A Forrester Total Economic Impact™
Study Commissioned By Arm
June 2020

The Total Economic Impact™ Of Arm Neoverse

Infrastructure Cost Savings And Increased Development Efficiency Delivered By Servers Based On Neoverse

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Benefits And Costs

30% to 60% lower upfront infrastructure costs

15% to 35% lower ongoing infrastructure costs

Cloud infrastructure cost savings of up to 80%

Executive Summary

The Arm Neoverse platform is a silicon architecture that has supporting system IP and broad ecosystem backing, which together provide the capabilities to develop specialized processors. Arm commissioned Forrester Consulting to conduct a Total Economic Impact™ (TEI) study and examine the potential benefits enterprises may realize by either deploying Neoverse-powered servers or adopting related cloud-based services. The purpose of this study is to provide readers with a framework to evaluate the potential financial impact of Arm Neoverse-based compute infrastructure on their organizations.

To better understand the benefits, costs, and risks associated with this investment, Forrester interviewed and surveyed several customers with experience using Neoverse, as well as two related cloud service providers. The Arm architecture enables the development of building blocks for dense, low cost, and energy efficient servers, which have a small footprint, low power, and performant compute silicon. The designs can be optimized to address specific workload requirements.

For end user organizations, this enables significant infrastructure cost savings for particular workloads and use cases. Furthermore, there are additional productivity benefits for developers of Arm-based applications because they avoid the need to emulate and/or cross compile. On the supply side, the Neoverse platform enables silicon developers, server suppliers, and cloud service providers to diversify their portfolios and address broader customer requirements.

Prior to Neoverse, the necessary infrastructure for compute mostly relied upon servers based on traditional processors or proprietary GPU-based systems for specific use cases or cloud services that are based on such technologies. For a number of use cases, these options were inefficient and suboptimal.

Key Findings

Quantified benefits. The following quantified benefits are representative of those experienced by the on-premises electronic design automation (EDA) use case:

- **Upfront infrastructure costs are 30% to 60% lower.** Processors based on Arm architecture have a smaller footprint, which enables a higher density of cores per server and therefore reduces the number of servers that need to be acquired and installed. Furthermore, the hardware acquisition cost of servers, based on Arm architecture, is nearly 20% lower. As a result, upfront and ongoing infrastructure costs are significantly lower for several use cases.
- **Ongoing infrastructure costs are 15% to 35% lower.** The ongoing costs of Arm-based servers are lower because they are more power efficient and require less cooling. Furthermore, because there are fewer servers required, the associated maintenance and facilities costs are also lower. The ongoing Arm server costs are 33% lower on a per core basis.

These on-premises infrastructure cost savings also translate to cloud-based offerings, which enable cost savings of up to 80% in some cases.

Unquantified benefits. The organizations experienced the following benefits, which are not quantified for this study:

- **Increased developer productivity for Arm-based applications.** In use cases when Arm-based infrastructure supports software or services for endpoints, developers avoid the need to emulate and cross compile from one architecture to another, reducing the need for some complex tasks; it can also increase server reliability and reduce costs.
- **Supply-side benefits.** The Arm architecture and ecosystem enables optimized development of compute silicon so that environments are better tailored for specific workloads; organizations across the ecosystem can partner and coordinate in flexible ways to build optimized silicon. Furthermore, Arm-based servers provide an alternative to pervasive traditional servers and related architectures, thus increasing supply-side diversity.

Costs. The organizations experienced the following costs:

- **Planning and implementation costs.** The Arm server ecosystem is relatively young, and as such, it is important that organizations plan and prepare for transitions and migrations. For cloud-based migrations, there is strong support available from the cloud service providers. In cases where organizations are not familiar with the Arm architecture, planning and migration costs are typically equivalent to around two weeks of a senior engineer's time. This time might be used to ensure that support tools and software are available to test, upgrade operating systems, and troubleshoot.

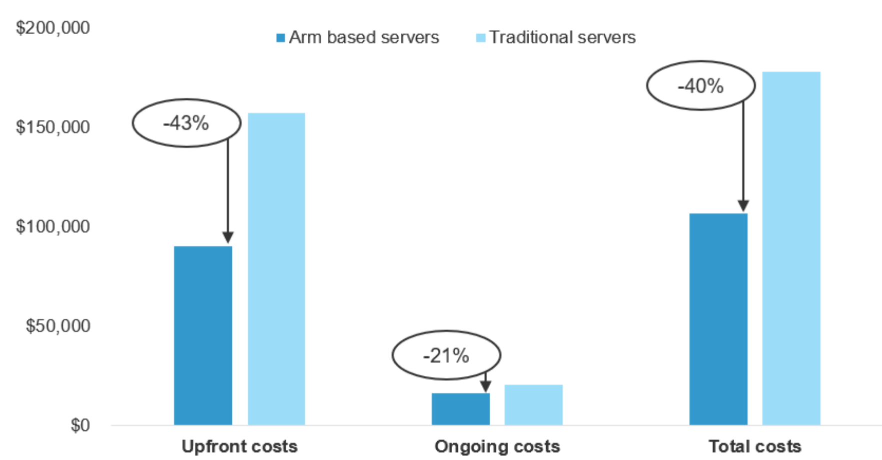
Forrester's interviews with four existing customers, a survey of 57 organizations, and the subsequent financial analysis found that an organization based on the EDA use case, of needing to have the capability to run 400 parallel simulation iterations, can reduce its upfront infrastructure costs by 43% and its ongoing infrastructure costs by 21%. Over the three years, this equates to a total cost savings of 40%, achieving a net present value of nearly $72K and an ROI of 67%. The business case for adopting cloud services based on Arm Neoverse servers is also strong for a number of use cases.

ROI
67%

Benefits PV
$178,121

NPV
$71,517

Upfront, three-year ongoing and total cost comparison of Arm and traditional servers for 400-core EDA simulation



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TEI Framework And Methodology

From the information provided in the interviews and the survey, Forrester has constructed a Total Economic Impact™ (TEI) framework for those organizations considering implementing Arm Neoverse.

The objective of the framework is to compare the costs of an Arm-based implementation vs a traditional server implementation. Forrester took a multistep approach to evaluate the impact that Arm Neoverse can have on an organization:

The TEI methodology helps companies demonstrate, justify, and realize the tangible value of IT initiatives to both senior management and other key business stakeholders.

DUE DILIGENCE
Interviewed Arm stakeholders and Forrester analysts to gather data relative to Neoverse.

CUSTOMER INTERVIEWS AND SURVEY
Interviewed four customers and two cloud service providers and surveyed over 50 organizations to obtain data with respect to costs, benefits, and risks.

REPRESENTATIVE USE CASES
Modelled a range of core-count implementations around the EDA use cases based on characteristics of the interviewed and surveyed organizations.

FINANCIAL MODEL FRAMEWORK
Constructed a cost comparison financial model representative of the EDA use case.

CASE STUDY
Employed four fundamental elements of TEI in modeling Arm Neoverse's impact: benefits, costs, flexibility, and risks. Given the increasing sophistication that enterprises have regarding ROI analyses related to IT investments, Forrester's TEI methodology serves to provide a complete picture of the total economic impact of purchase decisions. Please see Appendix A for additional information on the TEI methodology.

The Neoverse Customer Journey

BEFORE THE NEOVERSE INVESTMENT

Interviewed Organizations

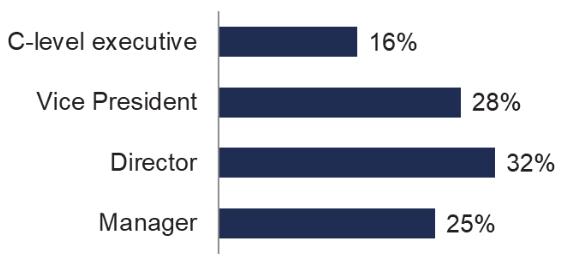
For this study, Forrester conducted four interviews with Arm Neoverse customers:

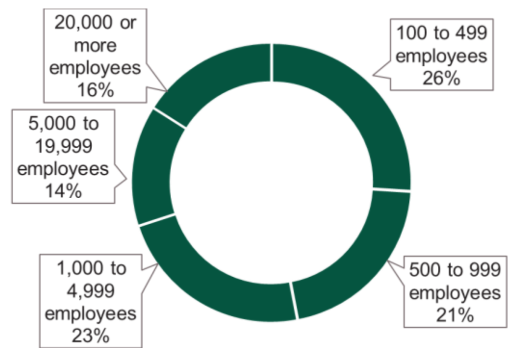
INDUSTRY	REGION	INTERVIEWEE	USE CASE	IMPLEMENTATION
Silicon development	Headquartered in US	Technologist, advanced silicon development	EDA	On-premises
Cloud photo storage	Headquartered in US	Principal operations manager	Image processing	Cloud – AWS
Mobile gaming	Headquartered in Europe	Director of cloud operations	Cloud gaming services	Cloud – Packet
Virtualization tools	Headquartered in US	CMO	Software development scale out	Cloud – AWS

The EDA use case has been modelled and is the only on-premises implementation of the four shown above, although it can also be done in the cloud. Forrester also conducted interviews with two cloud service providers, which support the Arm architecture; one of which, Amazon Web Services (AWS), supports the cloud photo storage and virtualization tools use cases, and the other, Packet, supports the mobile gaming use case.

Surveyed Organizations

For this study, Forrester surveyed 57 mostly IT decision makers in organizations of varying size that were either running or planning to run workloads on optimized silicon.





Key Challenges

Some of the key challenges and drivers behind investments into the Arm architecture were:

- **Pressure on infrastructure costs.** Infrastructure decision makers have a number of different priorities, as these are typically aligned with organizations' business goals. Reducing costs is a high or critical priority for 46%.

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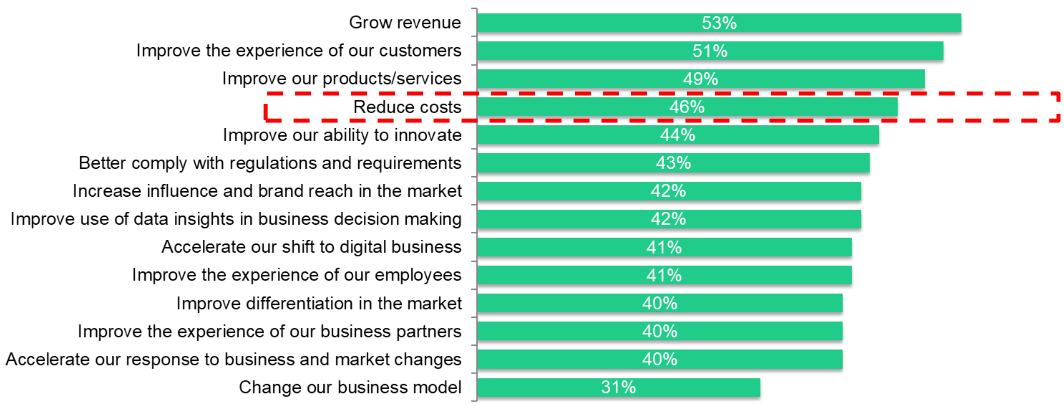
"Which of the following initiatives are likely to be your organization's top business priorities over the next 12 months?"

(High and critical priority respondents)



Base: 3,634 infrastructure decision makers
Source: Forrester Analytics Global Business Technographics® Infrastructure Survey, 2019

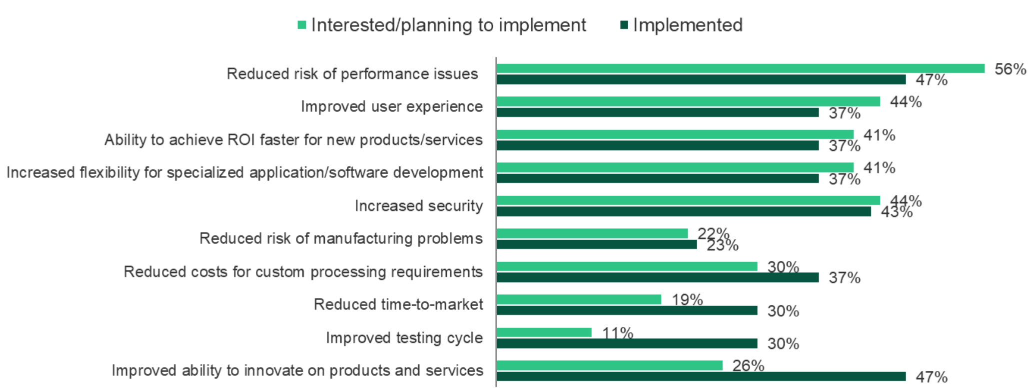
- **Space and power are limited resources.** The cost of power and real estate is an important consideration for any infrastructure environment. In edge environments, such as mobile network towers, the limitations are even more important.
- **Emulation and cross-compilation costs for Arm-based applications.** Cross compiling and emulating from one hardware architecture to another can be time-consuming, complex, and prone to error. Developers building Arm-based applications have to spend time and resources on the development and testing of non-Arm environments.

> "We rely heavily on cloud service providers; reducing these costs has a significant impact."
>
> *Principal operations manager, cloud photo storage*

There are a number of different applications and use cases for which alternative processor architectures or optimized silicon are typically considered; these can be broadly broken down into scale-out and intensive processing types. The chart below highlights the most important application characteristics that led to the consideration of alternative general central processor architectures or specialized silicon accelerators.

"Which of the following benefits have you realized/expect to realize as a result of migrating to alternative general central processor architectures or specialized silicon/accelerators?"

(Select all that apply)



Base: 57 manager level and above decision makers involved in IT architecture/infrastructure decisions at organizations who are interested in, planning to implement, or have implemented specialized silicon/accelerators
Source: A commissioned study conducted by Forrester Consulting on behalf of Arm, December 2019

Key Results

The interviews and survey data revealed that key results from the Neoverse investment include:

- **Reduced cloud infrastructure costs.** By moving to Arm-based cloud instances, organizations can significantly reduce infrastructure-related cloud costs. These cost efficiencies not only include reduced cloud service fees but also the additional benefits of moving from on-premises to the cloud.
- **Reduced on-premises infrastructure costs.** Upfront and ongoing infrastructure costs can be brought down, as in many cases hardware acquisition costs are reduced. This is due in part to both the higher core-per-server count and the reduced costs per server and per core. Furthermore, power consumption is more efficient and less heat is emitted, which reduces the costs of running the servers.
- **Developer productivity improvement when building Arm-based applications.** The need for emulation and cross-compilation when developing across heterogenous hardware environments creates additional cost and complexity. Working in an Arm-based environment to develop Arm-based applications eliminates the need for emulation and/or cross-compilation between the client and server, freeing up developer time and reducing cost and complexity.

"The performance profiles were appropriate for the workload so we could leverage Arm for cost savings. There is potential for 30% to 40% in cost savings per core; that is not insignificant."

Principal operations manager, cloud photo storage

EDA Use Case Modeling

The model Forrester built for this analysis is based on the EDA on-premises use case. It compares the cost of implementing and running silicon simulation software on Arm servers vs traditional servers at various core counts. The required software incurs typical annual license fees of $10K to $20K per core. An important caveat, however, is that organizations may choose to spend more on high performance hardware in order to reduce both their software requirement and overall costs.

The starting point of this analysis assumes the need for a certain number of simulations able to run in parallel, and so, a certain number of cores. The three-year upfront and ongoing costs of infrastructure for 50, 100, 200, 300, 400, and 500 cores were compared on the Arm compute architecture with general-purpose processor servers.

"When developing and testing for Arm-based applications, the Arm architecture is more reliable, more productive, and reduces complexity. There are cost efficiencies of up to 45% compared to general-purpose instances."

CMO, virtualization tools

Composite Organization

Description of composite. The composite organization is a large, US-based silicon design and manufacturing business. It is assumed that it had internal resources already familiar with the Arm architecture. While the modeling has been done for six different core counts, the results of the 400-core requirement are provided in more detail. These simulation workloads are not very compute heavy, but they require more network and disk input-output.

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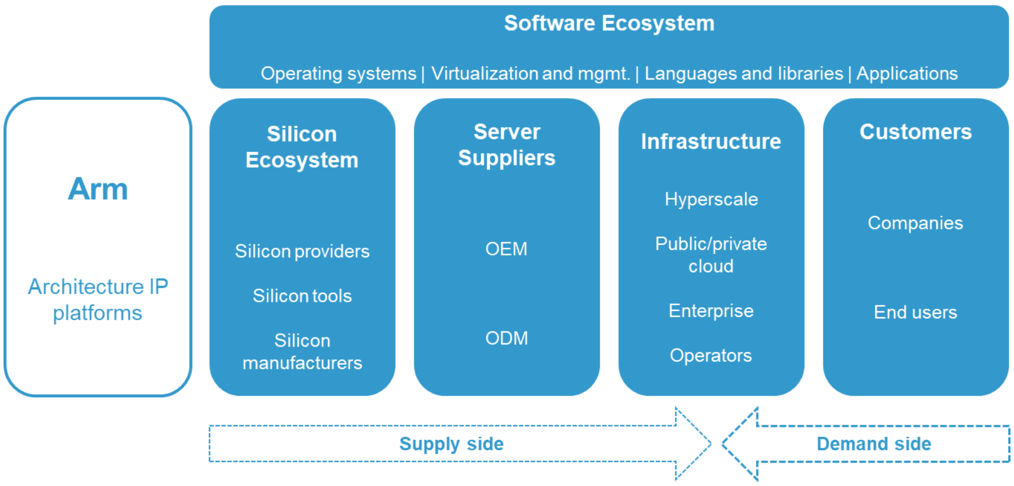
Analysis Of Benefits

BENEFITS ACROSS THE ECOSYSTEM

The Arm architecture supports a diverse ecosystem around infrastructure, consisting of five main components:



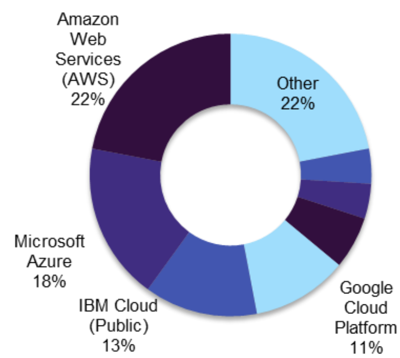
- The silicon ecosystem comprises of various elements which result in the fabrication of processors and include silicon vendors, related tools providers, and chipset manufacturers. Silicon design is an inherent part of this component, based around the architecture which Arm provides as IP.
- The server suppliers are the manufacturers that incorporate the processors into their server designs; these can either be branded servers or built to order.
- The infrastructure component includes any organization operating a data center, i.e., cloud service providers, telecom operators, and other enterprises. These organizations acquire servers from the server suppliers to deploy in their server farms.
- The customers are the end users of the infrastructure; whether they are in fact customers of the cloud service providers or organizational users that operate an application on server farms.
- The software ecosystem sits across these four pillars, and includes operating system developers, virtualization, and related technology providers, and the application vendors.

While these components are shown separately here, they can span across the same organization — this demonstrates one of the important benefits of the Arm architecture, namely, the ability to bring different parts of the ecosystem together in order to flexibly develop tailored silicon.

The ecosystem benefits have been broken down into demand side (i.e., those using infrastructure) and supply side (i.e., organizations providing infrastructure or components thereof). This report is mostly concerned with demand-side benefits, having interviewed a number of end user organizations. However, it is also clear that there are supply-side benefits.

Although the ecosystem is still relatively young, it is maturing. In particular, AWS, the largest hyperscaler cloud service provider, has

"Which vendor product does your firm currently use or plan to use as their primary public cloud platform provider?"



Base: 2,729 infrastructure decision makers whose firms are planning, implementing, or expanding public cloud adoption
Source: Forrester Analytics Global Business Technographics® Infrastructure Survey, 2019

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developed its own AWS-designed, Arm-based silicon: Graviton, which is now in its second generation (Graviton2 processors). Indeed, AWS itself benefits both on the supply- and demand-side, as described below.

Benefits Summary

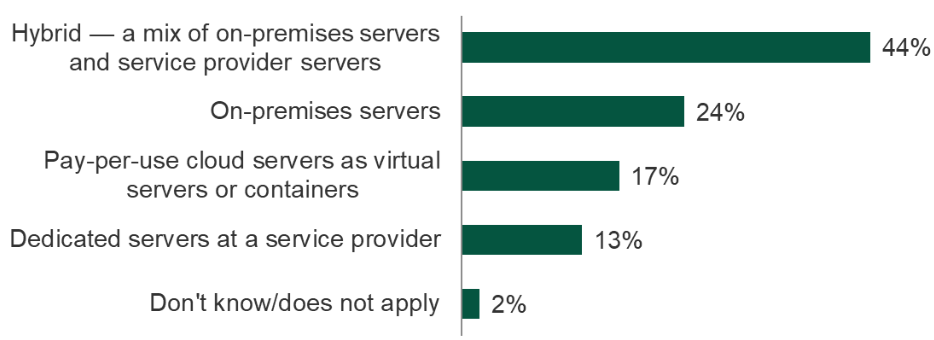
DEMAND-SIDE BENEFITS	DESCRIPTION
1. Infrastructure cost savings	For a number of use cases, the higher density and energy efficiency of Arm-based servers enables significant infrastructure cost savings, whether in cloud or on-premises environments.
2. Developer efficiencies	Emulation and cross-compilation processes for developers are avoided for the development of Arm-based applications.
SUPPLY-SIDE BENEFITS	**DESCRIPTION**
3. Custom silicon development	Organizations of sufficient scale can design their own silicon, based on the Arm architecture to address specific workload requirements.
4. Ability to address broader customer requirements/widen portfolio	The Arm architecture provides various parts of the ecosystem with the opportunity to develop new products and services that can address different customer needs.

Benefit 1: Infrastructure Cost Savings

Across the four use cases that were analyzed, hardware or cloud cost savings are a consistent upside of the optimized silicon vs general-purpose processors. The chart below demonstrates that both on-premises and service provider servers are used in non-traditional or specialized silicon/accelerator architecture environments.

"On which type of servers do you currently run alternative general central processor architectures* or specialized silicon/accelerators?"

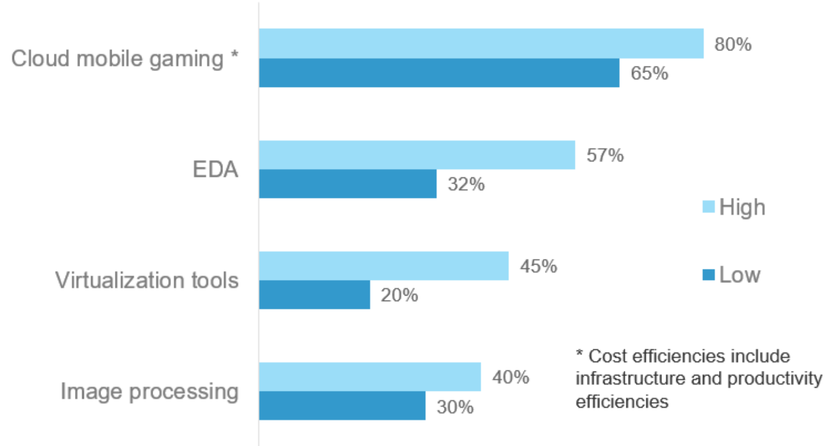
(Select one)



Base: 54 manager level and above decision makers involved in IT architecture/infrastructure decisions at organizations who are interested in, planning to implement, or have implemented specialized silicon/accelerators
Source: A commissioned study conducted by Forrester Consulting on behalf of Arm, December 2019

Forrester's research shows that through the adoption of Arm architecture, there are important opportunities to reduce costs for both cloud-based and on-premises-based infrastructures. Two of the analyzed use cases in this report are based on Arm instances offered by AWS; more details are provided in the Benefit 4 section further below.

The following chart summarizes the range of infrastructure cost savings that interviewees highlighted.



However, some context is required to understand the scope of cost efficiencies, which were provided by the interviewees.

- The case for cloud gaming on mobile devices is the strongest: such cloud native applications can most efficiently and reliably be delivered on Arm architecture because the client device also runs on Arm architecture, therefore avoiding the need for an emulation step. Cost efficiencies, including infrastructure and other productivity-related gains, are significant: between 65% and 80%.
- The case for EDA is a strong one that is purely based on the infrastructure cost savings, which range from 32% to 57%. However, the performance difference must also be taken into account, which may require a mix of different processor architectures to address different workload requirements.
- The virtualization tools use case can deliver infrastructure cost efficiencies of up to 45% alone. This can be broadened to a microservices or scale-out use case, where a particular element or layer of the application can run on Arm architecture. This is similar to the image processing case below, where a workload of the overall cloud applications can be delivered on Arm. However, in the case of internet-of-things (IoT) software development, there are additional benefits in terms of developer productivity because, like the cloud gaming use case, the architecture of the device (in this case the network component in IoT technology) is based on Arm architecture.
- The image processing use case, as mentioned above, uses Arm architecture in a microservices environment. There is scope to reduce the cloud infrastructure costs by 30% to 40%, related to image processing. This organization also told us that there is a potential to use Arm architecture for web-serving microservices, although the scope for cost savings is not so significant. This point was echoed by one of the cloud service providers we interviewed.

"Because Arm server processors typically carry higher CPU core counts and there are efficiencies in terms of power, heat and space, we see potential cost efficiencies of three-to-five times; this is also because all mobile handsets are compatible with the content of the games."

Director of cloud operations, mobile gaming service provider

"It's 3-to-5 times more efficient in the cloud mobile gaming use case. The general, web server, use case such as Nginx, will also work fine, but it won't blow your socks off."

CMO, cloud service provider

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- In addition to the four use cases, AWS itself also benefits on the demand side because it is, itself, a user of Arm servers internally. It has benefited from moving some internal services to the Graviton-based infrastructure, and thus reduced its costs: not only in the power savings and optimization efficiency gains but also in reduced hardware acquisition costs. (AWS acquired Annapurna Labs and so has the internal capabilities to design silicon[1].)

Benefit 2: Developer Efficiencies

Developers building Arm-based applications can eliminate the costs and complexities associated with emulation and cross-compilation. Two such use cases, cloud mobile gaming and IoT software development, are analyzed in this report. Because the server and endpoint environments run on the same underlying hardware architecture, there is no need to emulate or cross compile to the client device, removing an otherwise complicated step that requires additional time to set up and test. Cross compilation and emulation can also impact performance and reliability, reducing developer productivity and slowing project completion time. The tools required for cross-compilation and emulation can also incur additional costs, which are usually not significant.

While it has not been possible to quantify this benefit, the cloud gaming use case cost efficiencies were estimated at three-to-five times in total, covering infrastructure cost savings as well as developer productivity efficiencies. However, comparison with the other use cases suggests that around half of this benefit comes from the infrastructure cost savings and half from the productivity efficiencies.

Benefit 3: Custom Silicon Development

As shown in the ecosystem graphic above, Arm provides silicon architecture and support across its partner network: It designs and licenses CPUs and system IP, but it does not manufacture processors. It is therefore possible, as AWS has done with Graviton, to develop custom silicon designs to best suit specific needs. AWS developed Graviton to optimize performance and costs for a number of workloads in the cloud, having drawn upon its broad knowledge of such requirements. The first generation of Graviton[2], which was powered by Arm-based Amazon EC2 A1, became available in Q4 2018. Graviton2[3] was announced at the end of 2019, and the EC2 portfolio has therefore expanded. Indeed, AWS claims Graviton2 not only delivers cost savings but also competes in terms of price/performance with the latest generation of traditional processors.

By having control over the silicon design process, AWS is also able to focus on improvements for its purposes; there are also timing and planning benefits, such as making supporting capabilities available. It may also be able to reduce costs through its vertical integration. Furthermore, it is demonstrating that it is able to develop its own technology and does not have to fully depend on its suppliers' innovation and roadmaps.

In terms of the benefits of Graviton2 versus the first generation, AWS claims significant improvements in performance and memory capabilities.

As the ecosystem matures, Forrester expects the importance of developer efficiencies to grow. Two customers highlighted that in the future they could consider optimizing an Arm chipset to address their own specific workload requirements.

Benefit 4: Ability To Address Broader Customer Requirements/Widen Portfolio

Arm Neoverse is an alternative compute processor architecture and therefore provides the opportunity to deliver new products and services. This is relevant for infrastructure supply-side vendors, including the different parts of the silicon ecosystem, the server suppliers, and the cloud service providers.

The most important example is AWS, which has developed its own processor silicon in the form of Graviton processors.

AWS has therefore been able to broaden its portfolio of compute instances by adding those based on Arm architecture. This, in turn, offers its customers alternative cost/performance cloud compute infrastructure. Two of the interviewed organizations are using EC2 A1 instances, resulting in infrastructure cost efficiencies on top of the benefits associated with cloud environments. AWS highlights that the latest generation of Arm-based EC2 instances, based on Graviton2 processors, deliver attractive price performance capabilities for a variety of workloads, including: application services; microservices; high performance computing; EDA; gaming; open source databases; and in-memory cache.

Packet is a smaller cloud infrastructure provider and saw the opportunity to provide a differentiated service by offering bare metal Arm-based infrastructure, which it launched in mid 2019. It offers Ampere-based servers which are driven by their eMag processor as well as Marvell ThunderX-based servers[4]. One of the use cases included in this report has partnered with Packet as its primary cloud service provider and has implemented Arm-based servers in a number of different locations to support its mobile operator customer base. The two companies, being of similar size, ambitions, and mindset, felt well-suited to develop such solutions together for mutual benefit.

Flexibility

In some use cases, such as the image processing microservice, some resources have to be allocated upfront for testing, planning, and implementation. This might be to ensure all related tools, software, and support are available. However, there can be additional future Arm-based use cases on-premises or in the cloud once this cost has been sunk, making additional implementations easier, faster, and cost less. This flexibility is an additional benefit that can further support the business case for expansion of workloads deployed on Arm Neoverse over time.

Analysis Of Use Cases

SUMMARY OF USE CASES

Use Cases

USE CASE	SUMMARY	KEY BENEFITS
Electronic design automation	Simulation software is used to check silicon designs to ensure readiness for high scale manufacture.	Reduced upfront and ongoing infrastructure costs
Image processing (microservice)/web serving	Image serving microservice workload is part of cloud-based photo sharing and storage site.	Reduced cloud costs
Cloud mobile gaming	Delivering optimized content to mobile devices in an edge, private cloud environment.	Cloud cost savings and increased developer productivity
Containerized and scaled-out software development based on microservices	Use of microservices for development of software for IoT environments.	Increased developer productivity and cost efficiency

Forrester spoke to four organizations using Arm architecture for specific use cases; three are in the scale-out category and one, Use Case 1, falls into the intensive processing category.

Use Case 1: Electronic Design Automation

The verification of the design of new silicon chips is important to identifying and correcting any flaws before they are sent for fabrication. These designs tend to be very complex, but at the same time such projects typically experience time, reliability, and cost pressures. Engineers that design new chips require large scale server resources in order to perform these extensive simulations. The interviewed organization compared using 32 core Arm servers, based on Marvell Arm-based chips, against 20 core traditional servers for running silicon design verification software.

The silicon verification software investment is high at over $10,000 per core. We have modeled core-count requirements from 50 to 500; the details of which are outlined in a TEI Spotlight report. However, because Arm chips have a smaller footprint, they take up less space, can be built into denser servers, create less heat, and consume less power. This results in a number of different cost-saving benefits, which Forrester has put into two categories: upfront and ongoing costs.

First off, the upfront costs include the hardware acquisition and installation costs:

- An Arm server, with two processors and 32 cores each, costs 19% less than an equivalent traditional server that has two processors and 20 cores each; the cost per core works out at nearly half. Furthermore, depending on the number of required cores, the total number of Arm servers can also be reduced, further lowering hardware acquisition costs. These potential hardware acquisition cost savings are the most significant.

By reducing the number of required servers, there is also a reduction in the installation costs. Forrester assumes that the cost of installation, at around 5% of the server cost, is the same for both server types.

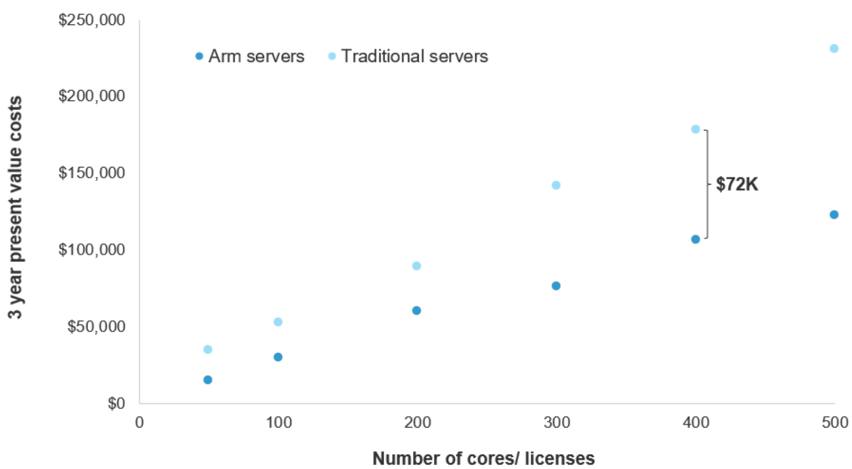
There are a number of components to the ongoing costs:

- The power consumption differences result in reduced energy costs. While the total power consumption of the Arm server is slightly higher than that of the traditional server, the power consumption per core is significantly lower. Assuming the servers run non-stop all year and are based in the US, the energy cost per Arm core is over 17% lower as compared to the general-purpose core.
- While the associated costs of real estate and operations for the data center are assumed to be the same for both types of servers, costs are lower for the Arm servers because fewer of them are required. The same is the case for the service and maintenance costs that are related to the data center.
- Finally, there are data center costs related to HVAC (heating, ventilation, air conditioning) energy. Because the Arm cores produce less heat, they require less cooling; Forrester assume that the Arm cores require 17% less energy to cool compared to the traditional cores, equivalent to power consumption reduction.

There is a 19% cost savings purely on the Arm server acquisition, compared to the traditional server equivalent.

The chart compares the total upfront and ongoing costs of using Arm versus traditional, CPU-based servers from 50 to 500 cores and licenses. In every case, there are significant savings from choosing the Arm hardware, ranging from 32% for 200 licenses ($29K) up to 57% for running 50 licenses ($20K). At 400 licenses the cost reduction is 40%, which is equivalent to a $72K cost savings; the average is 44% for the six scenario comparisons.

Comparison of total three-year infrastructure costs for EDA for 50, 100, 200, 300, 400 and 500 simulations



The most important assumption is that the performance of both is the same. However, the traditional processors have a higher maximum processing rate compared to this older generation of Arm cores, and so they are able to complete tasks faster, comparing cores on a one-to-one basis. This can be important in meeting important deadlines, reducing wait time for costly resources such as engineers, and bringing forward time-to-market. Moreover, it might be worthwhile investing in higher performance infrastructure in order to reduce the number of required software licenses, each of which costs in excess of $10,000.

Any additional performance complications are due to the types and number of workloads running in a server. Memory is shared among the processing units; the Arm servers have eight memory channels and the traditional servers have six. On the other hand, traditional servers have

27.5 MB of cache memory (1.375 MB/core) while the Arm servers have 32 MB of cache memory (1.0 MB/core).

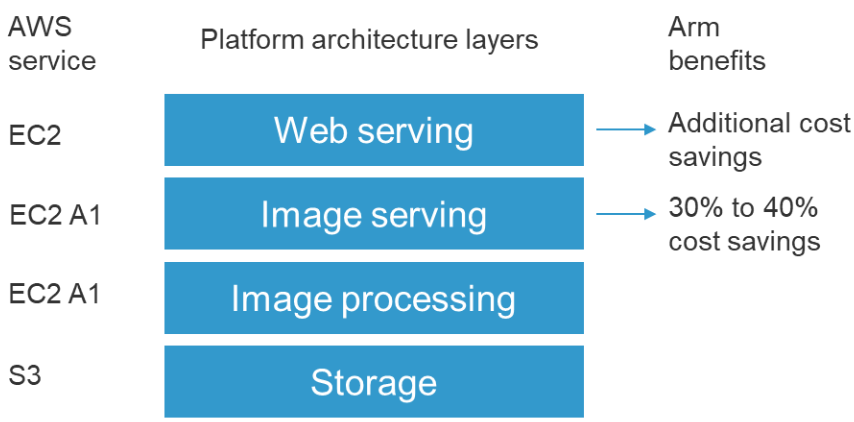
The optimal setup for many server farms used for EDA and silicon verification will depend on specific requirements, but typically a mix of Arm servers and traditional servers should be optimized to address performance and cost requirements and changing workload requirements.

Use Case 2: Image Processing (Microservice)/Web Serving

This organization provides a photo storage and serving service to millions of customers, managing billions of photos. Its infrastructure is based on AWS. It is also supported by a handful of internal operations employees. In this way, it is able to focus on serving photos to customers and maintaining a cost base that is small, agile, and low risk. It uses hundreds of Amazon EC2 instances, and therefore cloud-related fees are an important part of costs.

Amazon EC2 A1 instances, based on AWS's internally developed first generation Graviton processors, are an important way for this customer to reduce its costs. The architecture of the service provider has a number of different layers, which can be categorized as: storage, photo processing, image serving, and HTML web serving. However, it is the image serving layer, which sits between the web serving and image processing tiers, that are to be migrated to Arm optimized processors. It does not require heavy compute capability; essentially, it is pushing photos from one place to the next. And from this they see the potential for 30% to 40% per core cost savings. Viewed from another angle, the Arm instances are being used to support a microservice portion of the cloud application.

A summary of the architecture layers and related AWS instances and Arm benefits is shown below:



> "The image serving layer is a pure proxy layer; it is a relatively simple task, not requiring heavy computing capability, essentially pushing bytes through the wire. Arm is excellent for that."
>
> *Principal operations engineer, photo storage service provider*

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There is the potential for additional cost savings in the web serving layer of the architecture, which are to be explored in the future. Furthermore, this organization is looking to adopt EC2 instances based on Graviton2 processors for more compute-intensive tasks.

The costs of the Arm instance migration are limited; the majority of which are related to an operating system upgrade, which was due anyway. Therefore, no incremental costs are directly related to the Arm architecture. There were five business days of effort required for software testing and recompiling. These costs were small compared to the ongoing monthly cloud costs savings.

Time required for testing, migration planning and Arm recompiling: **5 days**

Use Case 3: Cloud Mobile Gaming

Due to the increased performance of cellular connectivity, and the rollout of 5G, live gaming services are increasingly viable and in demand on mobile. This use case is based on an organization which delivers cloud-based gaming capabilities to several leading mobile operators. Similar to the previous use case, this organization has a purely cloud-based infrastructure through a private cloud partnership with Packet and is able to support huge scale with a relatively small engineering team.

There are three areas of benefit in this use case:

- There's a higher number of cores per server, resulting in important cost savings. This can be put, as the interviewee did, in a different way: "The more games we can run on an individual server, the lower the costs of providing the service."
- There are additional cost savings of Arm servers, as compared to general-purpose servers in terms of power, heat, and space.
- General purpose processor code would need an emulation layer to be able to run on Arm-powered mobile devices, not only adding cost, but also reducing the performance.

"In the short term, there are important cost benefits because all mobile handsets are Arm devices. In the longer term, we could consider customizing an Arm chip for these specific workloads."

Director of cloud operations, mobile gaming service provider

Adding these three areas of cost efficiency results in a three-to-five-fold cost savings by using Arm servers; this is equivalent to a cost reduction of between 65% and 80%. The only downside that this organization highlighted was that it was an initial risk to lean on an architecture with limited support, in terms of hardware, tools, and frameworks. This risk is rapidly reducing as the architecture matures and more organizations in different parts of the ecosystem support it.

Use Case 4: Containerized, Scaled-Out Software Development Based On Microservices

The development team saves time by avoiding the need to cross-compile.

The fourth use case concerns the development of virtualization software to be used in the creation of IoT applications. One of the biggest factors holding back the deployment of IoT is, as shown below, concerns around costs and related challenges.

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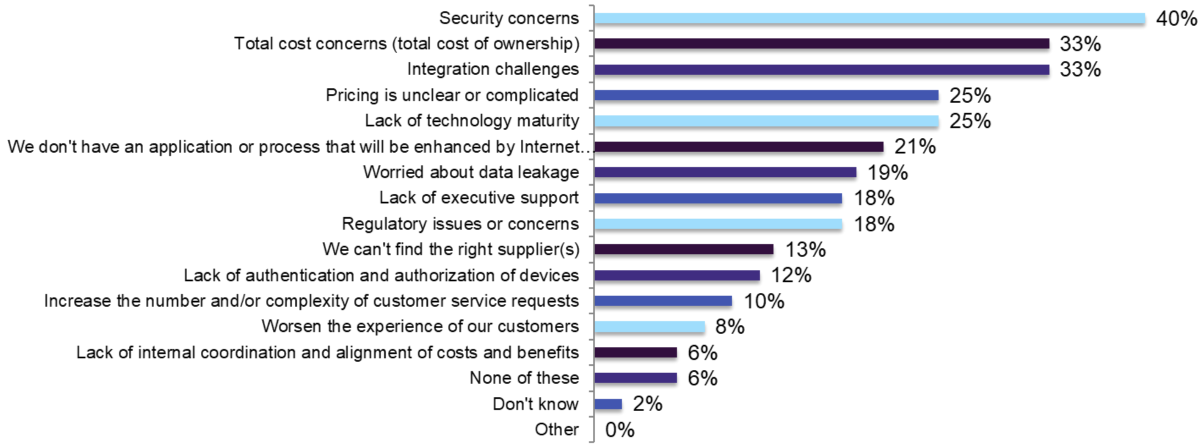
"What are your firm's concerns, if any, with deploying internet-of-things (IoT) technologies?"



Base: 3,627 telecommunications decision makers (20+ employees)
Source: Forrester Analytics Global Business Technographics® Networks And Telecommunications Survey, 2019

The majority of IoT-enabled endpoint devices are based on Arm architecture. Traditionally, Arm-based application development takes place on non-Arm architecture and so has to use compilers and emulators; this can be avoided by developing on Arm, as the software development organization did in this use case. Like the second use case, they also used Amazon EC2 A1 instances on AWS. This delivered a number of important benefits:

- By avoiding the need for cross compilers and emulation, the development team were able to save time. Such tools can be complex to test, set up, and use.
- The build and test processes on Arm are much more reliable than using an emulation program, avoiding the risks associated with mixing different architecture types, further enhancing developer productivity.
- Reduced infrastructure costs.

There were no additional costs, while infrastructure costs related to building and testing were reduced by up to 45%, driven by the cost savings from Arm-based Amazon EC2 A1 instances on AWS. As a result, the costs and risks of developing new IoT applications can be reduced, helping to support the business case of this growing opportunity.

> "The Arm EC2 A1 instances result in up to 45% more cost effectiveness, specifically for a workload that is scaled out, containerized, and based on microservices."
>
> *CMO, software developer*

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Analysis Of Costs

SUMMARY OF COSTS

Cost Summary	
COST	**DESCRIPTION**
1. Planning and implementation costs	Organizations which have never used Arm architecture for their infrastructure need to set aside some resources to ensure a smooth transition.

Cost 1: Planning And Implementation Costs

The deployment of a new infrastructure architecture may require some resources for planning and implementation. For three out of the four use cases described, there were already internal resources familiar with the technology, and incremental planning and implementation costs were minimal. The Arm Neoverse ecosystem is still maturing, and it is, therefore, worthwhile to set some time aside to plan and ensure that any tools, support services, or other software can be properly supported. AWS now has additional ecosystem support for Graviton and Graviton2.

Portable workloads can be easily migrated.[5] On the other hand, legacy applications with dependencies on hardware architectures will require more effort to recompile.

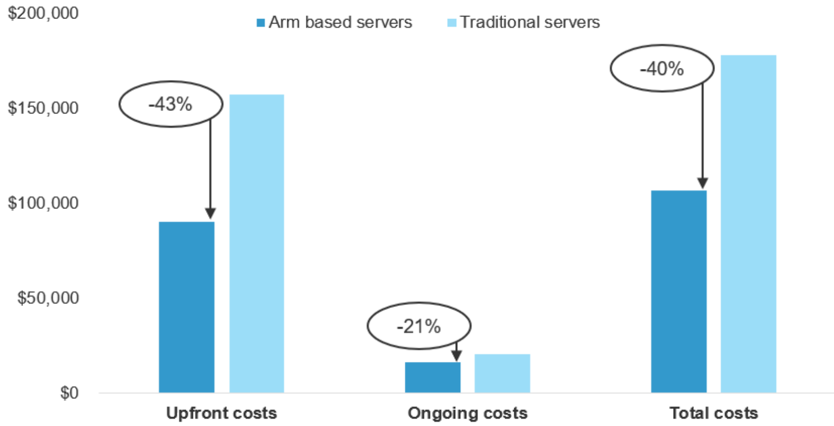
In the case of the photo serving use case there were a number of additional steps in preparation for the transition; the cost estimations are established on a senior engineer, based in the US, with a fully loaded salary of $100,000, which is equivalent to around $500 per day.

- Half a day was required for one senior engineer to test the AWS instances in terms of suitability for the software, benchmarking, and performance testing. Planning time may also be required to ensure that any tools and supporting software requirements are available, adding up to another half day.
- Several days were spent on an operating system upgrade. However, the interviewee highlighted that this was not specifically because of the Arm architecture, they would have had to upgrade, part of their normal operations. This was the bulk of the internal work required, totaling no more than ten days.
- A number of custom packages and software builds had to be recompiled; this required no more than two days of work, which is equivalent to around $1,000 for a senior engineer.

Financial Summary

THREE YEAR COST COMPARISON

Cost Comparison Of Acquiring, Installing, And Operating 400 Simulations On Arm Servers Vs Traditional Servers



Three-year, present value cost comparison details

	Arm server	Traditional server	Difference	Percentage difference
Upfront costs	$90,300	$157,500	$67,200	43%
Ongoing costs (annual)	$6,558	$8,296	$1,738	21%
Total costs (three-year PV)	$106,604	$178,121	$71,517	40%

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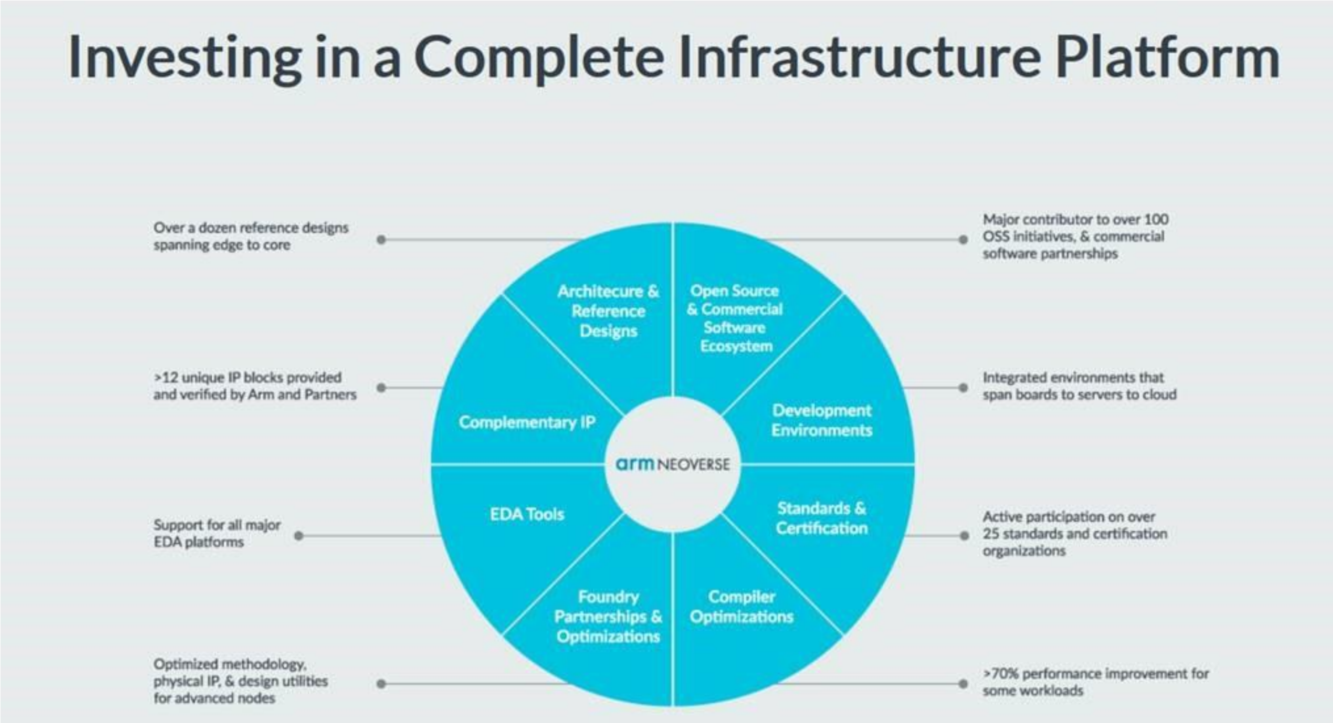
Arm Neoverse: Overview

The following information is provided by Arm. Forrester has not validated any claims and does not endorse Arm or its offerings.

Arm Neoverse is the secure cloud-to-edge infrastructure foundation for a world of a trillion intelligent devices. Arm Neoverse IP solutions deliver the performance, efficiency, choice and support to transform businesses.

Arm has invested in a complete, secure infrastructure platform:



See here for more details: http://www.neoverse.com

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Appendix A: Total Economic Impact

Total Economic Impact is a methodology developed by Forrester Research that enhances a company's technology decision-making processes and assists vendors in communicating the value proposition of their products and services to clients. The TEI methodology helps companies demonstrate, justify, and realize the tangible value of IT initiatives to both senior management and other key business stakeholders.

Total Economic Impact Approach

Benefits represent the value delivered to the business by the product. The TEI methodology places equal weight on the measure of benefits and the measure of costs, allowing for a full examination of the effect of the technology on the entire organization.

Costs consider all expenses necessary to deliver the proposed value, or benefits, of the product. The cost category within TEI captures incremental costs over the existing environment for ongoing costs associated with the solution.

Flexibility represents the strategic value that can be obtained for some future additional investment building on top of the initial investment already made. Having the ability to capture that benefit has a PV that can be estimated.

Risks measure the uncertainty of benefit and cost estimates given: 1) the likelihood that estimates will meet original projections and 2) the likelihood that estimates will be tracked over time. TEI risk factors are based on "triangular distribution."

The initial investment column contains costs incurred at "time 0" or at the beginning of Year 1 that are not discounted. All other cash flows are discounted using the discount rate at the end of the year. PV calculations are calculated for each total cost and benefit estimate. NPV calculations in the summary tables are the sum of the initial investment and the discounted cash flows in each year. Sums and present value calculations of the Total Benefits, Total Costs, and Cash Flow tables may not exactly add up, as some rounding may occur.

Present value (PV)

The present or current value of (discounted) cost and benefit estimates given at an interest rate (the discount rate). The PV of costs and benefits feed into the total NPV of cash flows.

Net present value (NPV)

The present or current value of (discounted) future net cash flows given an interest rate (the discount rate). A positive project NPV normally indicates that the investment should be made, unless other projects have higher NPVs.

Return on investment (ROI)

A project's expected return in percentage terms. ROI is calculated by dividing net benefits (benefits less costs) by costs.

Discount rate

The interest rate used in cash flow analysis to take into account the time value of money. Organizations typically use discount rates between 8% and 16%.

Payback period

The breakeven point for an investment. This is the point in time at which net benefits (benefits minus costs) equal initial investment or cost.

Appendix B: Endnotes

[1] Amazon Buys Stealthy Israeli Chip Startup Annapurna Labs
https://www.datacenterknowledge.com/archives/2015/01/23/amazon-buys-stealthy-israeli-chip-startup-annapurna-labs

[2] New - EC2 Instances (A1) Powered by Arm-Based AWS Graviton Processors
https://aws.amazon.com/blogs/aws/new-ec2-instances-a1-powered-by-arm-based-aws-graviton-processors/

[3] New – EC2 M6g Instances, powered by AWS Graviton2
https://aws.amazon.com/blogs/aws/new-m6g-ec2-instances-powered-by-arm-based-aws-graviton2/

[4] Ampere Arm Makes The Packet Processor Rite of Passage
https://www.nextplatform.com/2019/03/29/ampere-arm-makes-the-packet-processor-right-of-passage/

[5] Source: Along with open source software, workloads built on the following components are more easily migrated: interpreted languages; those that are not reliant on native CPU instruction sets; those built in containerized workload environments; and those built for Arm-based applications.

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