Technology Trends

Price/Performance Predictions for the Largest Supercomputers in the World

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HYPERION RESEARCH OPINION

This report looks at the pricing, performance and resulting price/performance of the top five supercomputers over the last 10 years, and forecasts where they may be in the next five years.

As the exascale race picks up across the world, from plans for Aurora 21, the first US exascale system scheduled to be installed at Argonne National Laboratory outside of Chicago, Illinois, to the Riken Post-K machine and the exascale programs in Europe and China, the desire to bring exascale to reality is driving the price tags up for these machines. To set the stage for first-generation exascale systems, Hyperion Research examined the price/performance for the top 5 computers in the world over the last decade.

We used the TOP500 list's Linpack benchmark results (Rmax Linpack) as the criterion for selecting the top 5 supercomputers in the world. Prices used in this report are Hyperion Research estimates (Hyperion Research is responsible for any errors in the price estimates.)

The TOP500 list is a useful census-tracker of trends affecting the world's largest supercomputers over time. It's in this context that Hyperion Research examined the price/performance of the top 5 supercomputers, historically during the past decade (2008-2018) and forecasted into the future towards 2028. Not surprisingly, the trends emerging from this exercise include rapid improvements in Linpack performance and associated price/performance, along with price increases for the top 5 supercomputers as a group.

Hyperion Research cautions readers to keep these factors in mind while looking through this report:

- While the Linpack benchmark test is a handy common denominator for comparing large HPC systems, in recent years the Exascale Computing Project (U.S.), the EuroHPC Joint Undertaking and some other leadership initiatives have adopted a different performance metric: *targeted sustained performance gains on specified portfolios of real-world applications*.
- For example, Japan's K computer costs more than other large supercomputers but also fared better than many of them on more demanding benchmarks (e.g., HPCG) and many real-world codes.

The historic trend in price/performance represents an improvement CAGR of 30% from 2009 to 2018 and an overall improvement of 96% from 2009 to 2018. This trendline projects that the cost of a Linpack PF will go from $100 million in 2009, to $110 by 2028, a roughly 1000X improvement in a decade.

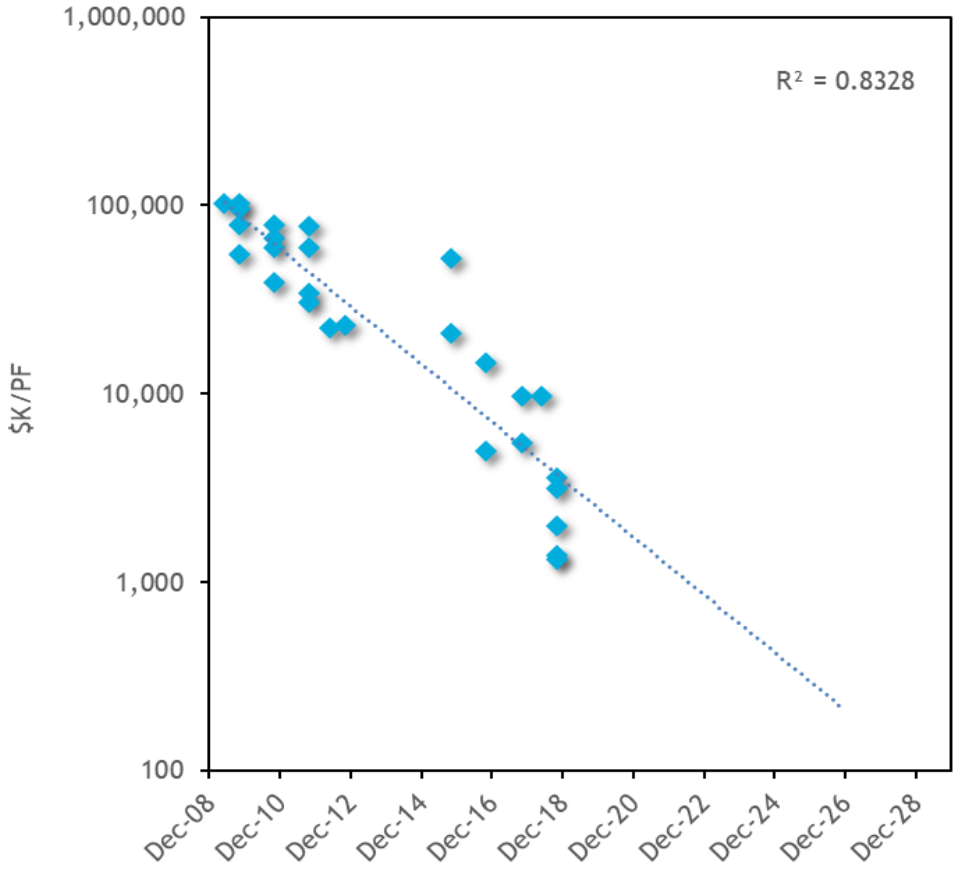
KEY FINDINGS

Price/Performance Projections of Large Supercomputers

Since 2009, the compute capabilities of the top machines in the world have increased dramatically, from machines topping out at one to two petaflops to now well over 100 petaflops for the highest spot on the list. And prices have also increased, but at a different rate. The net result in price/performance is shown in Figures 1.

FIGURE 1

Price/Performance of Top Supercomputers



Note: This figure uses a log scale.

Source: Hyperion Research, 2019

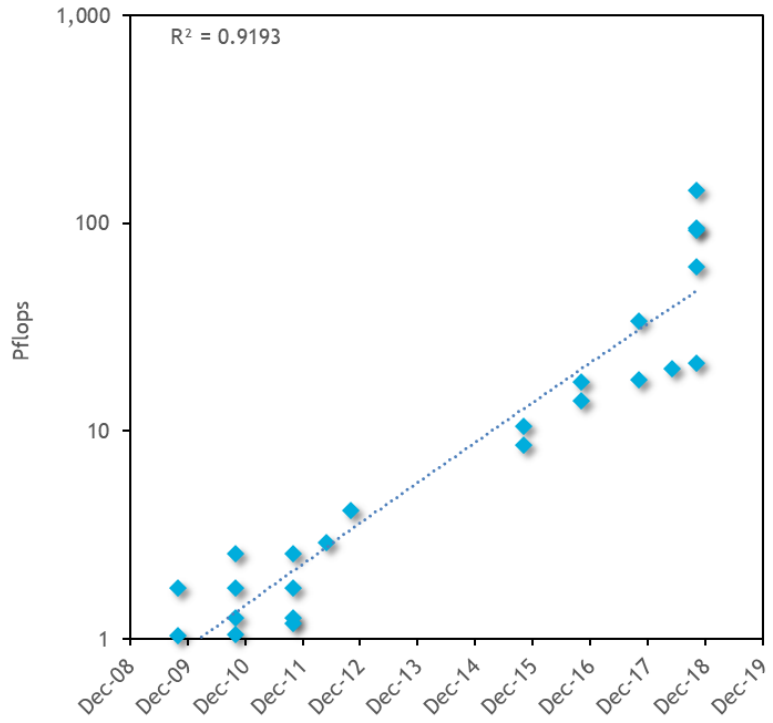
Large Supercomputer Performance Trends

In this document, each machine that held a position in the top 5 of the TOP500 at some point between June 2009 and the most recent list was examined, not only for its raw compute power on the Linpack benchmark, but also for the price tag that accompanied it. The price tag is just for the computer itself, not the infrastructure needed to house and power the machine but includes any custom R&D (NRE) spent on just that system. To date, the most expensive machine was the K computer, and thus it is the only major outlier from the trend line the price/performance over time. All of the prices are published figures or Hyperion Research estimates based on available public information.

Figure 2.A shows the trend in performance improvement for the Top 5 supercomputers from 2009 to 2018. For this trend line, the R-squared value is quite high, reflecting a strong correlation between the fit line and the data in the sample. The performance of the top machines has been increasing at a growing rate, especially in the last five years. The historic trend represents an improvement CAGR of 61% from 2009 to 2018 of the top five machines in the world.

FIGURE 2.A

Performance of Top Machines 2013-2018

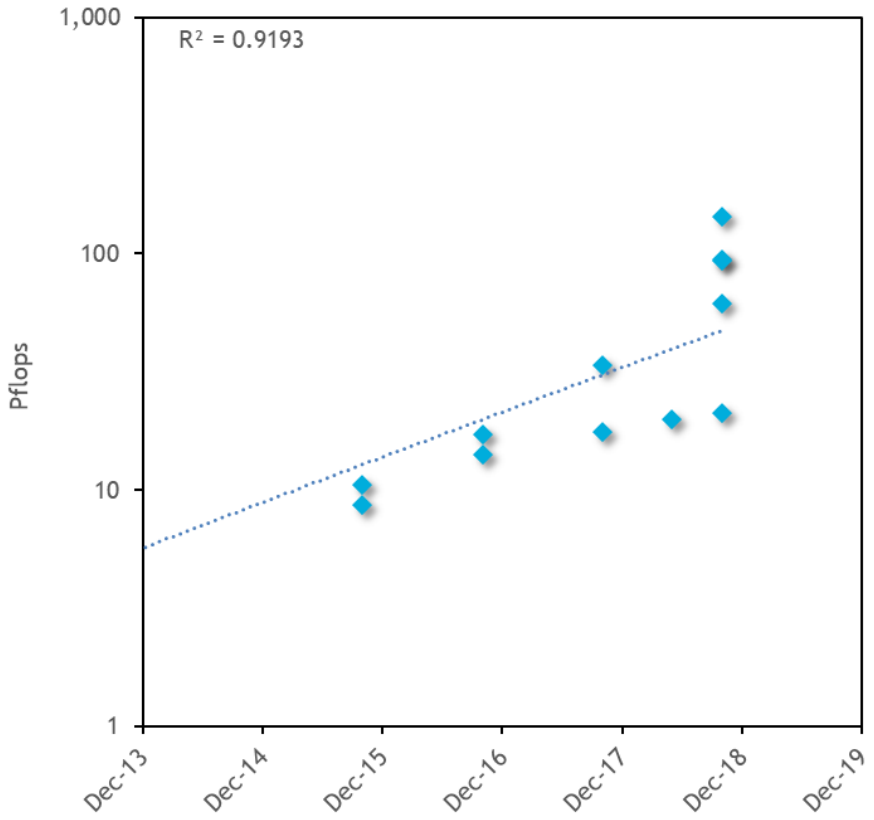


Source: Hyperion Research, 2019

Figure 2.B shows the more recent trend in performance for the top 5 supercomputers, from 2013 to 2018. Although the trend line misses the top three machines for 2018, the correlation is still quite strong for the data sample. The historic trend looking at just the most recent years, represents an improvement CAGR of 96% from 2015-2018 (as there were no new machines from 2013 to 2015).

FIGURE 2.B

Performance of Top Machines 2013-2018

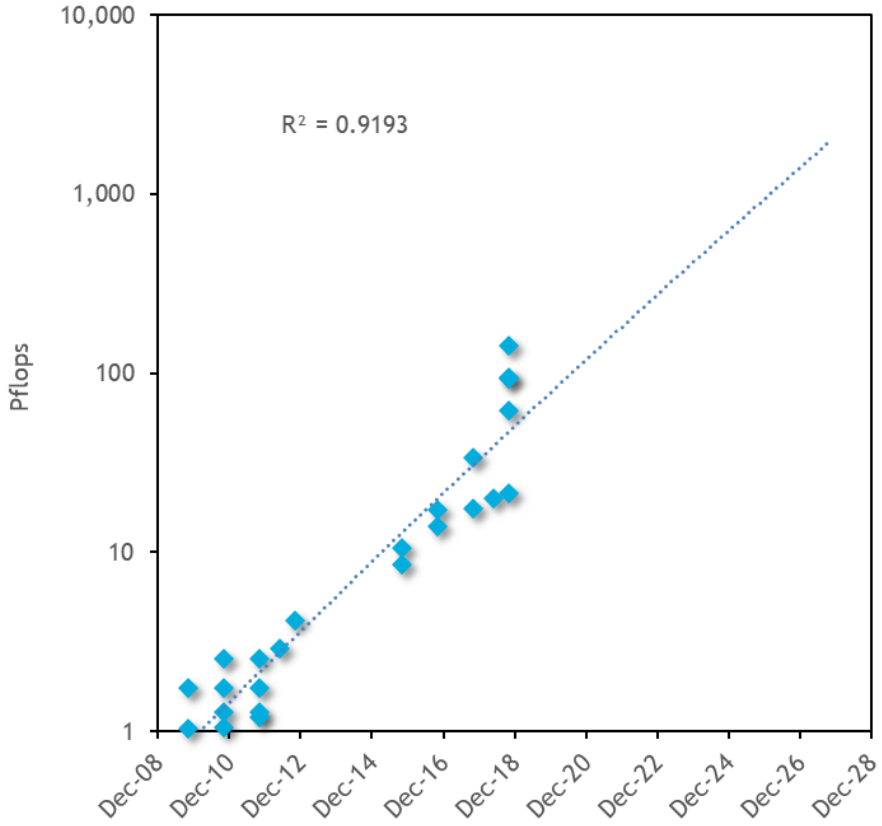


Source: Hyperion Research, 2019

Figure 2.C adds a projection going out to 2028, using the same curve/rate that was seen from 2009 to 2018. Using a simple exponential projection, Hyperion Research projects that the top supercomputers in 2028 will exceed 4 Exaflops (Rmax Linpack) each. Based on the trend of the data from 2009 to 2018, the rate at which the performance will increase promises to go up extremely quickly over the next decade.

FIGURE 2.C

Performance of Top Machines 2009-2018



Source: Hyperion Research, 2019

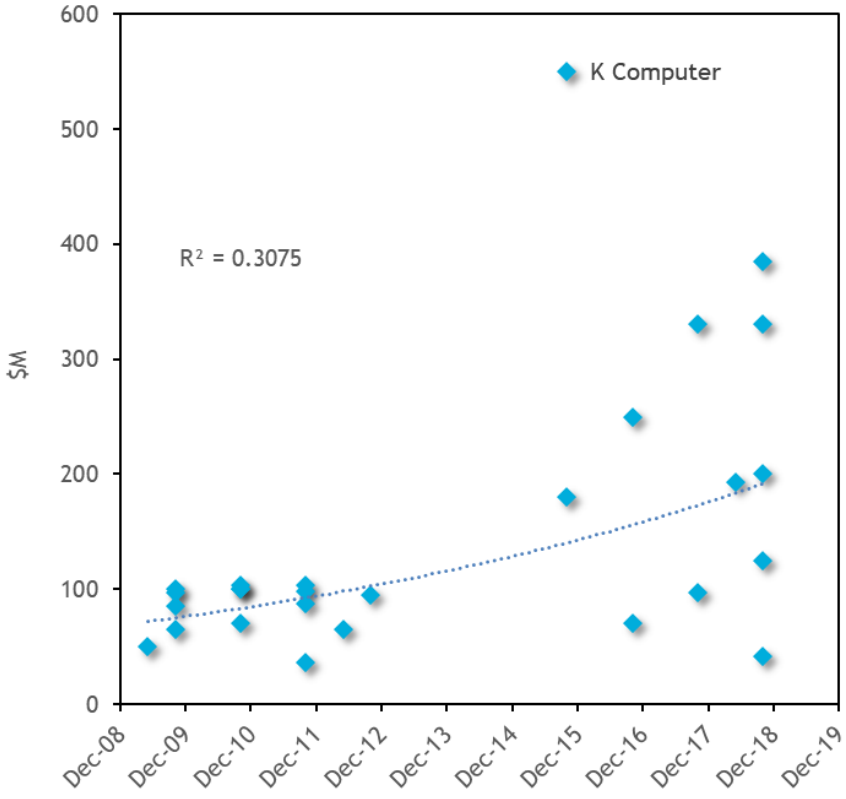
Large Supercomputer Price Trends

Figure 3.A shows the trend in price reductions for the Top 5 supercomputers from 2009 to 2018. It is important to note that in Figure 4, the outlier is the K computer, which cost more than any computer at the time. Now, as we approach the realm of exascale, we anticipate that the Post-K computer, which has not been formally named yet, will exceed the price of the other exascale computers due to the front end R&D for the new chip and the powerful interconnect within the system. (As noted in the Hyperion Research Opinion opening section of this report, the K computer has outperformed many of its top 5 supercomputers companions on tasks more demanding than the Linpack benchmark. Hyperion Research expects the Post-K computer to repeat this pattern.)

A trend line is shown in the figure, but the fit is very low, due to the great variability in system prices, unlike the performance trend line which has a much tighter trendline fit. From the figure, its clear that a number of very high priced systems started to appear around 2015, resulting in eight very expensive systems from 2015 to 2018.

FIGURE 3.A

Prices of Top Machines 2009-2018



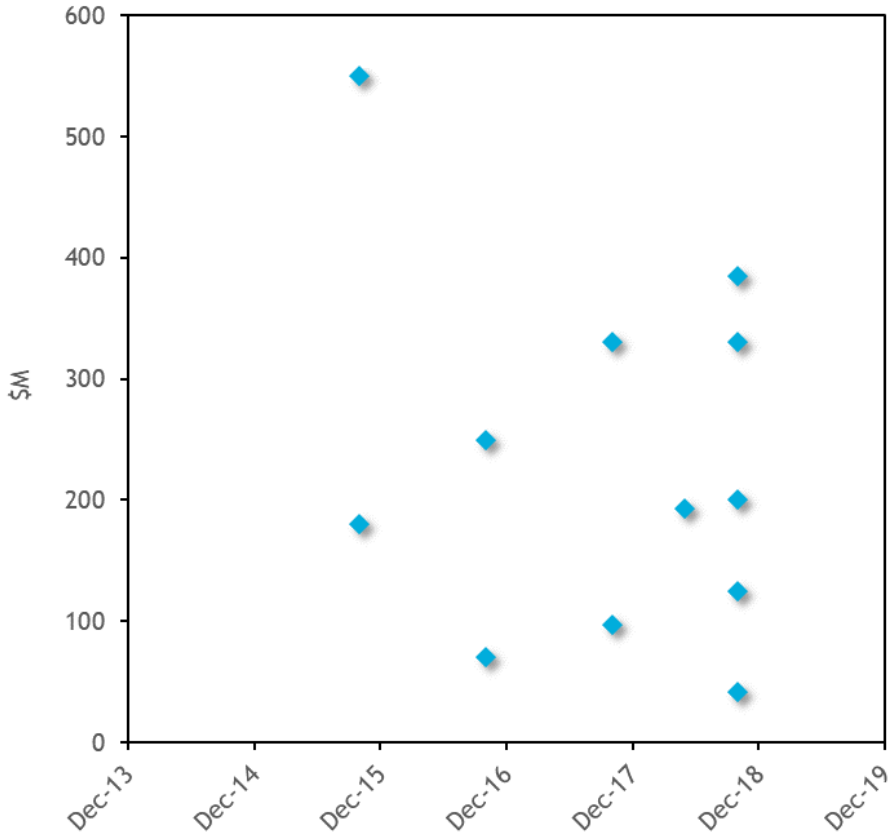
Source: Hyperion Research, 2019

Figure 3.B shows the more recent trend of greater price ranges for the top 5 supercomputers. The spread in system prices from 2015 to 2018 is so wide it's hard to tell if there is much of a trend yet. If one removes the K system, then the price of the most expensive system shows a strong upward trendline. The historic trend represents a price CAGR of 12% per year.

The price of the costliest system is expected to reach $500 to $600 million for the first few US systems and could exceed $900 million for the post-K system in Japan. Hyperion Research expects the top systems in China and Europe to vary between $300 to $500 million over the next 4 to 5 years.

FIGURE 3.B

Prices of Top Machines 2013-2018



Source: Hyperion Research, 2019

Top Supercomputer Price/Performance Trends

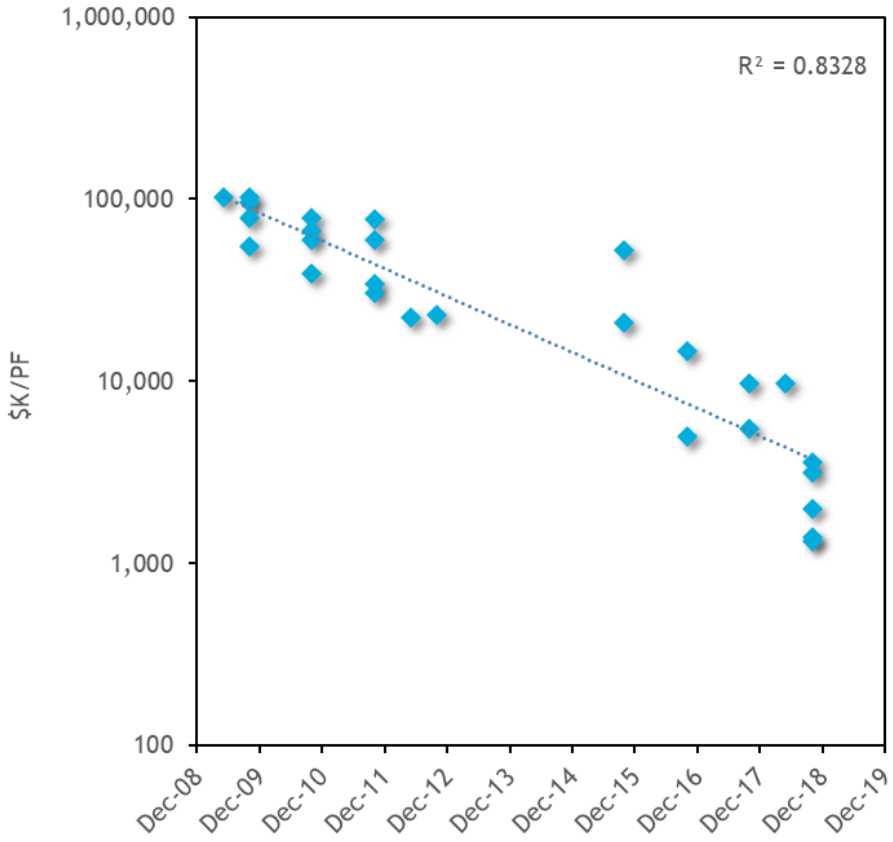
Figures 4.A and 4.B show the price/performance (Linpack) trend of the top supercomputers from June 2009 to November 2018. As can be seen from the data, there is a strong correlation between a negative exponential fit curve and the data points. Essentially, this means that for the time period in the analysis (2009-2018), the best equation and graph that describes the trend in data starts with a very steep negative slope but levels off as time progresses and creates a flat tail as you move further to the right on the graph, or in this case, move forward in time. During this period of 10 years, price/performance for the world's number one supercomputer improved by 97.5%, meaning that the cost of one petaflop in 2018 is 97.5% less than one petaflop in 2009, for the number one computer.

It is worth noting, as stated above, that the K Computer is the only major outlier for this data set. Other than that machine, the correlation is extremely strong, with an R-squared value of 0.83. For reference, an R-squared value is a measure of the accuracy of the trend line. A perfect set of data would have an

R-squared value of 1, yet we all know that the real world is hardly perfect. As a further point of reference, without the K Computer included, the trend line for the negative exponential fit line would be closer to 0.88.

FIGURE 4.A

Price/Performance of Top Machines 2009-2018

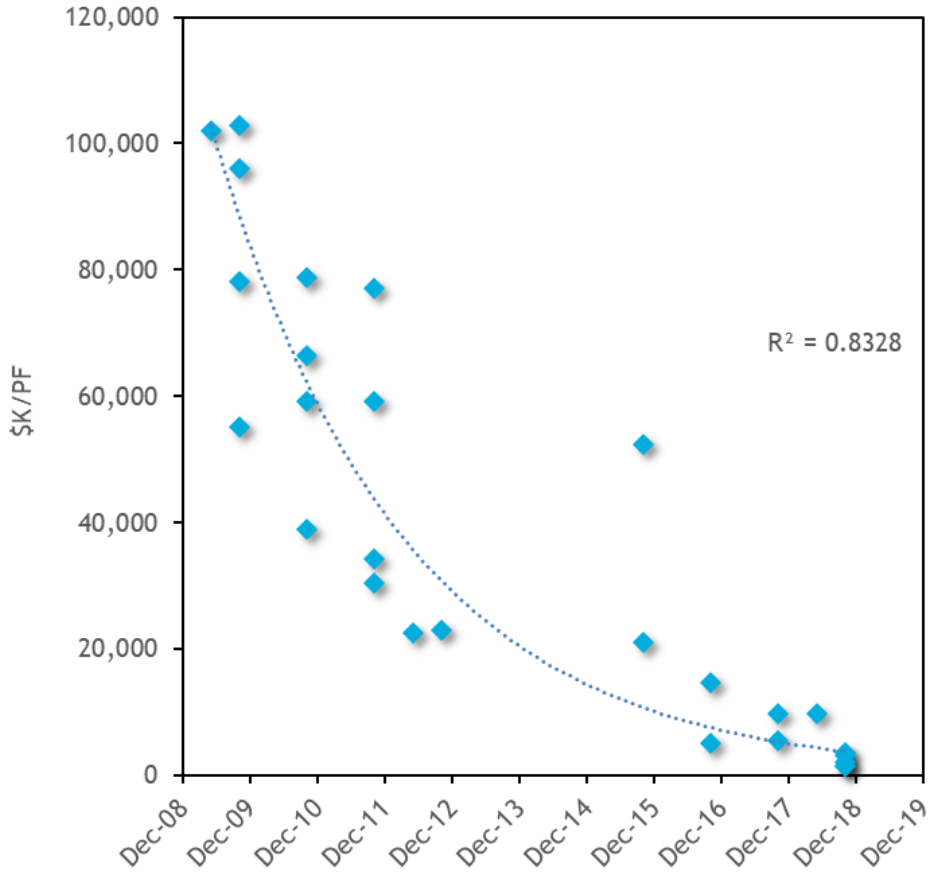


Note: This figure uses a log scale.

Source: Hyperion Research, 2019

FIGURE 4.B

Price/Performance of Top Machines 2009-2018



Source: Hyperion Research, 2019

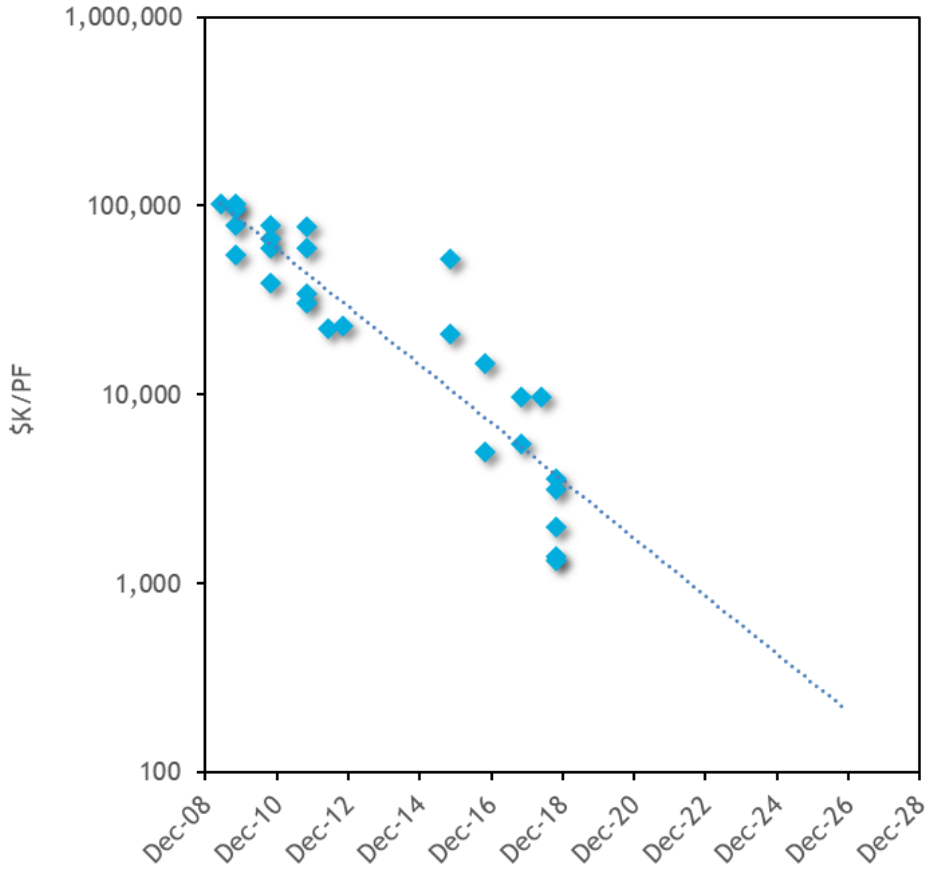
Figures 4.C and 4.D add a projection going out to 2028, using the same curve/rate that was seen from 2009 to 2018. The trendline projects that the cost of a Linpack PF will go from $100 million in 2009, to $110,000 by 2028, a roughly 1000X improvement in a decade.

So, this begs the question of what is next? Will this trend continue, or will the exascale race upset the trend of the past decade? Figures 4.C and 4.D extend the trend line out to 2028. As we move out towards 2028, the trendline projects that the price/performance of the top supercomputers will continue to decrease, but at a less aggressive rate than in the 2009 to 2014 time frame. Those six years, 2009-2014, showed a very steep decrease in the price of a petaflop, yet recently the trend has started to level off. Based on the information that has been made public, as well as the Hyperion Research analysts' predictions, the first exascale machines will cost around $500 to $600 million USD, on average. In context, the smallest price of a petaflop in the past decade was about $1.4 million, and a

$600 million exascale machine would come in at around $0.6 million per petaflop. So, the price should continue to decrease, but potentially at a slower rate.

FIGURE 4.C

Price/Performance of Top Machines 2009-2018 (projected forward)

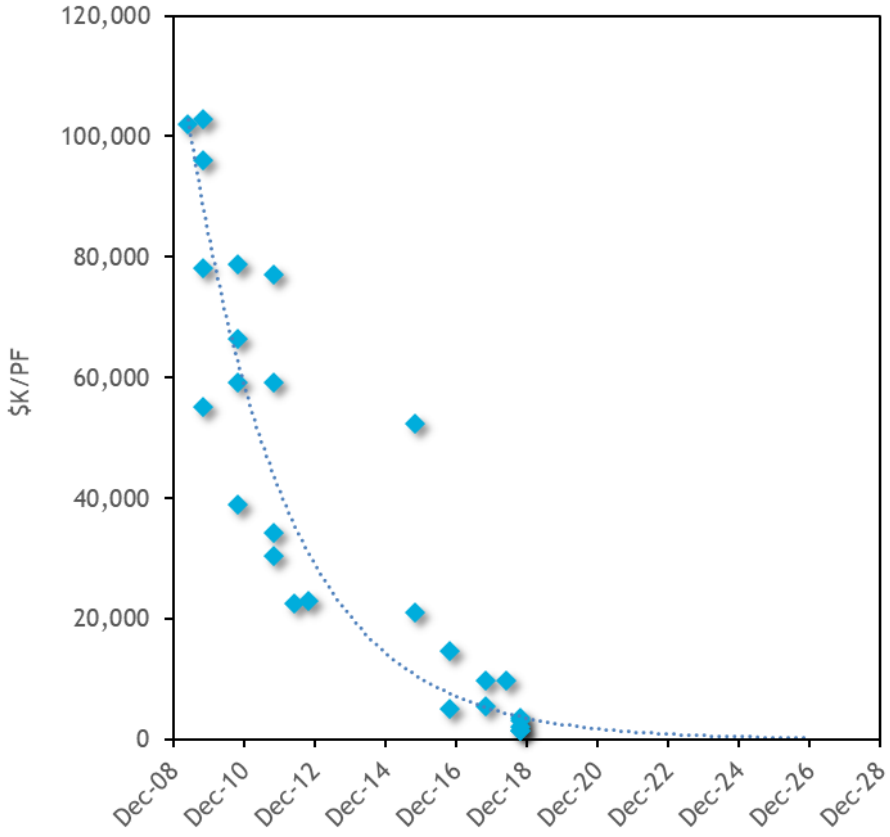


Note: This figure uses a log scale.

Source: Hyperion Research, 2019

FIGURE 4.D

Price/Performance of Top Machines 2009-2018 (projected out to 2028)



Source: Hyperion Research, 2019

FUTURE OUTLOOK

So, what does this mean? Price/performance (Linpack) for the world's top 5 supercomputers has been improving dramatically over the last decade but may improve at a slower rate over the next decade. Substantial Linpack performance gains will continue for this group, heavily boosted by the growing size and costs of the next generation of supercomputers, with prices for the top 5 exascale and post-exascale supercomputers reaching the $500 million to $1 billion range.

The exascale race is just beginning with the first systems already having their planned acceptance dates and locations, as well as the announcement of much of the technological specifications of the system. Many of these systems carry an extremely high price tag relative to the past decade. Before 2019, the most expensive machine was the K Computer, and that was an outlier in itself, but as the first round of exascale systems come into fruition, the prices of these new machines will dwarf the

previous generation of supercomputers. Hyperion Research estimates that the Aurora 21 machine will cost between $500 to $600 million, with three more in the US, with similar prices planned for installation in 2022-2023. The Post-K Computer may be the world's first billion dollar machine after all is said and done.

The TOP500 list's Linpack benchmark is a widely used common denominator for comparing the rough performance of the world's largest supercomputers. But an important trend in national/regional exascale programs is to measure the success of these leadership-class supercomputers based on targeted gains in sustained performance on specified portfolios of real-world applications. Some supercomputers may outperform their top 5 companions on challenging real-world codes while ranking lower on the Linpack test.

APPENDIX: SYSTEMS INVESTIGATED IN THIS STUDY

- Summit
- Sierra
- Sunway TaihuLight
- Tianhe-2A
- Piz Daint
- Tianhe-2 (MilkyWay-2)
- Titan
- Sequoia
- Cori
- K Computer
- Mira
- JUQUEEN
- Tianhe-1A
- Jaguar
- Nebulae
- TSUBAME 2.0
- National Supercomputing Center in Tianjin
- DOE/SC/Oak Ridge National Laboratory
- National Supercomputing Centre in Shenzhen (NSCS)
- DOE/SC/LBNL/NERSC
- Oak Ridge National Laboratory
- DOE/NNSA/LANL, National Institute for Computational Sciences/University of Tennessee
- Forschungszentrum Juelich (FZJ)

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Hyperion Research provides data-driven research, analysis and recommendations for technologies, applications, and markets in high performance computing and emerging technology areas to help organizations worldwide make effective decisions and seize growth opportunities. Research includes market sizing and forecasting, share tracking, segmentation, technology and related trend analysis, and both user & vendor analysis for multi-user technical server technology used for HPC and HPDA (high performance data analysis). We provide thought leadership and practical guidance for users, vendors and other members of the HPC community by focusing on key market and technology trends across government, industry, commerce, and academia.

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