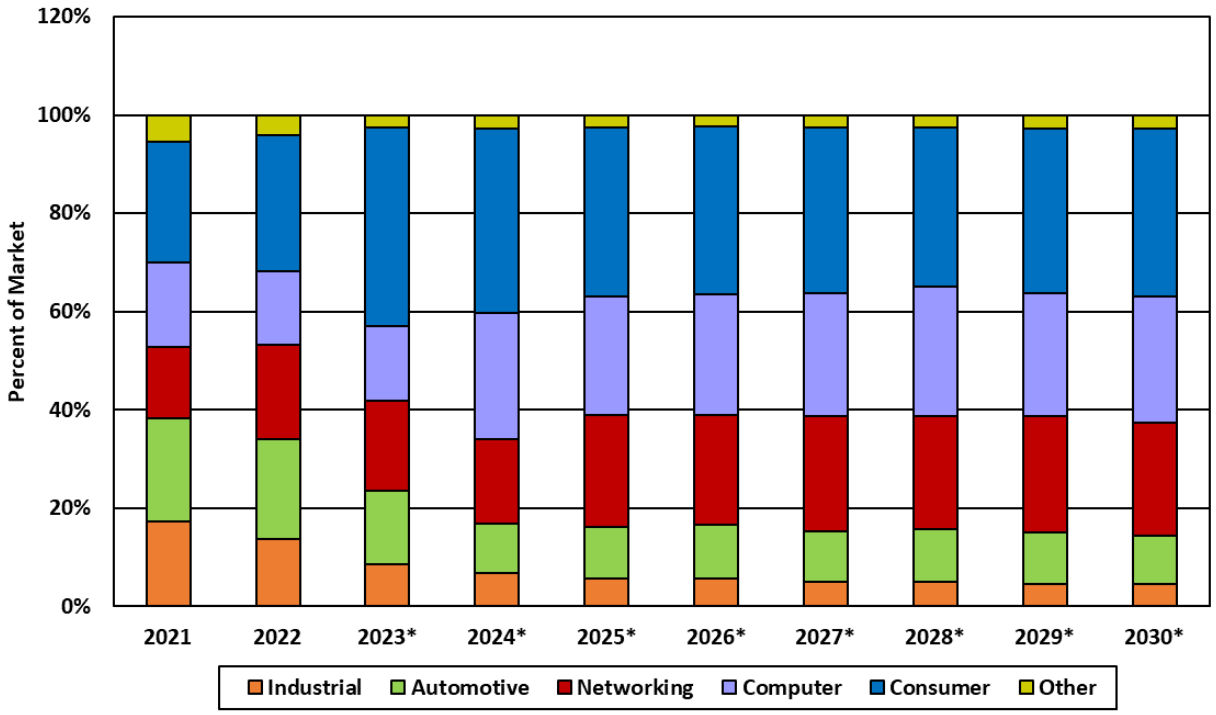
Table 6: RISC-V SoC Design Starts Share of Market by end Application Category

Design Start % Share	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***
Industrial	17.3%	13.6%	8.5%	6.7%	5.6%	5.7%	4.9%	5.0%	4.5%	4.5%
Automotive	20.9%	20.5%	15.0%	10.2%	10.6%	10.9%	10.3%	10.8%	10.5%	9.8%
Networking	14.5%	19.0%	18.4%	17.2%	22.6%	22.4%	23.5%	22.9%	23.7%	22.9%
Computer	17.3%	15.0%	15.2%	25.5%	24.2%	24.5%	25.0%	26.3%	25.0%	25.8%
Consumer	24.5%	27.8%	40.3%	37.7%	34.3%	34.3%	33.8%	32.5%	33.5%	34.1%
Other	5.5%	4.0%	2.6%	2.7%	2.6%	2.3%	2.6%	2.6%	2.7%	2.8%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Forecast* **Source: The SHD Group, January 2024**

- Consumer applications are forecast to have the highest market share with 40.3% of design starts in 2023 and are projected to retain the highest market share of designs by 2030 at 34.1%
- Networking applications are forecast to have the second-highest market share of design starts in 2023 at 18.4% and are projected to reach a 22.9% share of designs by 2030.
- Computer applications are forecast to have the third-highest share of design starts in 2023 at 15.2% and are projected to have a 25.8% share of designs by 2030.
- Automotive applications are forecast to have the fourth-highest share of design starts in 2023 at 15.0% and are projected to have a 9.8% share of designs by 2030.
- Industrial applications are forecast to have the fifth-largest share of design starts in 2023 at 8.5% and are projected to have a 4.5% share by 2030.
- Other applications are forecast to have the smallest number of design starts in 2023 at 2.6% and are projected to have the smallest share by 2030 at 2.8%

Figure 19: RISC-V SoC Design Starts Share of Market by end Application Category, 2021-2030



Forecast*

Source: The SHD Group, January 2024

Figure 20: Imagination Technologies with CPU, GPU and AI IP Solutions

Imagination Technologies is an example of how RISC-V has changed GPUs, CPUs, and AI through its Intellectual Property. Their GPUs are known for balancing high performance with power efficiency, an essential feature for applications demanding intensive graphics processing. In the CPU domain, leveraging RISC-V architecture, they offer solutions that are flexible and customizable, catering to a diverse range of client needs.

The entry of Imagination Technologies into the RISC-V community is another sign that the RISC-V ecosystem is gaining traction in the SoC market. Imagination is a leading supplier of GPU and AI-focused SoCs and has extended this to include the CPU IP market as well. SoC designers now have more choices when thinking about the need to include GPU or AI functionality into their silicon solutions. More choices create competition, which is necessary for a healthy and thriving market environment.

VI. RISC-V Regional Forecasts

The following section looks at the RISC-V based SoC revenues for each of the six application categories on a regional basis. Revenue here relates to the projected consumption of RISC-V SoCs.

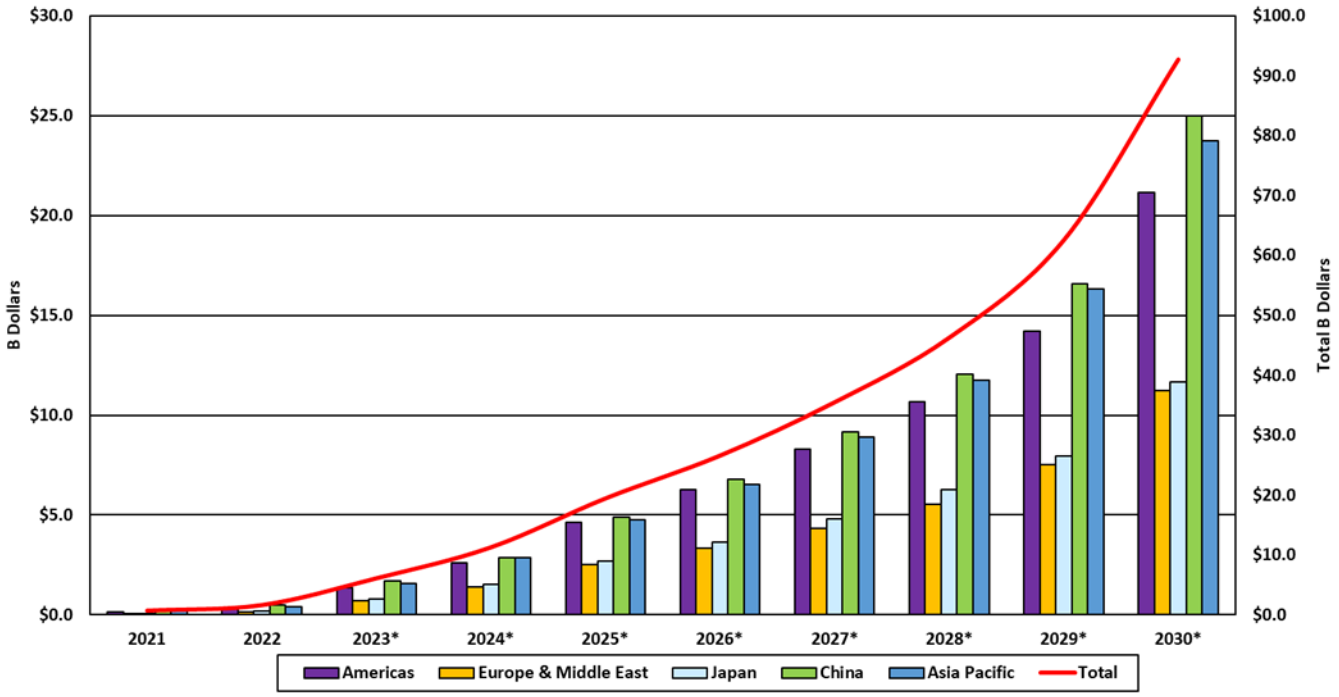
Table 7: Total RISC-V Revenues by Region 2021-2030

											CAGR %
B Revenues	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Americas	$0.2	$0.362	$1.337	$2.6	$4.6	$6.3	$8.3	$10.6	$14.2	$21.1	49.6%
Europe & EMEA	$0.1	$0.163	$0.722	$1.4	$2.5	$3.3	$4.3	$5.5	$7.5	$11.2	49.2%
Japan	$0.1	$0.202	$0.816	$1.5	$2.7	$3.7	$4.8	$6.3	$7.9	$11.6	47.4%
China	$0.2	$0.510	$1.702	$2.9	$4.9	$6.8	$9.2	$12.1	$16.6	$25.0	47.9%
Asia Pacific	$0.2	$0.416	$1.558	$2.9	$4.8	$6.5	$8.9	$11.8	$16.3	$23.7	48.8%
Total	$0.7	$1.653	$6.135	$11.3	$19.5	$26.6	$35.5	$46.3	$62.6	$92.7	48.6%
Percent Growth		130.3%	271.2%	84.2%	72.2%	36.7%	33.4%	30.3%	35.2%	48.2%	

***Forecast** **Source: The SHD Group, January 2024**

- The Americas regional revenue is forecasted to be $1.3B in 2023, forecast period starting at 2.6% in 2023 and forecast to end in 2030 at 2.7%.
- The Europe & EMEA regional market share started in 2023 at 7.4% and is forecast to reach 9.9% by 2030.
- The Japan regional market share started in 2023 at 7.1% and is forecast to reach 18% by 2030.
- The China regional market share started in 2023 at 33.8% and is forecast to decline slightly to 34% by 2030.
- The Asia Pacific regional market share started in 2023 at 45.5% and is forecast to decline to 32.6% by 2030.
- The total RISC-V market grows from a forecasted $6.1B in 2023, growing to reach $92.7B by 2030, a CAGR of 48.6%.

Figure 21: Total RISC-V SoC Regional Revenues 2021-2030



***Forecast**

Source: The SHD Group, January 2024

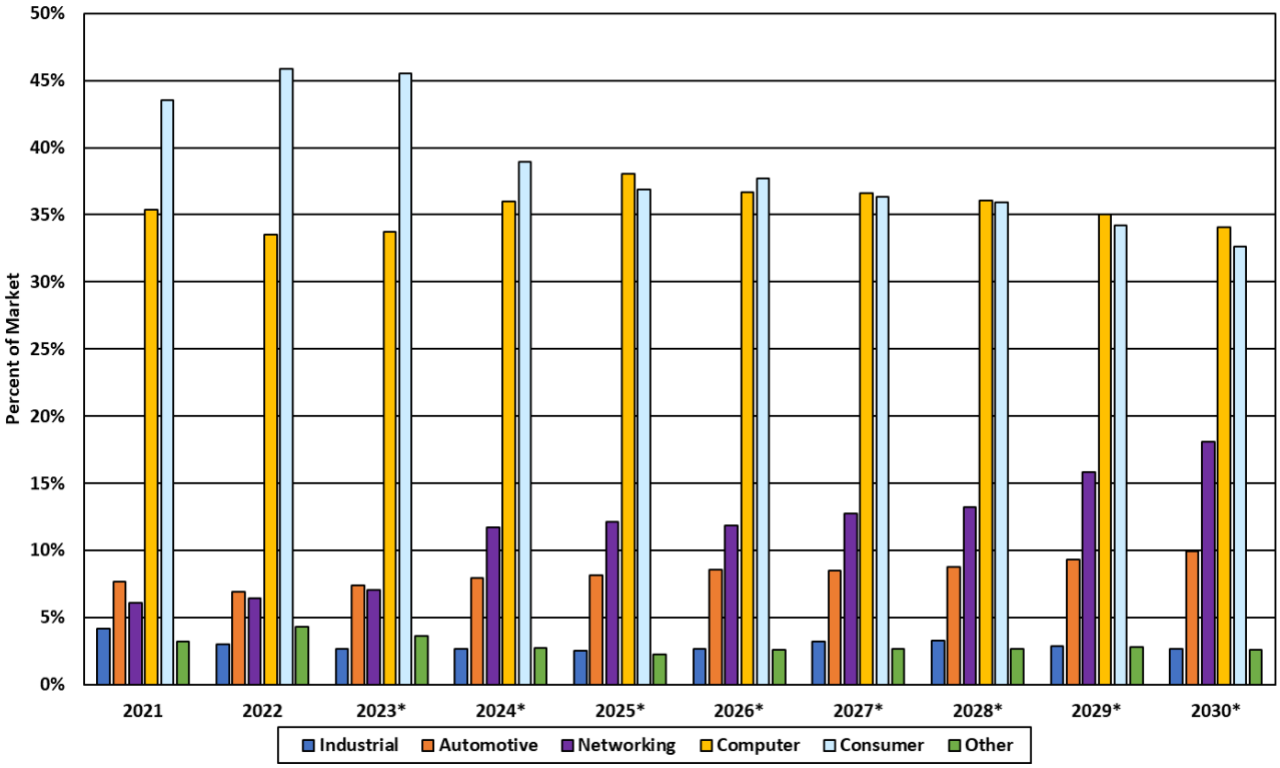
Table 8: Total RISC-V SoC Regional Market Share by Application Category 2021–2030

B Revenues	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***
Industrial	4.2%	3.0%	2.6%	2.7%	2.5%	2.7%	3.2%	3.3%	2.9%	2.7%
Automotive	7.6%	7.1%	7.4%	7.9%	8.1%	8.5%	8.5%	8.8%	9.3%	9.9%
Networking	6.1%	6.5%	7.1%	11.7%	12.1%	11.9%	12.7%	13.3%	15.8%	18.1%
Computer	35.4%	33.4%	33.8%	36.0%	38.1%	36.7%	36.6%	36.1%	35.0%	34.1%
Consumer	43.5%	46.5%	45.5%	38.9%	36.9%	37.7%	36.3%	35.9%	34.2%	32.6%
Other	3.2%	3.5%	3.6%	2.7%	2.3%	2.6%	2.7%	2.7%	2.8%	2.6%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

***Forecast** **Source: The SHD Group, January 2024**

- The Industrial application market share is roughly flat over the forecast period starting at 2.6% in 2023 and forecast to end in 2030 at 2.7%.
- The Automotive application market share started in 2023 at 7.4% and is forecast to reach 9.9% by 2030.
- The Networking application market share started in 2023 at 7.1% and is forecast to reach 18% by 2030.
- The Computer application market share started in 2023 at 33.8% and is forecast to decline slightly to 34% by 2030.
- The Consumer application market share started in 2023 at 45.5% and is forecast to decline to 32.6% by 2030.
- The Other application market share started in 2023 at 3.6% and is forecast to decline to 2.6% by 2030.

Figure 22: Total RISC-V SoC Regional Revenues by Application Category 2021-2030



***Forecast**

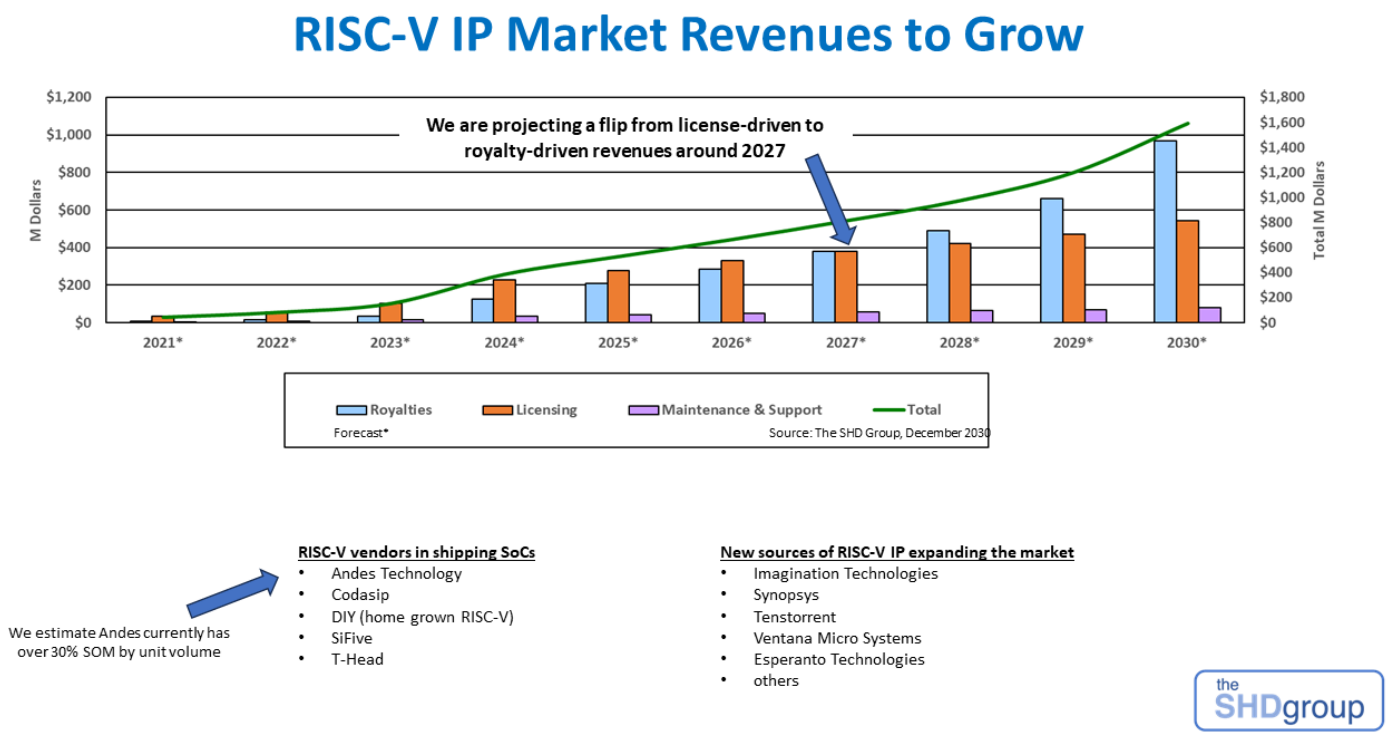
Source: The SHD Group, January 2024

VII. RISC-V CPU IP Market Analysis

Projecting RISC-V IP Into the Future

Figure 22 shows The SHD Group's forecast for the RISC-V CPU IP market from 2021 to 2030. In this forecast, we are projecting that around 2027, the royalty revenues will start to exceed the licensing revenues. By the end of this forecast period, we expect the royalties to be about 1.5X the licensing revenues.

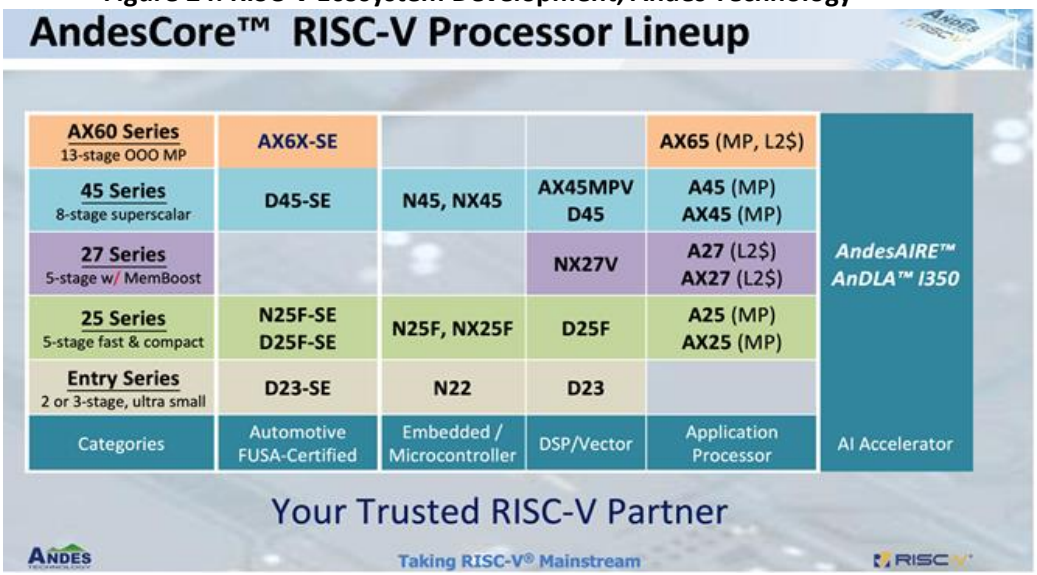
Figure 23: RISC-V IP Market Forecast 2021-2030



This change in the mix of revenues is driven by the ramping up of SoCs with RISC-V CPU cores shipping in greater volumes in the later years of the forecast period. A similar occurrence happened in the early years of the original CPU IP market and in the broader IP market as well. Eventually, the gap between royalty and licensing revenues tends to be reduced as IP types enter the market over time and licensing for the new types of IP blocks occurs. So, there is a tendency for these trend lines to tighten and loosen as these different IP types enter the market and are adopted at different rates by SoC designers.

A good example of this is the introduction of High-Definition Multimedia Interface (HDMI) IP in December 2002 by the HDMI Consortium. Initially, there was only one source for the IP, and licensing costs were high. As time passed, competing IP blocks from other IP companies entered the market, and licensing costs came down. At the same time, the initial adopters of HDMI started shipping in volume, and royalties started to accrue, finally outpacing the licensing revenues. Again, over time, the royalty rates tend to be reduced through competition, and the gap between royalty and licensing revenues tends to narrow.

Figure 24: RISC-V Ecosystem Development, Andes Technology



Our research indicates Andes Technology appears to be the leading RISC-V CPU IP vendor in the market by unit volume for SoCs using RISC-V IP today. They offer an extensive range of RISC-V CPU cores targeted from low-complexity SoCs all the way up to data center-class performance.

This could be a sign of a mature or maturing market. No new entrants or revolutionary advancements are being introduced to the market, just incremental improvements to the original IP specification over time.

This is not the case in what we are showing in Figure 70 above. The RISC-V market exhibits all the signs of a dynamic, growing, and evolving market and will do so beyond the forecast period of 2030 in this report. New companies are regularly entering the market, consistently introducing new, more powerful types of RISC-V CPU IP. In addition, the RISC-V ecosystem continues to be fleshed out and is growing quickly. At the same time, revenues continue to increase and are projected to ramp to $1.6B by 2030. These are not signs of a mature market.

An additional consideration is the nature of the CPU IP market. New, more powerful CPU cores are being introduced constantly, and designers are driven by the need to increase performance and functionality of their silicon creations as dictated by ever-rising market requirements. This is one of the reasons for the rise in device complexity, as shown in Figure 3. This makes the ratio between royalty and licensing revenues different from the other types of IP blocks and pushes the ratio higher in terms of royalty revenues. The SHD Group believes this market mechanism will apply to the RISC-V CPU IP market as well.

In doing the analysis for this report, we spoke to and interviewed over 30 companies that are members of the RISC-V ecosystem at all levels of participation. We also collected data from some of these companies under non-disclosure agreements (NDAs). As we collected more data, it became apparent that Andes Technology is the current market leader in terms of shipping volume, as reflected in Figure 18. We expect this situation to continue until the semiconductor partners of the other RISC-V CPU IP vendors start shipping their SoCs in volume.

Companies like HP, Dell, Oracle, many automotive manufacturers, and Tier 2 computer companies will source the parts from the general market almost immediately.

Western Digital, one of the original founding members of RISC-V International, has signaled they intend to use RISC-V-enabled solutions almost exclusively of other CPU architectures and have their designs manufactured by silicon foundries.

The real question is when do companies at large become comfortable with using RISC-V-based SoCs? When is the track record long enough for companies to abandon Arm or the other traditional CPU IP vendors in favor of RISC-V-based SoCs?

In The SHD Group's view, in a heterogeneous market, designers will not abandon the Arm architecture wholesale, electing to use the best-performing CPU core available for specific tasks instead. In this view, multiple different CPU cores will share die area on SoCs, each being tasked with performing different functions such as deeply embedded Finite State Machine, MCU, co-processor and Host Processor as needed. In this view, the RISC-V CPU cores need not function at the highest level of performance to be included in silicon solutions going forward. There will be co-existence between the cores, and an Arm core may reside next to a RISC-V core equally well.

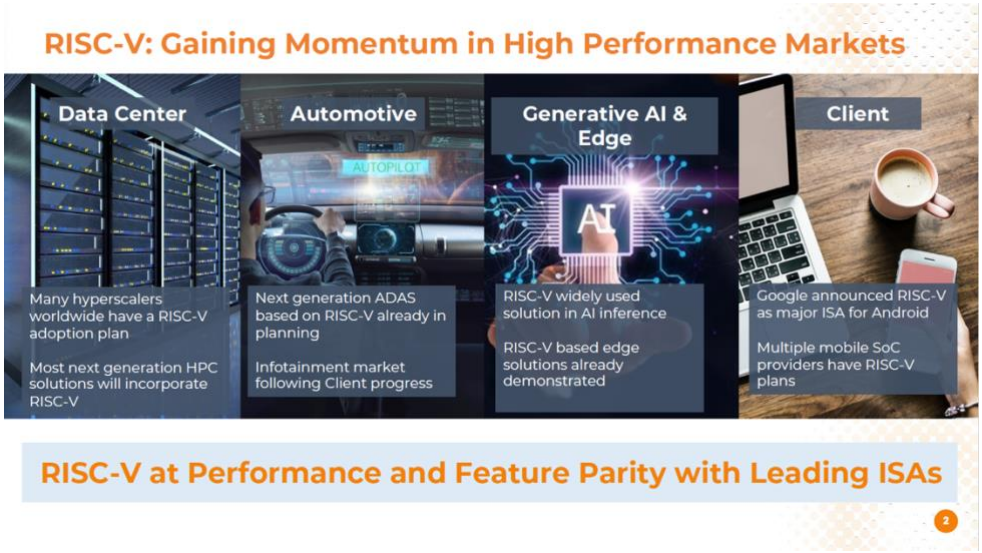
The transition to this type of architecture has been happening for the last several years and is gaining momentum as the RISC-V ecosystem continues to build out. This is especially true as Synopsys enters the RISC-V community with their own RISC-V-based CPU cores. The list of companies adopting the RISC-V architecture is now populated with enough major players in the industry to remove any doubts that the architecture has value and is valid.

What remains to be done is to get the RISC-V-based SoCs into the market in sufficient quantities and from enough vendors to allow sufficient choices for customers to select the right silicon solution to meet the market requirements in the applications they are targeting.

This stage of the market evolution is ongoing today and gaining momentum with every passing year as more companies offer viable CPU IP to the market, design with this IP, and ramp their unit shipments.

The SHD Group is conservative in its numbers in the early stages of the market where we are now, but we expect the unit volumes to grow over time. Still, there is room for upside in our forecasts, but this is based on the collective efforts of all the companies designing RISC-V-based parts and how quickly they can get those parts to market.

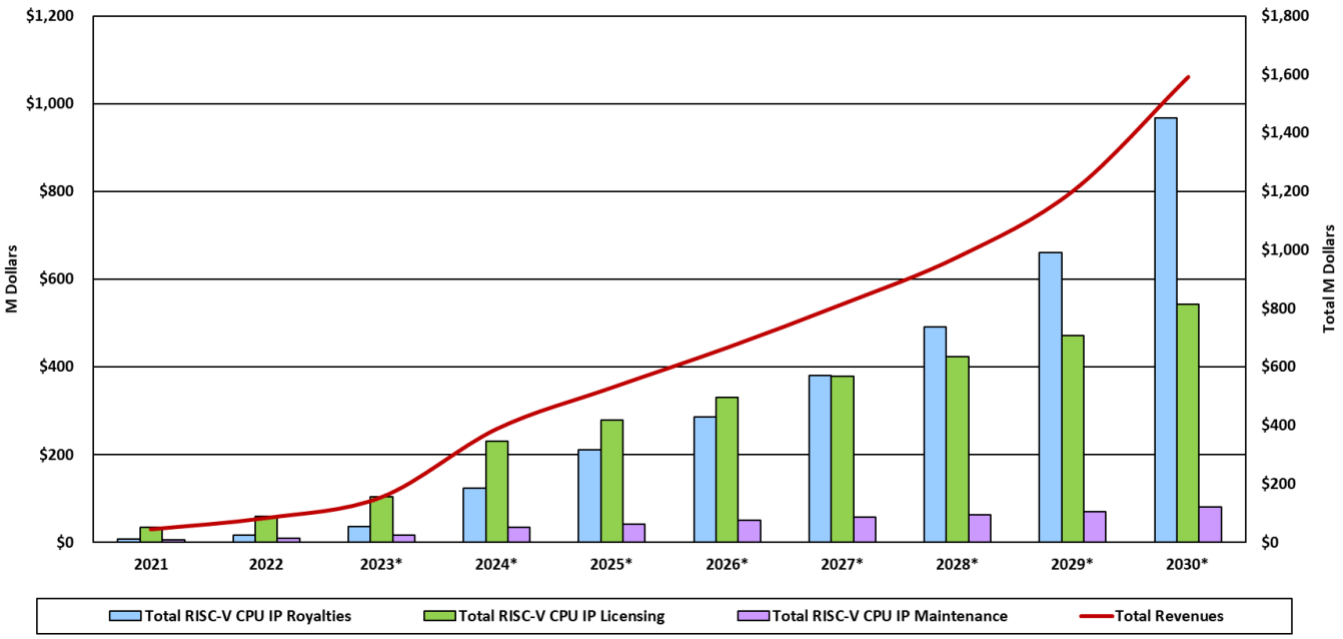
Figure 25: RISC-V Moving into Higher End Applications, Ventana Micro Systems
Source: Ventana Micro Systems, January 2024



Ventana Micro Systems has developed their own RISC-V CPU core targeted like the data center, ADAS automotive applications, Generative AI and edge applications, and for client computing applications. They are also developing their CPU cores to pursue chiplet implementations for this emerging market. In addition, the CPU core IP they have created is also available for licensing.

Ventana introduced their second-generation Veyron V2 SoC processor at the RISC-V Summit in November 2023. This SoC CPU core is geared towards the upper end of the performance spectrum and Data Center-class applications, and is another indication that the RISC-V ecosystem is advancing in capability.

Figure 26: Total RISC-V CPU IP Market Revenues 2021–2030



***Forecast**

Source: The SHD Group, January 2024

- Total RISC-V CPU IP royalties reached $16.7M in 2022 and are forecast to grow to $968.1M by 2030, a CAGR of 60.2%.
- Total RISC-V CPU IP licensing revenues were $59.1M in 2022 and are forecast to reach $542.9M by 2030, a CAGR of 26.8%.
- Total RISC-V CPU IP maintenance revenues were $8.9M in 2022 and are forecast to reach $81.4M by 2030, a CAGR of 25.4%.
- Total RISC-V CPU IP revenues were $84.6M in 2022 and are forecast to reach $1,592.4M by 2030, a CAGR of 39.4%.

The SHD Group believes this forecast is reasonable given the high degree of interest in the RISC-V ISA and the number of systems it can be deployed into. It is also necessary to state that the very high CAGR growth rates are due to coming from very low starting base numbers and then growing from there. These rates will moderate over time.

RISC-V CPU IP enters the market at an opportune moment, aligning with the ongoing wave of architectural innovation fueled by the burgeoning AI market, which is permeating nearly every existing application. The CPU IP market has been seeking an alternative to conventional CPU IP architectures, desiring high performance, reasonable licensing costs and configurability. RISC-V CPU IP addresses these needs, offering flexibility for user configuration and continual extension of the instruction set to better suit evolving market demands.

RISC-V International's extensive membership base of over 3300 members signifies widespread adoption and resonance within the design community. In forecasting the RISC-V CPU IP market revenues, The SHD Group has positioned royalty revenues below licensing revenues due to the anticipated ramp-up time for RISC-V powered SoCs in the market. During this initial phase, while RISC-V SoCs gain traction, the expectation is for a continuous influx of new licenses, causing licensing revenues to outpace royalties.

Several compelling factors contribute to the anticipated large-scale adoption and growth of the RISC-V architecture:

1. Rapid Adoption: The novelty of RISC-V generates significant interest and rapid adoption in the industry.
2. Availability of Second Sources: Unlike Arm and MIPS experiences, RISC-V had multiple sources almost from inception, allowing SoC designers easier evaluation and selection processes due to similar instruction sets among vendors.
3. Established Ecosystem: The broader IP market ecosystem supporting RISC-V is already well-established, contrasting the early days of Arm and other CPU vendors, where significant evangelization and ecosystem development were required.
4. Familiarity with IP: Contemporary designers are accustomed to working with IP, supported by numerous EDA tools geared toward IP utilization, a significant contrast from earlier eras.
5. Existing Applications: Unlike Arm's initial phase, primarily serving the emerging cell phone market, RISC-V enters a market with diverse existing applications shipping in substantial volume, poised to generate revenues more swiftly.
6. In addition, the pending emergence of the chiplet market poses another growth opportunity for the RISC-V architecture. Given the rise in the adoption of AI, chiplet designers will be looking to

add AI acceleration to their chiplet solutions, and RISC-V offers a prime CPU IP option to this design community.

The diversity and volume of existing applications poised to adopt RISC-V set the stage for rapid revenue generation. This distinguishes it from earlier CPU IP architectures that experienced a more extended period before significant revenue streams materialized. This aspect accelerates the potential for revenue generation within the RISC-V architecture.

The RISC-V IP starts out with very high growth rates compared to the CPU IP and total IP market segments. However, by the end of the forecast period, the RISC-V CPU IP growth rates moderate to be more in line with the growth rates in the other areas. However, RISC-V becomes a significant player in these segments, experiencing double-digit growth, while the other segments show growth rates in the high single digits.

VIII. RISC-V Ecosystem

The importance of designing SoCs in today's market using 3rd party IP cannot be understated. Without the types of IP available today, it is almost impossible to design these parts. The complexity levels are already high and are continually rising to meet increasing market demands for more functionality and richer feature sets. This is a never-ending task for system architects and silicon designers.

RISC-V IP Companies

- **Andes Technology,** a founding member of RISC-V International, specializes in a broad range of efficient and highly configurable 32/64-bit RISC-V CPU IP cores, catering to various functionalities including AI, DSP, FPUs, superscalar, vector processors, and multi-core capabilities. Renowned in the automotive sector with ISO 26262 certification and support for ASIL B to D, Andes extends its expertise to a full-featured RISC-V integrated development environment and comprehensive software/hardware solutions. With 16 years in the field, they stand as a global leader in embedded processor IP, offering a versatile platform solution that empowers customers to create tailored system architectures and optimize hardware/software partitioning, encompassing a wide spectrum of CPU IP, ISA for RISC-V designs, embedded processors, development platforms, toolchains, and software support systems, in one cohesive ecosystem.

- **Esperanto Technologies** is the first company to have created a commercial chip with over 1000 RISC-V cores. They are targeting the HPC and Generative AI markets for LLMs using their own in-house developed RISC-V silicon and are shipping systems today. The company is also licensing their 64-bit RISC-V CPU IP cores to customers on a strategic basis.

- **InCore Semiconductor** specializes in offering RISC-V related intellectual property (IP) and design services. Utilizing a distinctive design methodology, the company focuses on automated processes for CPU core development and streamlined implementation of IP and System on Chip (SoC) solutions. InCore places a strong emphasis on developing RISC-V accelerators, catering to the evolving trend in SoC architecture towards heterogeneous multicore designs. This approach aligns with the industry's shifting preferences for this architectural style.

- **Synopsys** is a premier member of RISC-V International, the leader in the EDA market and the #2 IP vendor. Synopsys has recently announced its plans for expanding its processor IP portfolio with the new RISC-V-based family called ARC-V. The company is introducing designs for these next-generation ARC-V processors, leveraging decades of processor IP and software tools experience, with the added benefit of the expanding RISC-V software ecosystem.

- **Ventana Micro Systems** targets primary markets like data centers and HPC. They have recently introduced their new 64-bit Veyron V2 chiplet and corresponding RISC-V CPU IP. Ventana's strategy is to enable the rapid and efficient development of customized, high-performance RISC-V processors via both chiplet and IP solutions**.**

- **Imagination Technologies**, a leader in the GPU IP market, is now creating new RISC-V CPUs built on their history of processor developments. Catapult is a RISC-V CPU IP product family designed from the ground up for deployment in key applications and configurable for a variety of uses. With nearly three decades of experience delivering complex solutions, Imagination's new CPU IP series will leverage the strong and ever-expanding RISC-V ecosystem. Catapult RISC-V-based CPU

IPs are available in four distinct product groups: dynamic microcontrollers, real-time embedded CPUs, high-performance application CPUs and functionally safe automotive CPUs.

- **Bluespec** has a product portfolio focused on three core areas of the RISC-V ecosystem. They deliver silicon IP RISC-V processor cores with full real-time operating system (RTOS) and Linux software stacks. Additionally, they offer a RISC-V high-speed emulation development tool that provides scalable on-demand virtual development boards in the cloud. The company also provides hardware acceleration tools that reduce development time and mitigate risks when developing accelerators coupled with RISC-V and other ISA processors.

- **SiFive** is at the forefront of RISC-V, partnering with some of the world's largest semiconductor manufacturers, global hyperscale data centers, and leading consumer device companies. They leverage the RISC-V standard to deliver superior high-performance, low-power compute density for wearables and other consumer devices, data centers, edge compute, automotive, and aerospace applications.

- **Codasip** designs their own RISC-V CPU IP cores using Codasip Studio with CodAL, their unique architecture description language. All Codasip processors are fully customizable, which leverages the potential of RISC-V. Customers can use the standard extensions or their own custom instructions to tailor the processor to the software.

- **Cortus** offers an IP portfolio that addresses applications such as automotive, consumer, IoT/NB-IoT, edge computing, and Industrial control. This lineup includes Cortus ISA and RISC-V ISA 32/64-bit processors and digital, analog, mixed-signal, RF, and security IPs.

- **Semidynamics** offers fully customizable Out-of-Order and In-Order, 64-bit RISC-V CPU IP cores.

- **MIPS** has transitioned their architecture to focus on RISC-V ISA and is targeting the high-performance segment of the processor market. They are leveraging its differentiation in real-time features, hardware virtualization, functional safety, and security technologies to offer products for automotive, edge compute, networking and switching, and large-scale computing systems.

- **Tenstorrent** has developed five different RISC-V CPU core IPs with two-, three-, four-, six-, and eight-wide decoding to use in its own processors or license to interested parties on a strategic basis. They are targeting a range of applications centered around the data center.

EDA Tool Providers

Talking about the 3rd party IP market is only half the story. The rest of the story is the EDA Tools available from multiple vendors today. One could argue that without the EDA tools, no designs would be accomplished, and not even creating the IP blocks used in the designs would be possible.

So, in the interest of telling a more complete story about the RISC-V market, The SHD Group has invested some time and effort to pull together a short list of EDA companies with tools focusing on designing CPU cores into SoCs of various types.

It should be noted that most EDA companies are CPU-agnostic when it comes to developing tools for specific CPU cores. This applies to their main EDA tool suites, such as for verification, simulation, or emulation operations. However, over time, different companies have adjusted their tools to offer more

coverage for specific parts of the design effort. This represents an ongoing effort by these companies to offer products more in tune with their customers' needs, as the design effort has become more complex over time. The introduction of AI-powered tools is an indicator of this.

Here is a short list of those companies which we hope to expand over time:

- **Synopsys** offers a wide range of EDA tools, including Design Compiler and Fusion Compiler, which aid in designing and integrating CPU cores into SoCs. They also provide solutions for IP integration and verification. In addition, Synopsys will transition their Metaware software development tools previously used on their standard ARC CPU cores to now support their new RISC-V CPU cores.

- **Cadence Design Systems** is known for their digital and analog design and verification tools like Genus, Innovus, and Xcelium. Cadence provides solutions for incorporating CPU cores into complex SoC designs.

- **Mentor, a Siemens Business,** provides tools like Questa and ModelSim for simulation and verification, aiding in the development and integration of CPU cores within SoCs.

- **Ansys** offers tools like Ansys RedHawk and Apache PowerArtist for power analysis, optimization, and thermal management, which are essential in designing CPU cores into SoCs.

- **Imperas,** recently acquired by Synopsys, specializes in virtual platforms and simulation technology for designing and testing embedded systems, including CPUs within SoCs, and offers RISC-V verification technology. Imperas recently released a new ISS specifically for developing tests and compliance suites for RISC-V processors.

- **OneSpin Solutions** provides formal verification solutions that can be applied to RISC-V designs for functional correctness and safety verification.

- **Breker Systems** delivers solutions that focus on SoC verification, including TrekSoC™ software, which assists in automatically generating self-verifying C test cases for verifying RISC-V processor cores within complex SoC designs.

- **Silvaco** provides EDA tools for CPU design, including software for circuit simulation, device modeling, and semiconductor process simulation.

These companies offer various tools and solutions that support the integration of CPU cores into SoCs, catering to different stages of the design, verification, and implementation process.

Figure 27: New EDA Tools Support Joining the RISC-V Ecosystem, Synopsys

Source: Courtesy of Synopsys, January 2024

Synopsys is the market leader in the EDA market today and their entrance into the RISC-V ecosystem brings added credibility to the ecosystem and brings extensive SoC development and design experience and expertise to the RISC-V community. Their entrance helps to build confidence in SoC designers that the tools and other building blocks necessary for complex SoC designs are coming into place as the ecosystem fleshes out.

RISC-V Software Development Tools & OS:

- **Synopsys (Metaware)** specializes in providing high-performance and efficient compilers, tools, and software development solutions for embedded systems, particularly targeting applications in the automotive, industrial, aerospace, and consumer electronics sectors. It is a complete solution that contains all the components needed to support the development, debugging and tuning of embedded applications for ARC and the just introduced RISC-V, ARC-V processors. The toolchain supports the complete family of ARC-V processors, including the 32-bit ARC-V RMX embedded processors, the 32-bit ARC-V RHX real-time processors, and the 64-bit ARC-V RPX host processors.

- **Red Hat** is a significant player in the open-source software industry and has been actively involved in supporting RISC-V technology. Red Hat focuses on adapting and optimizing their enterprise solutions, such as Red Hat Enterprise Linux (RHEL), for the RISC-V architecture.
- **Imperas** offers CPU models for RISC-V in addition to simulation and development tools that support RISC-V-based processor verification and debugging.
- **Emproof** offers security and IP integrity solutions for embedded systems, using unique techniques to protect algorithms and data while securing the entire device.
- **Canonical,** in relation to RISC-V, actively supports and optimizes the Ubuntu operating system for RISC-V architectures. Canonical contributes to the RISC-V open-source ISA ecosystem by working on Ubuntu porting, optimizations, and enabling software compatibility for devices running on RISC-V.
- **Wind River (a subsidiary of Aptiv PLC**) develops real-time operating systems (RTOS), Linux OS, and a safety-certifiable, multi-OS hypervisor supporting mixed levels of criticality for edge applications and silicon solutions.
- **Google (Android)** has announced they are porting Android to support the RISC-V ISA.
- **SUSE is** a global software company focused on open-source technology, enterprise-grade solutions, and support services. This positions them as a leading provider of Linux-based operating systems and infrastructure solutions for businesses operating in diverse IT environments.
- **Codeplay (Intel)** specializes in software development tools and technologies for heterogeneous computing systems. They focus on creating programming solutions for AI, machine learning, HPC, and automotive industries.
- **RISC-V Software Ecosystem (RISE)** is dedicated to enabling a robust software ecosystem specifically for Host Processors, including compilers, toolchains, system libraries, kernel, virtualization, programming languages, Linux distribution integration, and tools for debug and profiling.

FPGA (with RISC-V)

- **Efinix** is known for its FPGA solutions. The company supports RISC-V designs with its Trion® FPGA platform and associated design tools.
- **Xilinx (now part of AMD)** offers FPGA platforms such as the Versal ACAP and Vivado Design Suite. They support RISC-V implementations through their tools and provide resources for integrating RISC-V cores into their FPGA.
- **Intel (with the acquisition of Altera)** provides FPGA products like the Intel Agilex® and Intel Quartus® Prime Design Software. While focusing on their proprietary ISAs, their tool suite supports the integration of RISC-V cores into their FPGA platforms.
- **Microchip (formerly Microsemi)** offers FPGA solutions like the PolarFire® FPGA family and Libero® SoC Design Suite. They have tools and IP support for integrating RISC-V cores into their FPGA platforms.

- **Lattice Semiconductor** offers FPGA solutions such as the Lattice Nexus Platform and Lattice Diamond Design Software. While primarily focused on low-power and small form-factor FPGAs, they provide tools to integrate RISC-V cores onto their platforms.

- **QuickLogic** provides FPGA solutions like the QuickLogic EOS S3 and SensiML Analytics Toolkit. They offer tools and IP supporting the integration of RISC-V cores into their FPGA platforms focused on low-power and AI applications.

Related IP Providers

- Arteris is the leader in the interconnect IP market, offering non-coherent and coherent network-on-chip (NoC) interconnect IP that ties together different IP blocks used on contemporary SoCs and accelerates complex SoC designs. They also monitor the on-chip data networks and provide security and power monitoring functionality to SoC designers. Their Ncore cache-coherent NoC technology is ISO 26262 certified and their non-coherent FlexNoC technology is ISO 26262 certifiable for automotive safety and reliability for industrial and enterprise endurance. They are celebrating their third year of Automotive ISO 26262 Tool Confidence Level 1 (TCL1) certification for their SoC Integration Automation products.

- **Flex Logix** specializes in embedded FPGA (eFPGA) IP, which can be integrated with RISC-V processors in SoCs, enabling reconfigurable acceleration.

- **Dover Microsystems** offers IP for SoCs featuring dedicated sentry logic that acts as a host processor bodyguard. It monitors every instruction to ensure it complies with defined security, safety, and privacy rules. If an instruction violates an existing rule, CoreGuard prevents it from executing before any damage can be done.

- **OpenFive (an Alphawave Semi)** provides specialized IPs and design tools for RISC-V-based SoC design, including support for processor subsystems and interface IP development.

- **UltraSoC (acquired by Siemens EDA)** offers monitoring and analytics solutions that can be integrated into RISC-V designs, enabling real-time insights into the behavior and performance of RISC-V cores within SoCs.

- **Metrics Technology** specializes in verification and validation tools for RISC-V processors, aiding in ensuring correctness and reliability during the design process.

- **Rambus** provides verification IP solutions and tools tailored for RISC-V, assisting in verifying and integrating RISC-V cores into complex SoC designs.

These companies focus on providing tools and solutions tailored to leverage the open-source RISC-V architecture in SoC designs. They offer a variety of tools for different stages of development, from architecture exploration to verification and implementation.

IX. SWOT Analysis of RISC-V Ecosystem and Landscape

The following section is a SWOT analysis of the current RISC-V ecosystem and landscape. It is intended to outline the strengths and weaknesses of RISC-V today and also highlight the opportunities for this ISA and possible threats to its continued adoption and growth.

Strengths

- First new CPU IP architecture in the last 15 years that has gained any significant market presence.
- Enthusiasm and excitement around RISC-V not seen in the industry for many years.
- Multiple companies entering the ecosystem and developing products covering all aspects of SoC design requirements. Of note is the latest entry of the #2 IP company, Synopsys, into the RISC-V ecosystem.
- Multiple companies developing CPU IP cores in parallel, targeting full range of device and system performance envelopes.
- RISC-V community made up of many diverse companies with broad range of market presence and systems expertise – new ideas and concepts emerge faster than from only one company.
- Many companies innovating in parallel – innovation happening at a fast pace.
- Innovation fosters competition, which propels market growth.
- As market growth ramps up, more software companies are providing support for the ecosystem, and EDA tools companies are looking to incorporate some RISC-V-specific support in their products.
- Each new year sees advances in the high-end of the performance envelope, slowly closing the gap between the highest-performing CPU cores from the competition and RISC-V
- Core ISA is fixed, but customization of ISA extensions is possible, and new extensions are being approved continually.
- No evangelizing necessary to convince designers of the value of CPU IP cores. Host of applications are already in the market, shipping in mass volume, and ready to adopt RISC-V
- Low power consumption and increasing performance metrics attractive to SoC designers looking to craft more powerful silicon solutions to meet rising market requirements.

Weaknesses

- Many small companies developing products with little to no track records in the market.
- Many of these companies are start-ups and must continually raise money for funding before revenue streams start. This creates the possibility of high turnover rate and turmoil.
- No overall cohesion in product development between the companies, thus some duplication of efforts.
- Ability to customize ISA extensions could lead to ISA fractionalization, if not managed by an entity like RISC-V International.
- It will take time for the ecosystem to flesh out completely, while competitive ecosystems already in place. Software developer support is key to this; attracting these companies is critical for success.

Opportunities

- Ability to customize ISA extensions provides great flexibility to designers – especially when contemplating designs for domain-specific solutions.
- New, larger systems manufacturers are looking at the RISC-V ISA and several already have plans for adoption.
- Given the heterogeneous nature of the SoC design landscape today, great opportunity for RISC-V to be adopted and share die area with other competing CPU cores.
- Given the Open Standard nature of RISC-V, ability to constantly innovate is high. New ideas surface all the time.
- Emerging applications like AI and chiplets provide additional growth vectors for RISC-V into the future.
- Architectural exploration and development of solutions for AI silicon favors adoption of RISC-V CPU cores because of their low power envelope and rising performance metrics
- The relatively small size of RISC-V CPU IP cores allows any of them to be placed in the same die, maximizing die area efficiency, making them extremely attractive to SoC designers developing SoCs with large core counts.

Threats

- Concern over the Open Standard nature of RISC-V and confusion over the difference between specifications and implementations may lead to increased government oversight and over-regulation.
- Over-regulation may lead to curtailment of collaboration and hamper innovation.
- Market enthusiasm and momentum may dwindle over time, before the ecosystem can be completely fleshed out.
- EDA vendors may shift focus away from RISC-V to favor some other emerging technology over time.

What is the True Value of the RISC-V ISA and its Ecosystem?

When conducting an analysis like this on any market, it's always a good idea to examine what the core drivers of that market are and how they might be impacted by different events or situations that might arise over the course of time. The RISC-V market is no exception to this as the RISC-V ecosystem gains more traction with each passing year.

We have heard it said that the rise in interest in the RISC-V ISA has been sparked by a growing dissatisfaction with traditional ISAs like Arm and the high costs for their CPU IP cores. So, a fair question would be:

If Arm lowered their licensing costs tomorrow, would the interest in RISC-V disappear?

The SHD Group believes the answer to this question is no.

The reason for our answer lies not in the different licensing costs for the two architectures but in the value each brings to the design community. In the case of RISC-V vs any proprietary architecture, RISC-V brings:

1. Supplier independence. Simply stated, RISC-V software is largely independent of any RISC-V hardware supplier. A customer can switch from one RISC-V hardware provider to a different provider, based on their own business and technical needs, with minimal effect on their software tools or applications. Before RISC-V, changing from one ISA to a different ISA meant a complete swap out of software – which could be so expansive as to be financially impractical.
2. Greater selection. With a proprietary ISA like that of Arm, a single company controls both the specification and the implementations. Almost all customers would need to go through Arm itself to request changes and to purchase new implementations.
    - RISC-V International coordinates standardization of the RISC-V ISA and but doesn't disable developers from customizing their own extensions as needed. These efforts do not need to be filtered back through the association.
3. Freedom to innovate. Closed ISAs do not allow customization unless a customer agrees to an architectural license and corresponding restrictions. Depending on the product and the license terms, this can cost many millions of $USD while still having heavy constraints.
    - The RISC-V ISA is an open standard that any individual or company can obtain free of charge. Of course, if that entity wants to implement a CPU core usable in an SoC, that work still needs to be done but a finished CPU design can be competitively licensed from one of the RISC-V CPU IP vendors in the market today.
4. Quicker and greater innovation. Any closed ISA, such as that of Arm, comes from a single company. While that company may have extensive resources, innovation is confined to the confines of their company.
    - Even though the individual RISC-V CPU vendors are currently smaller in terms of internal resources, there are many of them with each looking at different markets and applications and each deploying their varied expertise to those markets and applications. Each of these companies is innovating independently and at their own pace. Thus innovations come from the work across many companies, with collectively greater resources than any single company possesses. As a result, we would expect invocations to come to market at an ever faster pace.

The bottom line to all the above points is this:

RISC-V enables more vendor independence, greater flexibility, more innovation and increased product selection. We see these as the true value brought by RISC-V as an Open Architecture .

X. Ecosystem Directory

The RISC-V ecosystem is dynamic and fast-growing. This report openly invited all RISC-V International member companies, and others, to participate. All content in this Directory was provided by the companies listed. ***Any company wishing to be included can be added at no charge by completing the entry information at:*** https://theshdgroup.com/company-profile-form/.

Company name: ACCELR
Website: https://accelr.lk
Headquarters Location: Colombo, Sri Lanka
Year Founded: 2019

Major Markets Served / Targeted:
- HPC, ML Acceleration, Big Data

RISC-V Product Categories:
- Design services
- Software development
- Staff Augmentation

Company Summary: ACCELR is the trusted technology partner in all your software and hardware system design and development needs. At ACCELR we pride ourselves in building elegant & maintainable products and solutions that enhance our clients' value proposition. We are guided by years of experience in delivering complex mission critical systems, and we strive for engineering excellence in all that we do.

Company name: ACL Digital
Website: https://www.acldigital.com
Headquarters Location: San Jose, California
Year Founded: 1988

Company Summary: ACL Digital, an ALTEN Group Company, is a digital product innovation and engineering leader. We help our clients design and build innovative products (AI, Cloud, and Mobile ready), content and commerce-driven platforms, and connected, converged digital experiences for the modern world through a design-led Digital Transformation framework.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Marketing

Major Markets Served / Targeted:
- Automotive
- High Performance Computing in Data Center and AI/ML
- Edge Inference Compute
- 5G and Networking

RISC-V Product Categories:
- FPGA, IC, and ASIC design services

Company name: Antmicro
Website: https://antmicro.com/
Headquarters Location: Sweden
Year Founded: 2009

Company Summary: Antmicro is a software-driven tech company providing development services, platforms, know-how and guidance to customers looking to innovate by applying new technological developments in hardware, software, FPGA, ASIC and edge-to-cloud AI systems.

RISC-V International membership level: Strategic
Major Markets Served / Targeted:
- Applied R&D services in robotics, drones, industry, agriculture, automotive, transportation, aerospace, defense and medical.

RISC-V Product Categories:
- Software & Services

Company name: Andes Technologies
Website: https://www.andestech.com
Headquarters Location: Hsinchu Science Park, Taiwan
Year Founded: 2005
Funding Status: Public
Employee Headcount: >100

Company Summary: A Founding Premier member of RISC-V International, Andes is a publicly listed company and a leading supplier of high-performance/low-power 32/64-bit embedded processor IP solutions, and the driving force in taking RISC-V mainstream. Its V5 RISC-V CPU families range from tiny 32-bit cores to advanced 64-bit Out-of-Order processors with DSP, FPU, Vector, Linux, superscalar, and/or multi/many-core capabilities. By the end of 2022, the cumulative volume of Andes-Embedded™ SoCs has surpassed 12 billion chips.

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:

- Board of Directors, Technical Steering Committee

General contact: america@andestech.com
Sales Office Locations: US: San Jose, CA; Taiwan: Hsinchu; Korea, Japan, Hong Kong, China
Engineering Locations: US: San Jose, CA, Portland, Oregon, Canada: Burnaby, BC; Taiwan: Hsinchu
Major Markets Served / Targeted: 5G, AI, Automotive, IoT, Networking, SSD, and Wearables
RISC-V Product Categories:

- CPU IP
- Compiler / development software
- Peripheral IP

Key Product Attributes: Andes Custom Extension (ACE) enables designers to create unique CPU instructions on the performance optimized AndesCore processors. ACE instructions designed specifically for the target applications eliminate the software bottlenecks and significantly improve runtime performance.

Company name: Arteris
Website: www.arteris.com
Headquarters Location: Campbell, CA
Year Founded: 2004
Funding Status: Public
Employee Headcount: >100

Company Summary: Arteris is the leader in the interconnect IP market, offering non-coherent and coherent network-on-chip (NoC) interconnect IP that ties together different IP blocks used on contemporary SoCs and accelerates complex SoC designs. They also monitor the on-chip data networks and provide security and power monitoring functionality to SoC designers. Their Ncore cache-coherent NoC technology is ISO 26262 certified and their non-coherent FlexNoC technology is ISO 26262 certifiable for automotive safety and reliability for industrial and enterprise endurance. They are celebrating their third year of Automotive ISO 26262 Tool Confidence Level 1 (TCL1) certification for their SoC Integration Automation products.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:

- Marketing Committee, Automotive, Market Development Committee

General contact: frank.schirrmeister@arteris.com
Sales Office Location: US: Campbell, CA; Austin, TX; France: Montigny, Paris, Nice; China: Nanjing; Korea: Seoul; Japan: Tokyo
Engineering Location: US: Campbell, CA; Austin, TX; France: Montigny, Paris, Nice
Major Markets Served / Targeted: Automotive, Consumer, Enterprise Computing, Communications, Industrial, AI/ML, Safety
RISC-V Product Categories: IP
Key Product Attributes: As the pioneer of network-on-chip (NoC) technology with over 71 patents, 3.5 billion SoCs shipped to date, 200+ customers and 725+ SoC design starts, our technology enables engineers working on RISC-V designs to:

- **Connect** computing subsystems plus RISC-V-based AI/ML acceleration subsystems with silicon-proven IP.
- **Unify** "Protocol Salad" of 100s of re-used IP Blocks ACE-Lite, AXI, AHB, APB, OCP, PIF CHI-A, CHI-B, ACE, ACE-Lite, ACE5-Lite, AXI4 Management.
- **De-risk** SoC integration and project schedules with proven system IP and expert support.

Company name: Beijing Institute of Open Source Chip (BOSC)
Website: https://www.bosc.ac.cn/
Headquarters Location: Beijing, China
Year Founded: 2021

RISC-V International membership level: Premier
Major Markets Served / Targeted:
- Open-Source community

Company Summary: BOSC has the mission of "constructing a technological system of open-source chips and accelerating ecosystem development for open-source chips." BOSC is dedicated to expediting the integration of the RISC-V innovation chain and industrial chain, as it strives to be the first to build a technological system of open-source chips by 2025 and become one of the world's leading centers of the RISC-V industrial ecosystem by 2030.

Company name: Codasip
Website: https://www.codasip.com
Headquarters Location: Munich, Germany
Year Founded: 2014

Company Summary: Codasip is a processor solutions company which uniquely helps developers to differentiate their products. We are Europe's leading RISC-V company with a global presence. Billions of chips already use our technology.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- HC Security
- SIG CHERI
- SIG Academia and Training
- SIG Automotive
- SIG Safety
- SIG AI/ML
- Tech Code size
- Tech CHERI

Major Markets Served / Targeted:
- Embedded, image processing, smart sensors, IoT devices, wearables, AI/ML, automotive

Company name: Codeplay Software (Intel)
Website: https://www.codeplay.com
Headquarters Location: Edinburgh, Scotland
Year Founded: 2002

Company Summary: Codeplay has developed a range of products called ComputeSuite™ that bridge the gap between the latest AI processors and AI application developers using well established open standard interfaces. These products have been developed for use in a range of market segments, including safety critical products such as ADAS and ultimately the autonomous vehicle.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- RISC-V Datacenter/Cloud Computing SIG

Major Markets Served / Targeted:
- AI, HPC, Automotive, IoT, Industrial, FinTech, Energy and Health
- Any industry seeking higher performance with accelerated compute

RISC-V Product Categories:
- Software
- OneAPI & SYCL

Company name: Cortus
Website: https://www.cortus.com
Headquarters Location: France
Year Founded: 2005

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Automotive RISC-V group

Major Markets Served / Targeted:
- Industrial and Automotive

RISC-V Product Categories:
- CPU IP
- Peripheral IP

Company Summary: Cortus, a fabless semiconductor company, designs and sells microcontrollers (MCUs) and system-on-chips (SoCs) for Automotive including AI inference, Avionics and Server markets using its large own proprietary IP portfolio including processors 32/64 bits (Cortus ISA and RISC-V ISA), digital, RF, analog, mixed-signal, security, safety, interconnects, and peripherals.

Company name: Daol Investment and Securities
Website: https://www.dailsecurities.com/top.jsp
Headquarters Location: Seoul, Korea
Year Founded: 1981

RISC-V International membership level: Community
Major Markets Served / Targeted:
- Korea

Company Summary: Daol Investment & Securities, originally founded in 1981 as Korea Technology Development Company, is a comprehensive financial group in South Korea. It offers a wide range of services including securities, savings bank, asset management, and private equity. The company has expertise in structured finance, institutional brokerage, and individual wealth management, with a focus on alternative investment products like real estate, aircraft and ship financing, and renewable energy. Daol Investment & Securities has expanded internationally with establishments in Thailand and New York, and it also manages a variety of subsidiaries including a savings bank, asset management, and private equity firms.

Company name: DeepComputing
Website: https://deepcomputing.io/
Headquarters Location: Hong Kong
Year Founded: 2022

RISC-V International membership level: Strategic
Major Markets Served / Targeted:
- RISC-V Laptop
- RISC-V Tablet
- RISC-V Consumer products

RISC-V Product Categories:
- System-level products using RISC-V

Company Summary: Headquartered in Hong Kong., DeepComputing share an enduring passion for advancing the adoption and implementation of RISC-V beyond existing ISA chipsets. Our aim is to create bold new products. With faith in our diverse and dedicated partners, we believe in the promising new future of RISC-V. Together, we will focus on driving the development of the RISC-V ecosystem with products such as laptops, pads, workstations, headphones, smart watches, smart speakers, AR glasses and autonomous driving for toys and real-world vehicles.

Company name: E4 Computer Engineering
Website: https://www.e4company.com
Headquarters Location: Scandiano, Italy
Year Founded: 2002

RISC-V International membership level: Strategic
Major Markets Served / Targeted:
- Academic and Enterprise Markets

RISC-V Product Categories:
- HPC clusters, Cloud, Data Analytics, AI, and Hyper-converged infrastructures

Company Summary: E4 Computer Engineering is an internationally recognized solution provider for high grade expertise in HPC, High Performance Data Analytics, AI and Deep Learning. E4 works with the some of the most prestigious Universities and important centers for research and computing, like CERN in Geneva, from whom we have received special acknowledgment.

Company name: Emproof
Website: https://www.emproof.com
Headquarters Location: Eindhoven, NL
Year Founded: 2021
Funding Status: Private
Employee Headcount: <25

RISC-V International membership level: Strategic
General contact: contact@emproof.com
Sales Office Location: Eindhoven, Netherlands
Engineering Location: Eindhoven, Netherlands; Bochum, Germany
Major Markets Served / Targeted: Automotive, Semiconductor, Industrial IoT, Avionics
RISC-V Product Categories: Security, Software, IP
Key Product Attributes: State-of-the-art embedded software security

- Code protection - prevents reverse engineering and subsequent IP theft
- Security hardening - Detects and secures against exploitation attacks
- Binary translation - with no access to software development process needed
- Functional safety compliant and ISO 26262 ASIL B Certified
- Ideal for resource constrained systems
- Support for RISC-V custom ISA extensions.

Company Summary: Emproof delivers high levels of security and IP integrity for embedded systems, using unique techniques that protect algorithms and data while securing the entire device. Our solution, Emproof Nyx, prevents reverse engineering, securing your valuable intellectual property and protecting against exploitation attacks. Hardware and software agnostic, Emproof Nyx, can be implemented at any stage of the product lifecycle, saving time, money and resources.

Company name: Esperanto Technologies
Website: https://esperanto.ai
Headquarters Location: Mountain View, California
Year Founded: 2014
Funding Status: Private
Employee Headcount: >100

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:

- Vector, ISA, compliance, graphics and more

General contact: info@esperanto.ai
Sales Office Location: Mountain View, California
Engineering Location: Mountain View, California; Austin, Texas; Portland, Oregon, Barcelona, Spain; Belgrade, Serbia
Major Markets Served / Targeted: AI Inference and HPC Computing Solutions
RISC-V Product Categories:

- Single Board Computers
- Accelerators
- Chips & Processors
- HPC Systems

Key Product Attributes: Extremely low power, high performance massively parallel AI inference and High-Performance Computing, from the datacenter

Company Summary: Esperanto delivers high-performance, energy-efficient computing solutions that are the compelling choice for the most demanding AI and non-AI applications. The changing, computationally intensive workloads of the machine learning era mandate a new clean-sheet solution, without the baggage of existing legacy architectures, or the programmability limitations of overspecialized hardware. Esperanto leverages the simple, elegant, open standard RISC-V instruction set architecture (ISA) to deliver flexibility, scalability, performance and energy-efficiency advantages.

Company name: Flex Logix Technologies, Inc.
Website: https://www.flex-logix.com
Headquarters Location: Mountain View, CA
Year Founded: 2014

Major Markets Served / Targeted:
- Data Center, Communications (Wired and Wireless), Connectivity, Automotive, Storage, Industrial, Security, Aerospace and Defense

RISC-V Product Categories:
- eFPGA IP
- DSP / AI IP

Company Summary: Flex Logix is a reconfigurable computing company providing leading edge eFPGA and AI Inference technologies for semiconductor and systems companies. Flex Logix eFPGA enables volume FPGA users to integrate the FPGA into their companion SoC, resulting in a 5-10x reduction in the cost and power of the FPGA and increasing compute density which is critical for communications, networking, data centers, microcontrollers and others. Its scalable AI inference is the most efficient, providing much higher inference throughput per square millimeter and per watt.

Company name: Imagination Technologies
Website: https://www.imaginationtech.com
Headquarters Location: Kings Langley, UK
Year Founded: 2005
Funding Status: Private
Employee Headcount: >100

Company Summary: At Imagination, we solve complex problems by creating innovative technologies that help our partners to succeed. We pride ourselves on empowering our partners to deliver innovation that inspires new products, and we thrive on high volume opportunities.
We're motivated to work in close partnership with our customers – developing relationships and provide the expertise needed to address specific markets with success.

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:
- Board of Directors, Technical Steering Committee

General contact: https://www.imaginationtech.com/contact-us/
Sales & Engineering Locations: UK: Bristol, Cambridge, Hertfordshire Manchester; China; Japan; Poland; Romania; South Korea; Taiwan
Major Markets Served / Targeted: Automotive, Consumer, Desktop, Mobile
RISC-V Product Categories:
- CPU IP
- GPU IP
- Compiler / development software

Key Product Attributes: Catapult, is a RISC-V CPU product line designed from the ground up for deployment in key applications and configurable for any use. Leveraging nearly three decades of experience in delivering complex solutions, Imagination's new CPU series is backed by the strong and ever-expanding RISC-V ecosystem. Catapult CPUs are designed for various market applications and also next-generation control, compute and heterogeneous compute needs.

Company name: Imperas (now part of Synopsys)
Website: https://www.imperas.com
Headquarters Location: Oxfordshire, UK
Year Founded: 2005
Funding Status: public (Synopsys)
Employee Headcount: >10,000 (Synopsys)

Company Summary: Imperas is a prominent company in the RISC-V ecosystem, known for development of embedded software and systems. Founded in 2005, Imperas has been a significant player in the tech industry, particularly in software development. The company's expertise lies in creating fast simulation models for CPUs – including RISC-V processors, focusing on virtual platform solutions. These solutions enable the efficient development of embedded software through advanced methodologies like high-level modeling, high-performance simulation, and sophisticated debugging techniques. Imperas was acquired by Synopsys on December 15, 2023.

General contact: LarryL@imperas.com
Sales Office Location: US, UK, Korea, Japan
Engineering Location: Oxfordshire, UK
Major Markets Served / Targeted: AI, Automotive, Silicon IP, Semiconductor, High Performance Compute (HPC)
RISC-V Product Categories: Imperas offers a range of key products focused on virtual platform simulation and processor modeling, particularly for RISC-V and other microprocessor ISAs.

- **ISS** - Instruction Set Simulator
- **DEV** - Virtual Platform Development and Simulation
- **M*SDK** - Advanced Multicore Software Development Kit
- **QuantumLeap** - Virtual Platform Simulation Acceleration
- **cpuGen -** CPU Model Generation
- **riscvOVPsim** - Free Imperas RISC-V Instruction Set Simulator
- **ImperasDV** - industrial quality RISC-V processor verification made easy

Key Product Attributes: Imperas has made a name for itself by providing tools to develop software for multi-processor core devices. It boasts an accurate library of models for a range of processors, extending from RISC-V to Arm, Imagination, MIPS, PowerPC, Arc, and others. This versatility showcases the company's adaptability and broad expertise in the embedded software domain.

Company name: InCore Semiconductor
Website: https://incoresemi.com/
Headquarters Location Chennai, India
Year Founded: 2018
Funding Status: Private
Employee Headcount: >25

Company Summary: InCore Semiconductors is a fabless core IP & chip design startup building fully customizable RISC-V cores and SoCs, to create high-performance, low-power, and cost-effective solutions for a variety of embedded applications. The founding team at InCore was previously responsible for the creation of India's first indigenously designed microprocessor (project Shakti at IIT Madras) and for India's first RISC-V silicon on a Linux-capable processor. Along with our partners in design & verification, manufacturing, and packaging, we have created a one-stop spec-to-silicon ecosystem to serve the world's custom silicon needs from India.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
RISC-V Compliance Group. Our CTO, Neel Gala is the co-chair. InCore has been the official maintainer of the RISC-V compliance suite since 2020.
General contact: deepak@incoresemi.com
Sales Office Location: Bangalore, India
Engineering Location: Chennai, India
Major Markets Served / Targeted: Embedded processor cores and SoCs for IoT, consumer and industrial electronics, automotive and military, with use-case focus on security, functional safety (FuSa) and multimedia.
RISC-V Product Categories:

- CPU IP
- Accelerators
- Chips & Processors

Key Product Attributes: InCore's RISC-V cores are heavily customizable at the ISA and Micro-Architecture levels. Our proprietary core-generator approach (powered by BSV, Python and YAML) customers can quickly synthesize a wide range of cores (ranging from deep embedded to high-speed edge compute) all generated from a single code-line. Beyond just cores, we also offer core-hubs which includes all the necessary interconnect fabrics, accelerators and non-core components, to ease SoC designs.

Company name: Lattice Semiconductor
Website: https://www.latticesemi.com
Headquarters Location: Portland, Oregon
Year Founded: 1983

RISC-V International membership level: Community
Major Markets Served / Targeted:
- Industrial and Automotive

RISC-V Product Categories:
- Semiconductor devices

Company Summary: Lattice Semiconductor is the low power programmable leader. We solve customer problems across the network, from the Edge to the Cloud, in the growing communications, computing, industrial, automotive and consumer markets. Our technology, long-standing relationships, and commitment to world-class support lets our customers quickly and easily unleash their innovation to create a smart, secure and connected world.

Company name: Lauterbach
Website: https://www.lauterbach.com/
Headquarters Location: Germany
Year Founded: 1979

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Debug Task Group
- Nexus Trace Task Group
- E-Trace Encapsulation
- Debug, Trace, and Performance Monitoring

Major Markets Served / Targeted:
- Automotive, Mobile, Industrial, Avionics, IoT, Medical

RISC-V Product Categories:
- Software Development & debug tools

Company Summary: Lauterbach is the leading manufacturer of cutting-edge development tools for embedded systems with more than 40 years of experience. It is an international, well-established company, serving customers all over the world, partnering with all semiconductor manufacturers and growing steadily. At the headquarters, near Munich, the engineering team develops and produces highly proficient and specialized, easy-to-use Development Tools under the brand TRACE32®. Subsidiaries in United Kingdom, Italy, France, Tunisia, on the East and West coasts of the United States, Japan and China and highly qualified sales as well as support engineers in many other countries make Lauterbach's full product range available worldwide.

Company name: Microchip Technology
Website: https://microchip.com
Headquarters Location: Chandler, AZ
Year Founded: 1989

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Marketing
- Security
- TEE

Major Markets Served / Targeted:
- Industrial, Aerospace and Defense, Communications, IoT, Medical, Automotive, Data Center

RISC-V Product Categories:
- Semiconductor devices

Company Summary: Microchip Technology Inc. is a leading provider of smart, connected and secure embedded control solutions. Its easy-to-use development tools and comprehensive product portfolio enable customers to create optimal designs which reduce risk while lowering total system cost and time to market. The company solutions serve more than 125,000 customers across the industrial, automotive, consumer, aerospace and defense, communications and computing markets. Headquartered in Chandler, Arizona, Microchip offers outstanding technical support along with dependable delivery and quality.

Company name: MINRES Technologies
Website: https://www.minres.com
Headquarters Location: Germany
Year Founded: 2012

Company Summary: We help customers to establish and improve embedded software engineering processes, methodologies and techniques tailored to meet their specific requirements and capable to adapt to future needs. Our key competency is to enable customers to materialize the full benefits of virtual platforms, which are considered to transform the way embedded software is developed. It is expected that virtual platforms will become a gating technology for future cyber-physical systems.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Fast Interrupt Task Group
- Debug, Trace, and Performance Monitoring
- Architecture Test SIG
- Certification Steering Committee
- Applications & Tools HC
- Debug Task Group
- SOC Infrastructure Horizontal Committee

Major Markets Served / Targeted:
- Embedded

RISC-V Product Categories:
- Virtual Platforms, Performance Analysis & Simulation

Company name: MIPS
Website: https://mips.com
Headquarters Location: San Jose, California
Year Founded: 2019

Company Summary: MIPS is a leading developer of highly scalable RISC processor IP for high-end automotive, computing and communications applications. With its deep engineering expertise built over 35 years and billions of MIPS-based chips shipped to-date, today the company is accelerating RISC-V innovation for a new era of heterogeneous processing. The company's proven solutions are uniquely configurable, enabling semiconductor companies to hit exacting performance and power requirements and differentiate their devices.

RISC-V International membership level: Strategic
Major Markets Served / Targeted:
- Automotive
- HPC & Datacenter
- Communications & Networking

RISC-V Product Categories:
- CPU IP

Company name: Qamcom
Website: https://www.qamcom.com/
Headquarters Location: Gothenburg, Sweden
Year Founded: 2001

Company Summary: Qamcom is a leading Swedish research and technology company with deep competence within hardware, software and system development. Qamcom offers value-driven technology solutions, products and services in the fields of advanced Signal Processing, Industrial AI and IoT, Wireless Communication and System Engineering. Qamcom's mission is to turn technology into value for society, industry and people. Based on insights and the needs of end users, Qamcom bridges the gap between technology and application to enable high ambitions for most industries and contexts.

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Soft CPU

Major Markets Served / Targeted:
- Automotive, telecom, smart city, manufacturing, defense, e-mobility, Greentech, IoT, aerospace, MedTech

RISC-V Product Categories:
- Consultancy, Solutions and R&D

Company name: RISC-V Alliance Japan
Website: https://riscv.or.jp
Headquarters Location: Tokyo, Japan
Year Founded: 2017

RISC-V International membership level: Community
Major Markets Served / Targeted:

- Automotive and Data Center
- Open-Source community

Company Summary: RISC-V Alliance Japan was incorporated as a non-profit organization in Japan. The purpose is to proliferate RISC-V, open silicon technology enabling RISC-V, and system technology enabled by RISC-V to Japan and neighboring countries. Strongly motivated to ally with RISC-V organizations worldwide.

Company name: RIVAI Technologies
Website: https://rivai-ic.com.cn/
Headquarters Location: Shenzhen, China
Year Founded: 2018

RISC-V International membership level: Strategic
Major Markets Served / Targeted:

- data center
- storage
- communications
- networking

RISC-V Product Categories:

- RISC-V CPU cores

Company Summary: Founded at the end of 2018, RiVAI Technology delivers RISC-V high-end core processor solutions. The company has its origins in the UC Berkeley RISC-V project, with its founder and CEO coming from the original RISC-V team. The company develops high-efficiency processor IP cores based on RISC-V designs, custom processor (DSA) design services, and custom chip solutions, enabling customers to meet the high computing power requirements in applications ranging from edge to data center. Its customers include many well-known domestic and foreign companies. RiVAI and its customers work cooperatively through IP authorization and customized SoC development.

Company name: SiFive
Website: https://www.sifive.com
Headquarters Location: Santa Clara, California
Year Founded: 2015
Funding Status: Private
Employee Headcount: >100

Company Summary: SiFive was founded by the inventors of RISC-V. Since then, we've earned more than 350 design wins by meeting previously unachievable performance, power, and area target combinations for today's most challenging workloads. For some applications, SiFive cores deliver comparable performance to equivalent Arm cores at 30% to 40% lower power in a smaller area. Best of all, they give you total control of design, build, and everything else.

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:
- Board of Directors, Technical Steering Committee,

General contact: https://www.sifive.com/contact-sales
Sales & Engineering Locations: US: Santa Clara, San Mateo, Berkeley, CA; Austin, TX; Boston, MA; France; India; Taiwan; Japan; United Kingdom
Major Markets Served / Targeted: Consumer, automotive, datacenter, AI, edge compute
RISC-V Product Categories:
- CPU IP
- Software
- Single Board Computers

Key Product Attributes: The SiFive Core IP portfolio meets customer application-specific needs with four distinct processor families based on the RISC-V ISA and offering scalar and vector high-performance solutions
- **Performance** - A family of high-performance, area-optimized application processors that delivers unparalleled speed and energy efficiency with a small footprint.
- **Intelligence -** Designed to address the future requirements of AI technology to the edge, with high performance scalar and vector compute capability.
- **Automotive -** High-end applications and deterministic real time processors tailored for automotive applications with leading performance in the smallest area, with optimized power consumption.
- **Essential** - A RISC-V processor family that gives you the freedom to start with a standard, pre-defined core, or to employ SiFive Core Designer to build your own processor configuration.

Company name: Synopsys
Website: https://www.synopsys.com
Headquarters Location: Sunnyvale, California
Year Founded: 1986
Funding Status: Public
Employee Headcount: >10,000

Company Summary: Synopsys ARC-V Processor IP™ builds on the existing ARC processor offerings, while giving customers access to the expanding RISC-V ecosystem. Covering a broad range of processor classes, including functional safety versions, the ARC-V portfolio has what you need to address your specific application requirements.
To accelerate software development, the ARC-V processors are supported by the trusted Synopsys MetaWare Development Toolkit. In addition, Synopsys' extensive portfolio of EDA tools provide an out-of-the-box development and verification environment to help design and fully verify RISC-V-based SoCs.

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:
- Board of Directors, Technical Steering Committee,

General contact: https://www.synopsys.com
Sales Office Locations: Global
Major Markets Served / Targeted:
- 32-bit embedded for ultra-low power
- 32-bit real-time for high-speed
- 64-bit host processors with SMP Linux and L2$ support

RISC-V Product Categories:
- CPU IP
- Compiler / development software
- Peripheral IP

Key Product Attributes:
- **Power & Area Efficient -** Achieve maximum performance with minimum power and area consumption
- **Configurable -** Optimize PPA of each processor instance
- **Extensible Instruction Set -** Make application-specific customizations
- **Broad Ecosystem -** Achieve faster time to market

Company name: Tessent Embedded Analytics (Siemens)
Website: https://eda.sw.siemens.com/en-US/ic/tessent/embedded-analytics/
Headquarters Location: Wilsonville, OR
Year Founded: 1847

Company Summary: Part of Siemens, Tessent Embedded Analytics is an industry leader in RISC-V trace and debug, enabling system-wide real-time debug and post-deployment analytics for complex system-on-chips (SoCs).

RISC-V International membership level: Strategic
RISC-V International Working Groups and Committees:
- Debug, Trace, and Performance Monitoring SIG
- E-trace Encapsulation task group

Major Markets Served / Targeted:
- On-chip circuitry and software that accelerates SoC debug, validation, and performance monitoring.
- Fully featured RISC-V trace solution that provides a mehanism to monitor the program execution of a CPU in real time, based on the RISC-V E-trace standard

RISC-V Product Categories:
- Semiconductor design software / EDA

Company name: Ventana Micro Systems
Website: https://www.ventanamicro.com
Headquarters Location: Cupertino, CA
Year Founded: 2018
Funding Status: Private
Employee Headcount: >50

Company Summary: Headquartered in Cupertino, Ventana Micro Systems was founded in 2018 to revolutionize the processor market by offering high-performance, extensible and secure compute chiplets based on RISC-V's open architecture.

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:
- Board of Directors, Technical Steering Committee.

General contact: info@ventanamicro.com
Sales Office Location: Cupertino, CA
Engineering Location: US: Cupertino, CA; India: Bengaluru, Pune
Major Markets Served / Targeted: Data center, automotive, 5G, AI, and client applications
RISC-V Product Categories:
- CPU IP
- Accelerators
- Chips & Processors
- HPC Systems

Key Product Attributes: Ventana offers the data center-class RISC-V processor and platform. It's a fully featured standards-based modular, scalable platform with customer innovation capabilities. The new Veyron V2 is the highest performance RISC-V processor available today and is offered in the form of chiplets and IP. V2 enhancements unleash innovation across data center, automotive, 5G, AI, and client applications.

Company name: Vyoma Systems Private Limited
Website: https://vyomasystems.com
Headquarters Location: Chennai, India
Year Founded: 2021

RISC-V International membership level: Community
Major Markets Served / Targeted:
- SoC development

RISC-V Product Categories:
- RISC-V Verification IP

Company Summary: Vyoma provides ready-to-deploy test generators, checkers and ISA coverage collectors for delivering high quality RISC-V products.

Company name: Win Source Electronic Technology
Website: https://www.win-source.net/
Headquarters Location: Shenzhen, China
Year Founded: 1999

RISC-V International membership level: Strategic
Major Markets Served / Targeted:
- European and American companies

RISC-V Product Categories:
- RISC-V MCUs and CPUs

Company Summary: As a customer-focused online superstore, we constantly improve our service, creating a humanized platform for customers (from best-in-class search and e-procurement engine, ample and up-to-date product information, to 24/7 service), where buyers can get instant access to ready-to-ship safety stock and complete procurement easily with a few quick clicks, rather than frantically calling sources from around the world for parts. At the same time, we offer a wide variety of Value-Added Services to better serve your company. All of our value-added services take place in one of our ESD compliant warehouses and carried out by highly trained (by SMTA & IPC organization) and experienced technicians.

Company name: XuanTie (Alibaba)
Website: https://www.xrvm.com/
Headquarters Location: Hangzhou, China
Year Founded: 2019

Company Summary: XuanTie offers a series of CPU cores, which can meet a full range of performance needs at high, medium, and low levels. XuanTie actively build the RISC-V full-stack software and hardware technology in multiple fields and accelerate the implementation of RISC-V. XuanTie processors are used in industries such as computer vision, data storage, IoT, networking and communication, smart home, biometrics, and information security protection

RISC-V International membership level: Premier
RISC-V International Working Groups and Committees:
- Application and Tools HC, Android SIG, Managed Runtimes SIG, Qemu SIG, RVM-CSI SIG, Unified Discovery SIG, Security Model TG, RAS SIG, Architecture Test SIG, Simulator SIG, Datacenter SIG, Embedded SIG, Server SOC TG.

Major Markets Served / Targeted:
- HPC, ML Acceleration, Big Data

RISC-V Product Categories:
- CPU IP
- Software

XI. Total SoC Market Metrics and Analysis

Table 9: Total SoC Market Revenues by Application 2021–2030

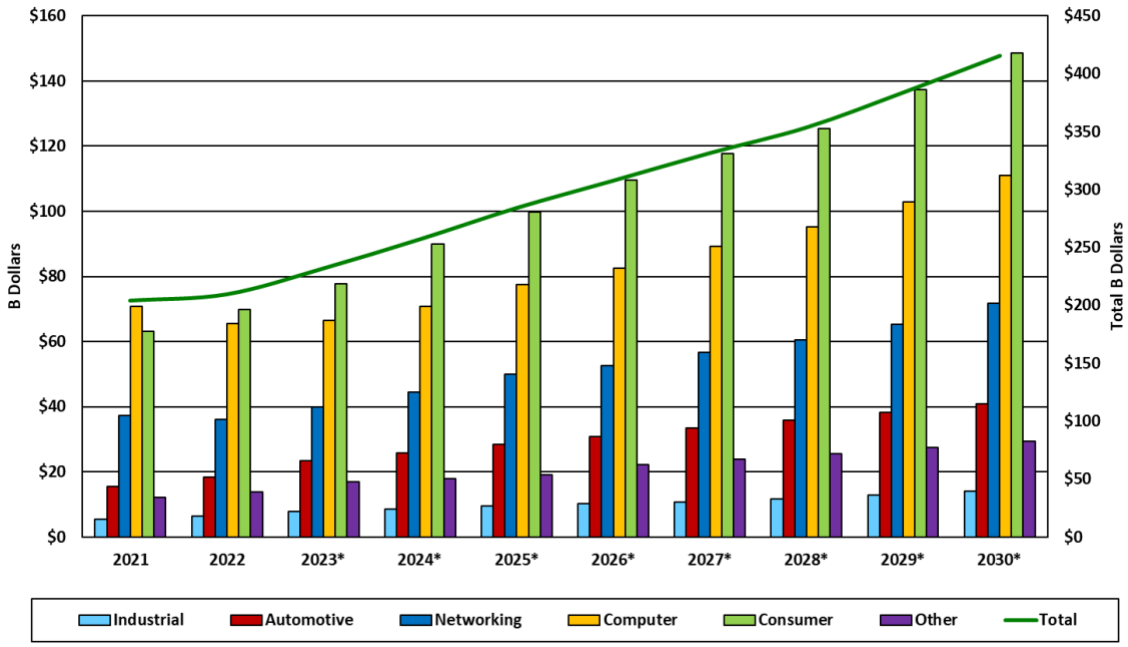
											CAGR %
B Revenues	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Industrial	$5.55	$6.47	$7.86	$8.49	$9.57	$10.17	$10.77	$11.64	$12.83	$14.19	8.8%
Automotive	$15.53	$18.27	$23.30	$25.78	$28.35	$30.80	$33.39	$35.75	$38.33	$40.80	8.3%
Networking	$37.31	$36.10	$39.86	$44.46	$49.97	$52.68	$56.66	$60.52	$65.27	$71.85	8.8%
Computer	$70.81	$65.48	$66.59	$70.88	$77.55	$82.60	$89.26	$95.10	$102.93	$110.93	7.6%
Consumer	$63.07	$69.80	$77.78	$89.98	$99.78	$109.54	$117.81	$125.34	$137.31	$148.59	9.7%
Other	$12.23	$13.83	$16.91	$17.87	$19.22	$22.20	$23.94	$25.56	$27.36	$29.30	8.2%
Total	$204.49	$209.96	$232.31	$257.46	$284.44	$307.99	$331.83	$353.91	$384.02	$415.67	8.7%
Percent Growth		2.7%	10.6%	10.8%	10.5%	8.3%	7.7%	6.7%	8.5%	8.2%	

***Forecast** **Source: The SHD Group, January 2024**

Total SoC market revenues reached $232.3B in 2023, a growth of 10.3% over 2022 and are forecast to grow to $415.7B by 2030, a CAGR of 8.7%. The SoC market, in general, is characterized by rising complexity levels driven in part by the introduction of AI and continuing increases in connectivity and computing performance requirements.

- The Consumer segment is the largest category at $77.8B in 2023, a growth of 11.4% over 2022. It is forecast to reach $148.1B by 2030, a CAGR of 9.7%, and driven by all cell phones, UHDTVs, game consoles, and other high-value consumer systems. The Computer segment is the second highest category, reaching $66.5B in 2023, a growth of 1.7% over 2022. It is forecast to grow to $110.9B by 2030, a CAGR of 7.6% over the forecast period of the identified applications.
- The Computer segment is the second highest category, reaching $66.6B in 2023, a growth of 1.7% over 2022. It is forecast to grow to $110.9B by 2030, a CAGR of 7.6% over the forecast period of the identified applications.
- The Networking market represents the 3rd largest category and reached $39.9B in 2023, growing 10.4% over 2022. It is forecast to reach $71.9B by 2030, driven by networking switches and infrastructure build-out, with a CAGR of 8.7%.
- The Automotive segment is undergoing a complete transformation as ADAS and other AI functionality are being added along with the electrification of vehicles in general. This market was $23.3B in 2023 and grew 27.6% over 2022. It is forecast to reach $40.8B by 2030, a CAGR of 8.9%.
- The Other category has the 5th lowest growth rate and is projected to reach $29.3B by 2030, a CAGR of 8.2%.
- The Industrial segment is the smallest market, reaching $7.9B in 2023, a growth of 21.4% over 2022 and is forecast to reach $14.2B by 2030, a CAGR of 8.2%.

Figure 28: Total Market Revenues for all SoCs by Application 2021–2030



*Forecast

Source: The SHD Group, January 2024

Table 10: Total Market Unit Shipments for all SoCs by Application 2021 - 2030

											CAGR %
M Units	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Industrial	1,459.8	1,701.3	1,973.4	2,232.1	2,503.8	2,766.5	3,036.2	3,466.8	3,935.0	4,572.8	12.8%
Automotive	721.7	825.6	1,284.9	1,429.7	1,571.4	1,714.4	1,888.8	2,056.8	2,269.9	2,505.4	10%
Networking	2,425.9	2,805.8	3,180.6	3,559.6	4,177.4	4,614.1	5,131.8	5,679.3	6,412.7	7,346.2	12.7%
Computer	5,655.0	5,441.1	5,630.2	5,957.9	6,488.9	6,945.6	7,556.9	8,135.0	8,994.6	9,701.7	8.1%
Consumer	13,070.1	14,005.4	14,986.8	17,383.8	19,873.1	22,855.6	25,565.3	28,596.4	33,413.6	37,918.9	14.2%
Other	2,548.4	2,874.3	3,300.7	3,518.5	3,976.4	4,683.1	5,247.6	5,845.0	6,602.7	7,238.7	11.9%
Total	25,881.0	27,653.4	30,356.7	34,081.6	38,590.9	43,579.2	48,426.5	53,779.4	61,628.5	69,283.8	12.5%
Percent Growth		6.8%	9.8%	12.3%	13.2%	12.9%	11.1%	11.1%	14.6%	12.4%	

*Forecast

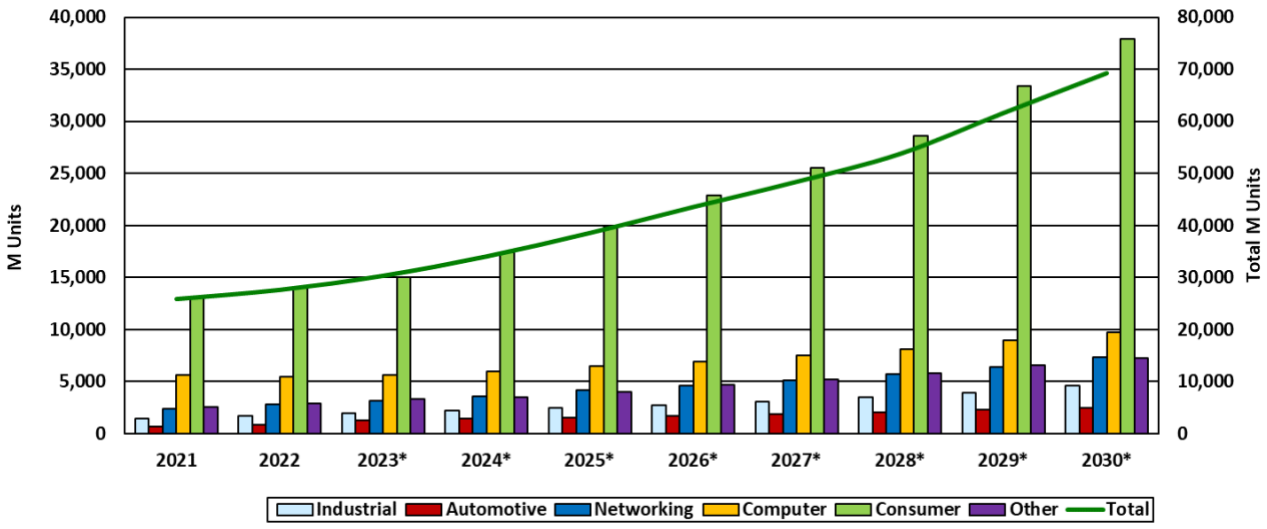
Source: The SHD Group, January 2024

Total SoC market unit shipments reached 30.4B units in 2023, a growth of 9.8% over 2022 and is forecast to grow to 69.3B units by 2030, a CAGR of 12.5%. The SoC market, in general, is characterized by rising complexity levels driven in part by the introduction of AI and continuing increases in connectivity and computing performance requirements.

- The Consumer segment is the largest category at 15.0B in 2023, a growth of 7.0% over 2022. It is forecast to reach 37.9B units by 2030, a CAGR of 14.2%, and driven by all cell phones, UHDTVs, wearables, and other high-volume consumer systems.

- The Computer segment is the second highest category, reaching 5.96B units in 2023, a growth of 3.5% over 2022. It is forecast to grow to 9.7B units by 2030, a CAGR of 8.1% over the forecast period of the identified applications.
- The Other category has the 3rd largest growth rate at 3.3B in 2023 and is projected to reach 7.2B units by 2030, a CAGR of 11.9%.
- The Networking market represents the 4th largest category and reached 3.2B units in 2023, growing 13.4% over 2022. It is forecast to reach 7.3B units by 2030, driven by networking switches and infrastructure build-out, with a CAGR of 12.7%.
- The Industrial segment is the 2nd smallest market, reaching 1.97B units in 2023, a growth of 16.0% over 2022 and is forecast to reach 4.6B units by 2030, a CAGR of 12.8%.
- The Automotive segment is undergoing a complete transformation as ADAS and other AI functionality is being added along with the electrification of vehicles in general. This market was 1.3B units in 2023 and grew 55.6% over 2022 as a great deal of new functionality is being added to vehicles of all types. It is forecast to reach 2.5B units by 2030, a CAGR of 10%.

Figure 29: Total SoC Market Unit Shipments by Application 2021–2030



***Forecast** **Source: The SHD Group, January 2024**

XII. Total IP Market Analysis

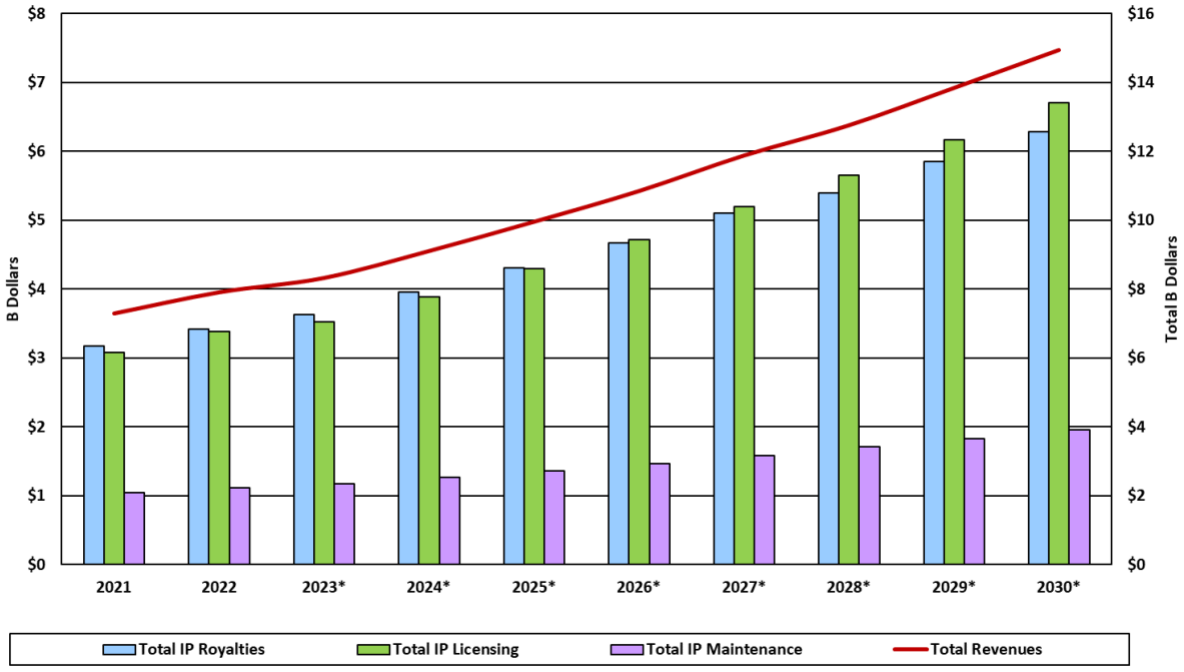
This section looks at the current state of the overall IP market, the CPU IP market as a subset of that and a breakdown of the CPU IP Market by Instruction Set Architecture (ISA).

Table 11: Average Number of IP Blocks in SoC Designs 2021–2028

											CAGR %
B Dollars	**2021**	**2022**	**2023***	**2024***	**2025***	**2026***	**2027***	**2028***	**2029***	**2030***	**23 - 30**
Total IP Royalties	$3.2	$3.4	$3.6	$4.0	$4.3	$4.7	$5.1	$5.4	$5.9	$6.3	8.1%
Total IP Licensing	$3.1	$3.4	$3.5	$3.9	$4.3	$4.7	$5.2	$5.7	$6.2	$6.7	9.6%
Total Maintenance	$1.0	$1.1	$1.2	$1.3	$1.4	$1.5	$1.6	$1.7	$1.8	$2.0	7.5%
Total	$7.3	$7.9	$8.3	$9.1	$10.0	$10.9	$11.9	$12.8	$13.8	$14.9	8.7%
Percent Growth	9.2%	8.4%	5.3%	9.4%	9.3%	8.9%	9.5%	7.4%	8.5%	7.9%	

***Forecast** **Source: The SHD Group, January 2024**

Figure 30: Total IP Market Revenues 2021–2030



***Forecast** **Source: The SHD Group, January 2024**

- Total IP royalties reached $3.4B in 2022 and are forecast to grow to $6.3B by 2030, a CAGR of 8.1%.
- Total IP licensing revenues were $3.4B in 2022 and are forecast to reach $6.7BM by 2030, a CAGR of 9.6%.
- Total IP maintenance revenues were $1.2B in 2022 and are forecast to reach $1.7B by 2030, a CAGR of 7.5%.

- Total 3rd party IP revenues were $7.9B in 2022 and are forecast to reach $14.9BB by 2030, a CAGR of 8.7%.

The state of the total 3rd party semiconductor IP market today is strong, demonstrating good growth attributed to the escalating complexity of devices and the need to add increasing levels of functionality and richer feature sets as market requirements increase. This increase in functionality is being added by the increasing use of IP and the number of IP blocks being instantiated into SoCs of all types and complexity. Presently, royalty revenues marginally surpass licensing revenues. As billions of SoCs incorporating 3rd party IPs are shipped, the increase in IP integration within evolving SoCs indicates a continual rise in royalty revenues as these SoCs evolve with enhanced performance and functionality.

The SHD Group's forecast indicates that royalty revenues are poised to outpace licensing revenues due to several key factors:

- The ongoing emergence of AI accelerators and their associated applications.
- The ascent of chiplet designs requiring IP translates into an increase in IP licensing and royalty revenues.
- An initial surge in licensing revenues as companies secure IP for new chiplet designs, followed by a shift where royalty revenues surpass licensing revenues as products commence volume shipments.
- The impact on licensing revenues may not be substantial initially with chiplets, possibly representing a smaller subset of the overall IP market.

Reflecting on historical trends within the IP market, similar patterns emerged as specific types of IP entered the market, requiring rush licensing to meet market demands. For instance, the introduction of HDMI or SerDes IP required time for unit volumes to scale up, leading to a translation into royalty revenues. Eventually, as competition increased, previously sole-source IP, such as HDMI, transitioned into multi-sourced solutions, leading to a decline in licensing costs.

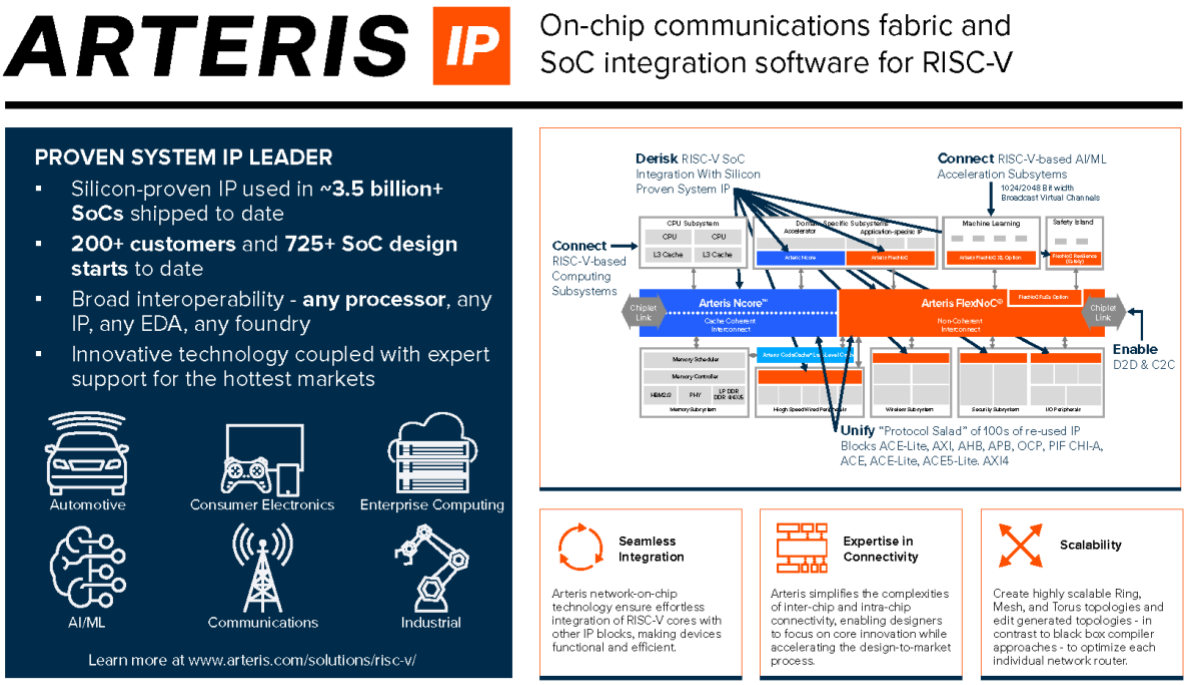
It's crucial to note that the total IP numbers encompass a wide array of IP categories, some of which are presently costly to license, while others are relatively affordable. This diversity has a moderating influence on licensing revenues.

The SHD Group anticipates an accelerated growth trajectory in licensing revenues, foreseeing the entry of various IP types into the market. Simultaneously, royalty revenues continue to grow as more SoCs are shipped into the market. Arm partners alone shipped 30.6 billion units in 2022, signifying growth potential for vendors offering different IP types. The expectation is for royalty revenues to steadily accelerate over time, portraying a more consistent growth rate compared to the fluctuations seen in the licensing segment.

While maintenance revenues currently constitute the smallest category in the IP market, they are also on a growth trajectory, albeit at a slower rate compared to licensing and royalty revenues. The SHD Group expects this trend in maintenance revenues to persist at a similar pace over the forecast period.

Overall, the IP market holds substantial significance within the SoC design community and is expected to maintain its importance in the foreseeable future, considering its pivotal role in advancing SoC evolution and functionality.

Figure 31: IP Support for Complex SoC Designs, Courtesy of Arteris



An example of how the ecosystem is building out around the RISC-V CPU is shown in Figure 83 above. Arteris is the leading interconnect IP vendor in the market today and has support for both Arm CPU cores and RISC-V CPU cores in SoC designs. Interconnect IP ties all the IP blocks in an SoC design together allowing them to communicate with each other and manages the flow of data between the blocks in the design.

One of the important factors that allows design complexity to increase is the ability of interconnect IP to grow as the designs grow, providing the right level of communication bandwidth between the blocks. Another key factor in growing design complexity is the increase in the size of the embedded memories used in these SoCs, as well as the memory wall that requires smart data transport architectures to supply the computing engines with the appropriate data while reducing access to external DRAMs. Extensive use of cache memories, especially for AI-enabled designs and complex computing architectures, requires networks-on-chip (NoCs) to offer cache-coherency capabilities to SoC designers.

With the reuse of significant numbers of IP blocks in RISC-V designs, the on-chip interfaces of these IP blocks are not necessarily RISC-V specific. They typically follow industry standards like AMBA AXI, CHI, OCP, and others. Arteris' supports RISC-V SoC designs and relieve designers of the task of creating these very complex on-die communications channels by themselves, saving time and resources, and de-risking top-level integration beyond the RISC-V portions of designs. Arteris also provides IP-XACT based SoC Integration Automation technology for the integration of IP blocks and Control Status Register (CSR) automation.

As time passes, more IP vendors are joining in support of RISC-V designs, aiding in the growth of the RISC-V ecosystem, a sure sign of industry support for this ISA.

Figure 32: RISC-V Ecosystem Continues to Grow, InCore Semiconductor

Source: InCore Semiconductor, January 2024

InCore Semiconductor provides RISC-V related IP and design services, leveraging a unique design methodology for CPU core development with significant automation for IP and SoC implementations. InCore emphasizes the design of RISC-V accelerators to leverage heterogeneous multicore designs in recognition of the growing shift in SoC design to this type of architecture.

Their RISC-V designs enable domain-specific accelerators, aligning with the industry's shift towards heterogeneous multicore designs, along with full customization. This strategic focus aligns with the broader market dynamics of RISC-V where the total market for RISC-V IP, valued at $156M in 2023, is forecasted to reach nearly $1.6B by 2030, with a CAGR of 39%, reflecting the significant growth opportunities for companies like InCore.

XIII. Conclusions and Recommendations

As design complexity has risen over time in response to market requirements and demands, we have seen the semiconductor and EDA industries respond with continued inventiveness and ingenuity with new, more comprehensive solutions that enter the market. This is a continuous process of innovation that has evolved to give SoC silicon designers an unprecedented capability to create very innovative and powerful solutions that are employed throughout our society and economy.

The IP market has been one of the main drivers of innovation for SoC designers, constantly refining and improving their products in response to rising market requirements and demands.

The introduction of the RISC-V ISA is a direct response to the evolutionary forces that drive the industry to develop ever more creative and powerful products. While it is a coincidence that RISC-V has emerged just as the AI functionality has emerged, RISC-V can ride the AI wave as it happens and experience some of the same growth that Arm and other CPU and IP vendors experienced as the mobile phone took off.

The SHD Group believes that the RISC-V architecture represents an opportunity for growth and innovation to those companies that are forward-thinking and innovative in their constitution.

We also believe that IP subsystems and chiplets based around the RISC-V architecture can provide additional areas for growth in the near future.

The future is indeed bright for RISC-V!

XIV. Acknowledgements

The SHD Group wishes to thank the following companies who have either contributed direction to the insights and data points in this report, agreed to be interviewed, or advised us in the overall report construction.

Andes Technology	Imperas
Arowanie	InCore Semiconductors Pvt. Ltd.
Arteris	Intel Corporation
Axelera AI	MIPS
Beijing Institute of Open Source Chip	Menta
Bluespec	Nexty Electronics
Breker Systems	Open Hardware Group
Codasip	Red Hat
E4 Computer Engineering	RISC-V International
Electronics and Telecommunications Research Institute	Siemens
Eliyan Labs	SiFive
Emproof	SUSE
Esperanto Technologies	Synopsys
Hemisphere Ventures	Ventana Micro Systems

A special thank you to the many sponsors that contributed to the success of this report.

XV. Report Methodology

Data sources were a combination of public and private data gathered by company briefings and interviews.

The SHD Group has conducted both primary and secondary research to compile this report. We have also completed 30+ in-person interviews with companies prominent in the RISC-V ecosystem to get their perspectives on how they view the market today and into the future. We have kept responses by interviewees anonymous, if so requested.

XVI. Comparison of Abridged vs Complete Report

This is an abridged version of a more comprehensive, detailed RISC-V report. The complete report, unabridged, is 225 pages in length, with 107 tables and 89 figures. Below is a list of the additional Tables and Figures included in the Complete report. To obtain information about receiving the full report version, please contact m.kinman@theshdgroup.com

Additional Tables in Full Report

Additional Figures in Full Report