High Performance Computing

Solve.

The Exascale Effect: the Benefits of Supercomputing Investment for U.S. Industry

Compete.

Council on Competitiveness

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research, under Award Number DE-SC0008764.

For more information, please contact:

Chris Mustain
Council on Competitiveness
202 969 3398
cmustain@compete.org

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From Our President

On behalf of the Council on Competitiveness, it is my pleasure to release *Solve*, a publication of the High Performance Computing (HPC) Initiative. For more than a decade, the Council has led the nation to understand, promote and strengthen America's ability to leverage advanced computing for competitive advantage. America must lead in this game-changing technology that pushes the frontiers of science and commerce in virtually every discipline and sector.

The Council brings together America's top HPC leaders from industry, academia, government and the national laboratories. Through expert analysis and results-driven recommendations, through on-the-ground engagement with manufacturers, and through collaboration with an unparalleled network of HPC executives, the Council strives continually to increase U.S. competitiveness through the transformational use of advanced computing. We know from experience that to out-compete is to out-compute.

This report takes a fresh look at:

- The value of HPC to U.S. industry;
- Key actions that would enable companies to leverage advanced computing more effectively; and
- How American industry benefits directly and indirectly from government investment at the leading edge of HPC.

I would like to thank the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research, for its support of this work. I also would like to acknowledge the efforts of the Council's senior HPC team, Chris Mustain and Cynthia McIntyre. To produce *Solve*, the Council engaged and worked closely with Intersect360 Research to interview more than 100 HPC-using companies across sectors.

It is often said that information and knowledge are power. Future products, business models, industrial processes and companies are being built on the ability to collect, analyze and use data at a scale that is nearly inconceivable. Nations wishing to lead the future and enjoy more prosperous lives for their citizens must also lead in the deployment of HPC hardware, software and talent that underpin that future. The leadership challenge is complex and continuous, as the technology and the way it is applied evolve. But it is a challenge Americans stand ready to solve.

Sincerely,

Deborah L. Wince-Smith

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

SECTION 1

Executive Summary

High performance computing (HPC) is inextricably linked to innovation, fueling breakthroughs in science, engineering, and business. HPC is a tool used by leaders in diverse fields to help design new products, to improve existing products, and to bring products to market more efficiently. HPC is viewed as a cost-effective tool for speeding up the R&D process, and two-thirds of all U.S.-based companies that use HPC say that "increasing performance of computational models is a matter of competitive survival."

In this study, the U.S. Council on Competitiveness engaged Intersect360 Research to assess how government investment in HPC benefits U.S. industrial competitiveness and what areas of continued investment would provide the greatest benefit moving forward. During a six-month research period, Intersect360 Research conducted 14 in-depth interviews with forward-thinking representatives of industrial HPC-leading organizations and then gathered 101 responses to a comprehensive online survey of U.S.-based, HPC-using companies. The key findings from this study are:

1. Although they struggle to imagine the specific discoveries and innovations that will come about, U.S. industry representatives are confident their organizations could consume up to 1,000-fold increases in capability and capacity in a relatively short amount of time.
2. Software scalability is the most significant limiting factor in achieving the next 10x improvements in performance, and it remains one of the most significant factors in reaching 1,000x.
3. U.S. industry sees a benefit from government leadership in the investment in supercomputing technologies, but the links between government and industry need to be strengthened.

Although U.S. industry sees value in their own HPC investment, getting expenditures approved for HPC versus other priorities is an ongoing challenge, and companies vary in

> The greatest rift between potential performance and actual insights is in application software.

their approaches to justify the value of HPC. The potential value of a future innovation is difficult to conceive, making future return on investment (ROI) challenging to quantify. On the other hand, top-tier companies nurture cultures that strive continually to innovate, to invent, and to lead their industries. When this is their charter, companies must keep their innovation capabilities on par or ahead of their competitors, and HPC is an essential tool that powers innovation across many industry sectors.

Still, cost is not the only barrier to greater HPC scalability; in fact, it is not even the most significant one. As new hardware architectures are developed to bring about new echelons of supercomputing scalability, the greatest rift between potential performance and actual insights is in software. The HPC application software market for industrial users is diverse and specialized, split roughly in thirds between in-house development, open-source downloads, and purchased, commercially licensed applications from independent software vendors (ISVs). Different industries follow different usage patterns, and each individual company's software footprint is unique to that organization. And while industry demands more from its software—greater scalability, greater performance, increased features, and support for new architectures—generally companies would prefer to pay less for licenses or for application development, leading to difficulty in defining successful business models for software.

U.S. industry needs HPC, and it needs help in the form of partnerships to create the software that will drive a new generation in innovations. In order to solve the discrete problems faced by diverse segments, these partnerships should be specific in scope, with discrete goals for supporting ISVs, bolstering open-source communities, boosting in-house development, and encouraging HPC adoption. Such partnerships will by necessity include multiple players from industry, academia and the national laboratories.

In a world where computing leadership will increasingly determine economic leadership, industry recognizes the essential role played by the federal government. As an investor and first adopter of new computing technologies, the federal government does more than fulfill critical missions in national security and breakthrough science. By pushing the leading edge of computation, new technologies and capabilities first funded by government ultimately become available for business—in aeronautics, pharmaceuticals, finance, energy, automotive and many other sectors. If the United States were to lag in computing behind key competitor nations that actively support national industries, the economic implications could be significant.

Many of the greatest business opportunities today center around the ability to make sense and to create value from massive amounts of data. The ability to manage such data—and to perform modeling, simulation and analysis—will determine the products, industrial processes, business models, and industries of the future. If America is to lead that future the public and private sectors must work together to establish HPC ecosystems of talent, technology, and software that are continually world-class.

SECTION 2

Overview

The story of American discovery and innovation includes significant roles played by both the private and public sectors. As the high performance computing (HPC) industry has evolved, businesses in diverse sectors have continued, in each new era of capability, to apply computational methods to strengthen their competitiveness. While government and academic research labs collaborate with private vendors to advance HPC technology, there is a growing group of industrial users that leverage those technologies as they come to market, leading to breakthroughs in diverse commercial applications, such as manufacturing, pharmacology, risk mitigation, electronics design, content management and delivery, chemical engineering, and the optimal development of energy sources.

These advancements better the lives of consumers in both profound and subtle ways, from safer cars to shinier hair. But as diverse as the myriad commercial applications of HPC may seem, they are linked in an important way. In each case, the application is linked to the core mission of the company, to its innovative lifeblood. One representative of a U.S. manufacturer described it this way:

> *We're using HPC for analysis and simulation… We have a better chance of verifying that the product meets the spec before we actually build any physical prototypes…What intensive parallel processing is going to allow us to do is to optimize the designs much earlier in the design process, so we don't waste resources down the road to do the optimization afterwards…We can put out a higher-quality product that's more optimized by using more intensive computing resources…We have also been able to put out products that are meeting higher standards.*
>
> **Interview 3, Large equipment manufacturing**[1]

To be sure, it takes time for industrial applications to take advantage of new capabilities. Each new level of scale achieved by the world's most powerful supercomputer carries implied changes to computational methods and system management. A company might need to invest significantly over time in software and skill sets in order to realize its next breakthrough. The leaders will be the organizations that have the commitment, the resources, and the imagination to think beyond their current paradigms, to visualize better methods, to invest in sustained leadership, and to continue the innovative drive at the heart of their mission.

In this project, the Council on Competitiveness engaged Intersect360 Research to interview exactly this set of leaders. The project aims to assess the potential impact of federal investment in supercomputing on the broader industrial community, surveying business leaders across multiple vertical domains. Federal leaders in advanced computation have a deep understanding of how leading-edge HPC is essential for national security, basic science, and other government missions. Less well understood is the value of advanced computing to America's economic competitiveness. This research combines broad surveys with in-depth interviews of business leaders to deliver a deeper understanding of the impact of exascale, not because of an exaflop, but because of what can be done with a petaflop, an exaflop, a zettaflop…today, in a decade, in a century. The Council coined the assertion, "To out-compete is to out-compute." This research report examines and reaffirms that assertion as we move toward the next generation of computation.

1 For demographic information on this and other quotes throughout the report, see Section 4: Research Methodology and Demographics.

SECTION 3

Key Findings

The primary purpose of this research is to assess the potential impact on U.S. industry from government investment in supercomputing technology leadership, particularly in the march toward exascale levels of performance. [See "The True Meaning of Exascale" on opposite page.] From the combination of qualitative interviews and quantitative surveys, the key findings that emerged are as follows.

1. Although they struggle to predict the specific discoveries and innovations that will come about, U.S. industry representatives are confident that their organizations could consume up to 1,000-fold increases in computing capability and capacity in a relatively short amount of time.

Companies make strategic, long-term investments in HPC technologies to realize benefits that improve their core competitiveness. As such, HPC-using organizations continually discover new ways to improve. Over time, these improvements tend to require greater computational scalability, as HPC is brought to bear on ever more challenging problems.

An important distinguishing characteristic of HPC is that it is applied in most cases to problems that can be examined at arbitrarily greater levels of granularity (at the micro level) or universality (at the macro level). A climate simulation, for example, can be made increasingly local ("How much rain will fall on this field on Thursday morning between 9:00 and 9:15 a.m.?") and increasingly global ("How does algae bloom in the Gulf of Mexico affect global temperatures in a 100-year climate model?").

This scalability at the problem level leads HPC to be applied to increasingly difficult problems over time. We do not design the same bridge twice; we design a new bridge, and usually it's a more difficult one, designed to perform better. One representative from an oil discovery company described the escalation in complexity this way:

> *If you go back to analog days, there was a person whose job title was called "computer," and the kind of data quality—the kinds of [oil] fields we were able to discover—were very simple. The fields that we're looking for today are not possible to explore effectively without computing. When it costs a few hundred million dollars to drill a well, you can't afford to just go out and do that randomly.*
>
> **Interview 6, Oil and gas exploration**

A different respondent from the same field said it succinctly:

> *"The easy oil is gone. It's getting harder and harder to find."*
>
> **Interview 1, Oil and gas exploration**

But if the commitment is ongoing, the planning horizon is nevertheless short. Very few commercial organizations in the world have petascale capabilities today, and imagining specifically what they would do with exascale—or with 1,000x, or 100x, or even 10x more capability than they currently have installed—often was beyond the imagination bound by managing this year's problems and next year's upgrades. Asked how they would use an exascale computer, some respondents were able to describe certain "grand challenge" problems they might like to work on, but typically the conversation steered back to the relatively common challenge of getting applications to scale effectively on existing systems. One oil company representative said:

> *"What would be nice is to run reverse time migration 10 times faster than we can now."*
>
> **Interview 1, Oil and gas exploration**

The True Meaning of Exascale

"Exascale" is the preferred industry nomenclature for describing the next generation of supercomputers, which will be 1,000-times more capable than today's "petascale" systems. The naming convention follows the sequence of metric prefixes that are familiar at the low end but that become increasingly obscure with scalability: kilo-, mega-, giga-, tera-, peta-, exa-, etc. The de facto metric of computer performance is "flops," floating-point operations per second. A 100 teraflops (100TF) computer is capable of 100 trillion calculations per second. (This is usually a theoretical peak number, although the same description can apply to actual performance on a specific benchmark or application.)

As we approach exascale, leaders recognize that all aspects of a system, not solely computation, must scale effectively in order to achieve any practical benefit. This includes technical elements such as memory technologies, networking, and storage; facilities considerations such as space, power consumption, and cooling; and human elements such as programmability and administration. Most importantly, a wide range of software applications must succeed in utilizing all the disparate elements of such a supercomputer in parallel, without degrading from failures in individual nodes, or else the mighty supercomputer will be super only in name, without delivering real value to those who would use it.

This viewpoint that productive systems cannot focus solely on peak computation (flops) is a greater issue now than at any previous point in supercomputing history. In practice there is little difference between "exascale" and "exaflop." Generally a person will say the first and mean the second, albeit with acknowledgement that he or she envisions the eventual computer as being useful. Intentions aside, the moment anyone builds an exaflop-capable computer, the industry will decree the exascale era to have arrived, and not beforehand. Done properly, exaflop supercomputers will be exascale in more than prefix only.

Nevertheless, there is tremendous optimism across industry that increases in capacity would be consumed productively. Looking at their most demanding HPC applications today, 68 percent of respondents felt they could utilize a 10x increase in performance over the next five years. Perhaps more surprisingly, 57 percent of respondents—more than half—say they could make use of a 100x improvement in performance over five years, and 37 percent—more than one-third—still agreed when the threshold was increased to 1,000x. (See Figure 8.) This finding is supported by the qualitative interviews, as follows:

> *There are two Holy Grails at exascale that I am just dying for. One of them is computational steering, taking the engineer, the scientist, the doctor, the accountant, putting them in the chair, give them the joystick, basically running through the application and continuously optimizing to whatever state they want to be at. The other Holy Grail is being able to do digital holography, where I can truly create virtual objects, which is the ultimate VR [virtual reality]…To me, that unlocks human creativity, and we have another Renaissance period, a scientific Renaissance.*
>
> **Interview 12, Consulting services for industrial supercomputing adoption**

> *I don't think anybody can exactly articulate the extent to which it's going to change how we do product development, but it could be radical. It could take our development time to less than half, perhaps, if you don't have to build prototypes and have systems in the field and do all of the testing virtually. Who knows?*
>
> **Interview 3, Large equipment manufacturing**

In a research mode, we can evaluate a [single] design, but to put it into full production and try to evaluate the [entire] product line, it's impossible at that level. We can impact things at a research level—to try to understand the benefit, can we go in this direction—but to really have a broad impact on the whole product group, it's prohibitive. We're going to need somewhere between 10x and 100x in order to achieve that.

Interview 7, Large equipment manufacturing

In addition, 53 percent of survey respondents believe new applications will come online that will drive the need for increased computation. (See Figure 10.) Given a chance to opine on how much of a performance boost would be required, several provided details, including the following:

I tend to think in terms of 100x. However, if I view today's compute power [next] to what we used for modeling and simulation just a couple of decades ago, I have to believe that 1000x will be needed. I just can't get my head around this yet.

Quantitative survey, Large product manufacturing

Hard to quantify this, but to take just one significant metric, we need to reduce a task from a 6 hour run to less than 1 minute. This has been proven possible in a test environment, so we know it can be done!

Quantitative survey, Energy

One leader from the financial industry did provide a detailed roadmap of what his organization could do with each new level of application scalability:

There's a whole hierarchy that happens in every product in finance. When people start trading a product, the first thing they need is a price. They need to be able to compute an arbitrage-free price based on other securities…That involves having a model that you can calibrate to the market and price the security. That's one level of computation. If it's a complicated model, it can take significant computing power to do it.

Now, the next level up, once you can do that, you want to say, how is the price going to change if the market changes? Now you have to perturb all the market input models, and there could be five or 10 or 20 or 30, and recompute, so now you're talking about increasing the level of computation you need by an order of magnitude.

And then once you can do that, there's two other directions it goes. Now I want to analyze the strategy that's involving the security, so I want to pull historical data and try running out the strategy using this model every day over the last five years. So now you have a huge amount of computation to run each of these tests, another couple orders of magnitude. And then once you're trading these successfully you have a portfolio of them that you need to analyze how the whole portfolios going to behave, so it's another several orders of magnitude…

As the computing gets faster it makes more things possible…Once your computing catches up and you can do it on an interactive basis, you can respond to market changes, and it opens up a whole new world. When you have to do your portfolio analytics overnight, then it's a different world than when you can do them in real time, interactively, where I can say, 'Oh, the market moved suddenly. How does that impact my entire portfolio? Can I track my VaR [value at risk] as the market moves?' That's an innovation that could have a major impact on the markets.

Interview 2, Financial services

2. Software scalability is the most significant limiting factor in achieving the next 10x improvements in performance, and it remains one of the most significant factors in reaching 1,000x.

"Your mileage may vary." These four iconic words took up residence in advertisements for higher-mileage cars in the wake of the 1970s gas crises, a legal notification that if you don't drive your car in the precise way in which it was tested, don't be surprised if your actual, realized miles per gallon comes up short of the theoretical benchmark.

Similarly, peak flops is an idealized metric. Performance ultimately comes down to applications using a system's resources efficiently at scale. Measuring a computer solely by its peak flops rating is like measuring a person's typing speed in words-per-minute, assuming generously that every word could be "a." And just as there are marked differences in typing "a a a a a a a …" versus, "Dear Sir, We are pleased to inform you that your dog has been accepted to …" versus writing the next great American novel, so too are there differences in peak flops performance, peak Linpack[2] (TOP500) performance, and applications for calculating air flow, vibrations, signal refractions, and the like.

The best methods for optimizing an application depend on the underlying computing architectures, and changes in how computers are built can have significant ramifications. For today's new generations of HPC systems, the software scalability issue is exacerbated by the evolution of underlying processor technologies. Whereas previous years' peak flop boosts came from processor speed improvements (measured in megahertz then gigahertz), recent performance gains have introduced a new era: multi-core. Rather than increasing the clock speed, multi-core processors keep individual processing elements the same speed, but make them progressively smaller, fitting more of them together with each successive chip. Everyday small tasks, which make up the volume of the market, can be dynamically assigned to one core or another without penalty, but for large jobs designed to run across all the processors in a system, multi-core introduces yet another stratum of parallelism at the processor-chip level. The burden is on the software programmer to use the disparate cores efficiently.

Alternatives to multi-core—and there are many—offer similar challenges for the programmer. The accelerated computing model with graphics processing units (GPUs) offers a "many core" option in which supplemental co-processors take on heavy-lifting tasks. Lighter-weight processors based on architecture from ARM Holdings have a limited instruction set that makes them less expensive and less resource-hungry. There are considerations for Reduced Instruction Set Computing (RISC) processors, field programmable gate arrays (FPGAs), digital signal processors (DSPs), and even quantum computing. The point of this background is not to recommend a superior technology, but rather to emphasize that there are new processing paradigms in the market, and therefore there is a burden on software providers and programmers to find new paths to application scalability.

2 Linpack, or more precisely, HPL (High Performance Linpack), is the benchmark used to determine ranking on the TOP500 list of the 500 most powerful supercomputers in the world, published semiannually at http://www.top500.org. Although there are certain applications that mimic its performance and requirements, Linpack is sometimes criticized for not mirroring the complexity of most real-world applications.

There are new processing paradigms in the market, and therefore there is a burden on software providers and programmers to find new paths to application scalability.

When you look at what Intel and IBM and others are doing with chip technology, because of the thermal cap they're dealing with, we're seeing a higher and higher level of parallelism. It's another variable in the complexity of this total problem. I'm not worried that we can't stand up the capacity; I'm not worried that we can't find power for it; I'm not worried that we can't figure out how to do it economically… What we're very concerned about is whether or not we're going to be able to get our problems to scale.

Interview 4, Oil and gas exploration

I'm concerned that the exascale conversation hasn't focused on software enough…We're going to have to have software that takes advantage of parallelization and shortens the solve time for hard problems.

Interview 9, Consumer product manufacturing

If you go to many cores, there are various issues regarding how to efficiently utilize that resource…We are using an ecosystem of tools that span a range of scalability. We have some tools now that we feel could take advantage of dramatic increases in computational power, and we use other tools in our current HPC environment that clearly could not take advantage of increases in computation, because they don't have the built-in scalability. We're always thinking, will this tool work on the next generation of computer architecture? What do we need to do to get it there? It really is a spectrum; it's not just one tool.

Interview 11, Automotive, industrial, and consumer manufacturing

Against this backdrop of evolving models of parallelism, the greatest barrier to improved effectiveness of HPC systems for U.S. industry is software, specifically, enabling applications to reach higher delivered levels of performance commensurate with the increases in peak flops. The survey revealed that HPC-using companies perceive software scalability to be the greatest limitation in achieving their next 10x improvement in performance. Fifty-one percent of survey respondents rated "scalability of software" a 4 or 5 on a five-point scale, where 5 was the greatest limit to scalability. This challenge proved to be a greater barrier than any cost, facilities, or personnel/expertise limitation measured in the survey. (See Figure 11.) When companies think out to 1,000x scalability increases, scalability of software retains the perception of a major barrier, behind only the cost of the hardware. (See Figure 12.)

One interview respondent from an oil discovery company addressed the MPI (message passing interface) programming model specifically:

> *It seems once you get to 100 computers in your job, any glitch in the network or in one node causes the job to fall over. That's a limitation in the MPI layer, where it's not very resilient to errors or failures. The software is a limit there. Something beyond MPI has to come into play, if we're going to run larger-scale models and jobs.*
>
> **Interview 1, Oil and gas exploration**

And a manufacturer criticized what he perceived as the general lack of HPC software investment:

> *Right now the software industry is not dealing with parallelization very well. They have stopped innovating…There's too big a gap in engagement between the national laboratories and academics and the ISVs who make their living in software…They're doing open source, and open source to an ISV is a problem…Why are the ISVs not engaging with the academics and the national labs at a much higher level?*
>
> **Interview 9, Consumer products manufacturing**

3. U.S. industry sees a benefit from government leadership in the investment in supercomputing technologies, but the links between government and industry need to be strengthened.

> *Can the benefits of ARPAnet and the Internet be quantified?*
>
> **Quantitative survey, Electronics design**

This question was raised rhetorically by one survey respondent, asked whether he could quantify the benefit to his company of past government investments in supercomputing technologies.

Other long-answer responses in the survey were less succinct, but they echoed the sentiment that although the benefits of government investment can be difficult to quantify, they most certainly exist.

One interview respondent said:

> *We obviously look to the national labs. We partner heavily with the national labs in the utilization of machines and learning how to use the leading-edge machines that will ultimately show up in our place. We look there for inspiration.*
>
> **Interview 8, Aerospace company**

Another survey respondent said it this way:

> *Without the needs of NSA, NASA, NOAA, and the military (DARPA) for ever faster systems, there would be less R&D into the development of the actual hardware we are using now. These operations are so demanding that R&D must come up with new platforms.*
>
> **Quantitative survey, Professional services**

Despite the lack of precise, quantifiable metrics, 62 percent of respondents agreed (or strongly agreed) with the statement, "Past government investments in new generations of supercomputing have had a benefit on your company/industry." Only 4 percent disagreed with the statement. (See Figure 14.)

Fifty-six percent of survey respondents agree that work done by national government research organizations can "act as major driver for advancing HPC technology, leading to products and software that we will use in the future." Fifty-six percent also agree that federal research leadership "provides software, techniques, and technology that we closely watch and incorporate into our HPC operations." (See Figure 16.)

Fifty-two percent of the industry respondents agreed that U.S. government exascale initiatives were relevant to industry, and 71 percent agreed that the initiatives are important to the country. (See Figure 20.)

Despite this optimism, the more in-depth qualitative interviews indicated that there is more work that can and should be done in order to provide more direct benefit to industry from government investment in scalability and expertise:

> *There's encouraging stuff along the way. National labs …have become a lot more open and willing to collaborate with companies, and as a result of that openness, the barriers of collaborating with national labs have decreased. And there are many barriers. One obvious one would be cost, but there are other barriers such as the legal requirements, dealing with intellectual property. I like this trend; I think it's a positive trend. The only point I want to make is that I think these are first steps. I think a lot more can be done, and a lot more should be done to have larger investments, a number of these larger machines that can be dedicated to joint work between national labs and industry. And there's a tremendous amount of expertise at the national labs …which would then be able to convince corporations to invest in high performance computing within the company itself.*
>
> **Interview 11, Automotive, industrial, and consumer manufacturing**

> *The smaller ISVs, [in fact] anyone smaller than a large multinational, seem not to be engaged. Every time [ISVs] show up to the labs, they just want to sell them stuff; they don't show up to the labs to do collaborative research and development. And I hear whining from both sides; I'm not going to fix blame…On the ISV side, all they hear is that the labs don't understand commercial engagement and are not very forthcoming with intellectual property that they can make a business out of.*
>
> **Interview 9, Consumer products manufacturing**

> *The technology transfer piece is quite weak. As I visit industrial customers, one of the biggest complaints I hear about is the lack of good HPC programmers…We've not done a good job as a community in the education moving to industry in creating the next crop of engineers.*
>
> **Interview 10, Supercomputing technology provider**

> *There is no more important competitive asset that the United States uniquely has than the combination of government investment in national science labs, world-class academic research, and an industrial base that invests in research. That collaboration, and the flow of technology through that collaboration, is the major competitive advantage that the United States has…High performance computing needs to be a partnership between those three entities if we're going to be successful.*
>
> **Interview 8, Aerospace company**

SECTION 4

Research Methodology and Demographics

Working closely with the Council on Competitiveness, Intersect360 Research took a two-step approach to this research project, incorporating both a quantitative survey and a qualitative discussion guide to assess the industrial use cases for exascale computing.

In-depth interviews

In the qualitative research segment, Intersect360 Research interviewed forward-thinking leaders across multiple industries. These phone interviews were constructed to be exploratory, allowing the freedom to dive more deeply into interesting topics as they evolved, but following a standardized discussion guide. The full content of this discussion guide is given in Appendix A; it contained the following high-level topic areas, with multiple subtopics per question:

- How does your company use HPC today, and how does it relate to competitiveness?
- How would exascale computing (or a computer 1,000 times more powerful than you have now) contribute to your organization's strategy, capability, and competitive advantage?
- Where do you see leadership in new HPC scalability coming from?

Intersect360 Research completed 14 phone interviews over a three month period from late 2013 through early 2014. These interviews were recorded, and excerpts from them appear throughout this report, protecting the anonymity of the respondents and their organizations. All interview respondents represented U.S. companies or the U.S. operations of multinational companies. The vertical markets and dates of the completed interviews are given in Table 1.

Table 1: Vertical industries and dates of qualitative interviews

Interview	Vertical Industry	Date
1	Oil and gas exploration	October 30, 2013
2	Financial services	October 31, 2013
3	Large equipment manufacturing	October 31, 2013
4	Oil and gas exploration	November 4, 2013
5	Oil and gas exploration	November 6, 2013
6	Oil and gas exploration	November 7, 2013
7	Large equipment manufacturing	December 2, 2013
8	Aerospace company	December 6, 2013
9	Consumer product manufacturing	December 13, 2013
10	Supercomputing technology provider	January 16, 2014
11	Automotive, industrial and consumer manufacturing	January 16, 2014
12	Consulting services for industrial supercomputing adoption	January 16, 2014
13	Supercomputing technology provider	January 22, 2014
14	Satellite imaging and intelligence	January 29, 2014

The interviews included two supercomputing technology providers, complementing the views of the end-user community. These interviews followed a slightly modified discussion guide, covering the same topics and asking the participants to answer question on behalf of their U.S. industry customers based on their experience and expertise.

Quantitative survey

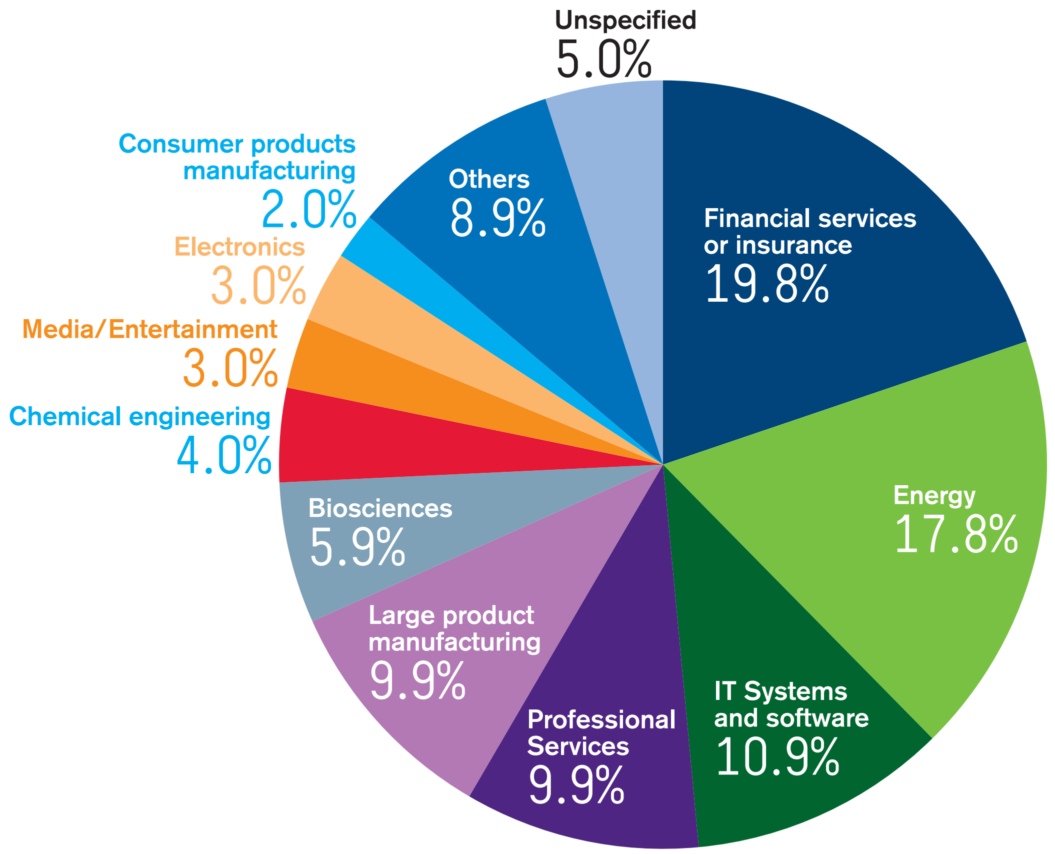
The insights gleaned from the qualitative interviews provided more than illustrative quotes for this report. They also introduced and guided topics that were plumbed in depth in the second phase of research, a broad-based HPC site survey to provide quantitative data that formed the primary basis of analysis. The full text of this survey is given in Appendix B.

The primary survey population was the internal HPC user list of Intersect360 Research, including the HPC500 user group. (See About Intersect360 Research, Appendix C.) Supplemental target respondent lists came from the Council on Competitiveness and from a partnership agreement with Gabriel Consulting Group. The targeted organizations were invited by email to participate in the web-based survey; all surveys were completed in the first half of 2014. All responses were audited and compiled by Intersect360 Research, keeping only valid responses from U.S.-based commercial operations running HPC applications.

In total, Intersect360 Research collected 101 completed surveys.[3] The survey respondents covered a broad range of vertical markets, as shown in Figure 1.

Figure 1: Survey Respondents by Vertical Market

N = 101



3 Not all survey respondents chose to answer all questions. For each figure, the number of respondents to that question is given.

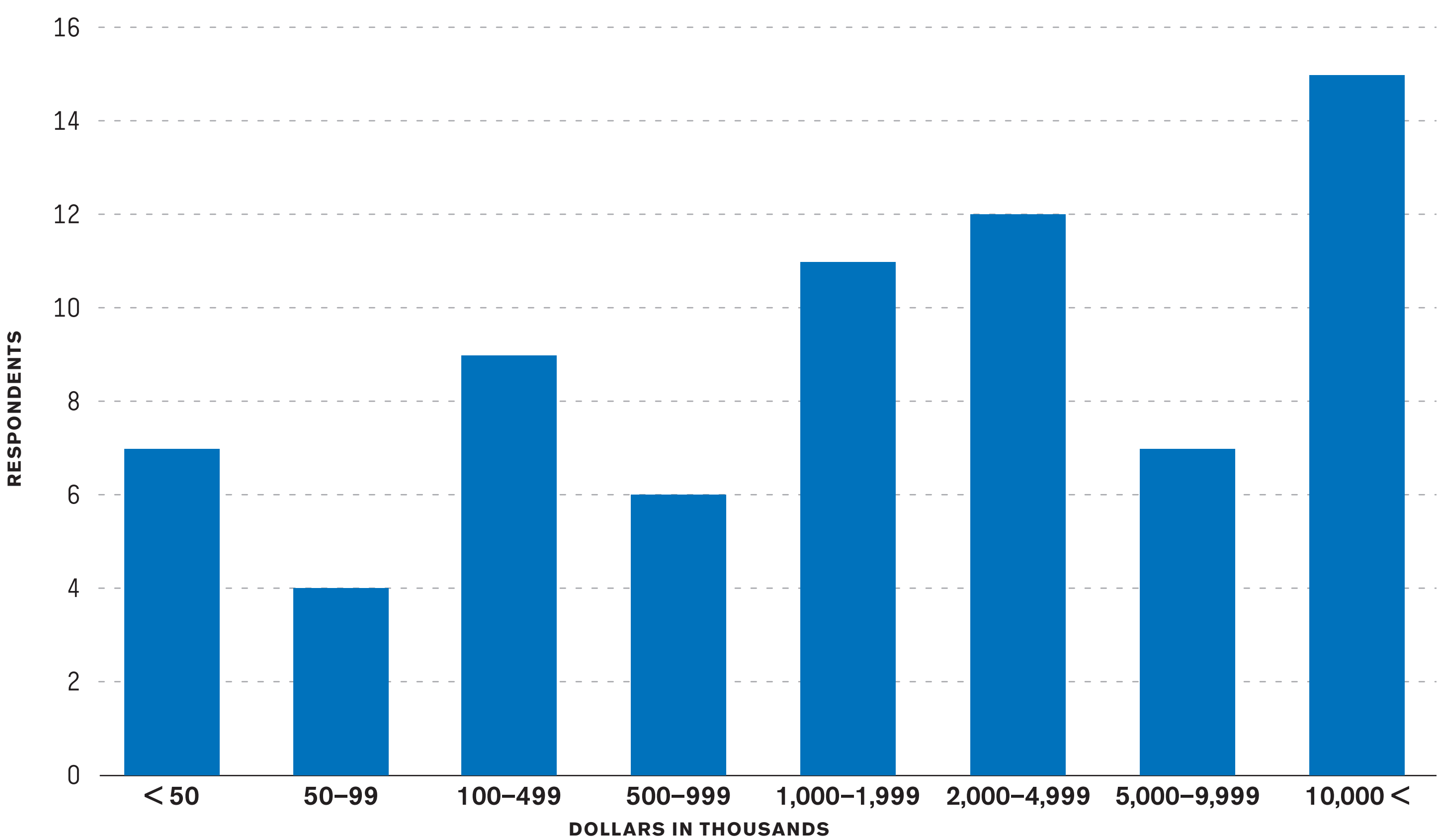
The survey respondents covered a broad range of expertise and scale of HPC systems, from modest, entry-level HPC infrastructures to robust supercomputing environments. Seventy-one of the 101 respondents were able to share data about their annual HPC budgets, which ranged from under $50,000 per year (10 percent of respondents) to over $10,000,000 per year (21 percent). (See Figure 2.)

In addition to their annual budget for HPC, respondents were asked to identify the class of system used by their most demanding applications, according to the following definitions:

- Entry-level HPC System—Generally small clusters under $50,000, used to support individuals or small groups, or for dedicated applications.
- Midrange HPC System—Generally single rack clusters under $250,000, used to support small organizations or projects.
- High-end HPC System—Generally a full rack or multi-rack cluster under $1.5 million, used to support larger organizations, often with several independent subgroups. These systems can also be dedicated to supporting large ongoing (often mission-critical) applications.
- Supercomputer—Multi-million-dollar, multi-rack systems, designed or configured to address problems that cannot be effectively addressed by general-purpose systems. Although generally seen as scientific and engineering systems, supercomputers can be used for any application that requires extraordinary capabilities in such areas as computational power, input/output (I/O) performance, or scalability.

Figure 2: Annual HPC Budget of Respondents, Where Provided

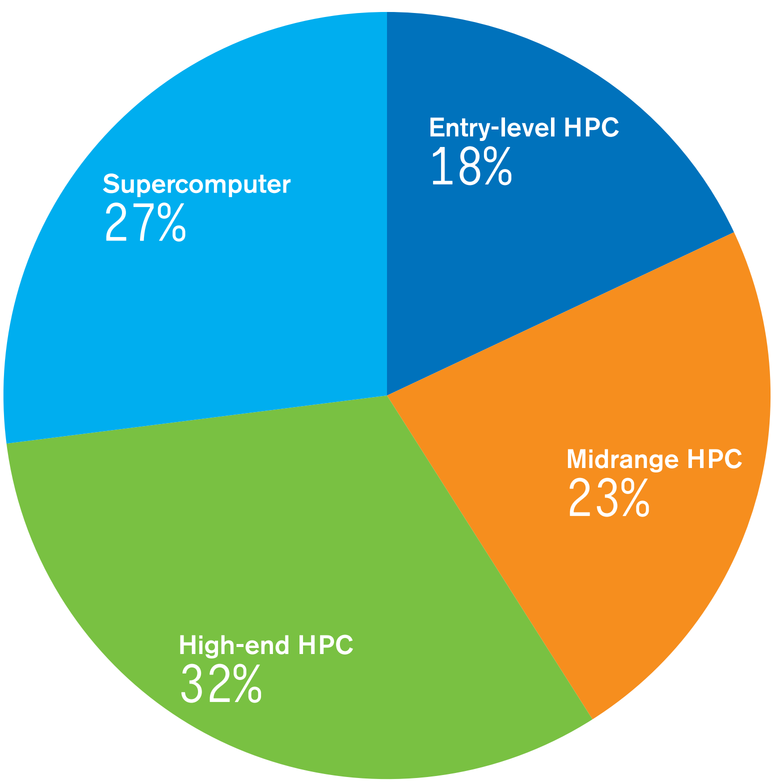
N = 71



As would be expected given the range of annual HPC budgets, the survey respondents represent a range of HPC scalability in their existing HPC infrastructures. Forty-one percent of the survey respondents have a maximum of entry-level or midrange HPC systems. (See Figure 3.) This is important in exploring how government investment in supercomputing can influence the entire HPC user community beyond sophisticated supercomputing users, pervading the industrial use cases down to more modest installations, which still provide important innovations in their respective fields.

The above demographics—vertical industry, budget, level of HPC—represent data segmentations that were investigated for differences in responses. These segmentations are given throughout the report where interesting or meaningful insights were found in the distinctions.

Figure 3: Level of HPC Scalability Among Survey Respondents
N = 100



SECTION 5

Full Research Results and Analysis

This section details the research results for the assessment of how industry values U.S. federal investment in next-generation supercomputing technologies. For this section we present results in cohesive components, mostly following the order adopted in the quantitative survey (see Appendix B), inserting excerpts from the in-depth interviews (see Table 1, under Methodology) where appropriate, and providing analysis of the data throughout the section.

As with any in-depth survey, there are more potential data views, cross-tabulations, and segmentations than can practically be included in a written report. We present responses at a high level together with a selection of segmentation data found most relevant to our analysis. For additional inquiries into the data in the report, please contact the Council on Competitiveness or Intersect360 Research.

The Value of HPC

Respondents were polled on the importance of HPC to their organizations, primarily through a series of agree/disagree statements. Companies tend to deploy HPC in areas that are the most strategic for their respective organizations. Manufacturers use HPC for manufacturing; pharmaceutical companies use HPC for drug discovery; financial services organizations use HPC to reduce risk relative to gains. Therefore it isn't surprising to see that the majority of respondents tend to favor the notion that HPC is of strategic importance. Nevertheless it is instructive to see how dominant and pervasive this sentiment is across industrial HPC users. (See Figure 4.)

There is not a single statement exploring the organizational importance of HPC that does not get strong agreement in the survey. Seventy-two percent feel that HPC is a cost-effective tool for R&D, and 76 percent feel that improving their computational methods is a matter of competitive survival. Looking forward, 83 percent feel their businesses would benefit from improvements in modeling and simulation, and 86 percent agreed with the simple statement, "HPC is critical to the future direction of our business."

> *The metrics that we track for quality …have improved tremendously over the past 20 years: failures per machine, number of warranty items inside the warranty period, …the regulations for meeting emission controls for highway equipment. That's where we have made the most strides using these computing resources, by being able to do simulation up front.*
>
> **Interview 3, Large equipment manufacturing**

> *We're using [HPC] to find oil, and if you're not finding oil, you're not very competitive as an oil company…Where you set the well, and how the well is set, and how the well performs, for 20 or 30 years in many cases, is critical to the economics, and being able to have high-resolution images increases your NPV [net present value] associated with the asset…If you're talking about a $200 million well, getting it perfect the first time is really important, and having a really good picture of the subsurface and how those fluids are sitting is critical to that.*
>
> **Interview 4, Oil and gas exploration**

> *It's real hard to say what's the impact that high performance computing [has] had. Essentially it lets us evaluate more options much more quickly than we ever would have before, the probability of landing on an optimal solution is much, much higher. From that perspective…it is a competitive advantage.*
>
> **Interview 7, Large equipment manufacturing**

There have been all sorts of changes and innovations in the financial markets that have been associated with computation. Derivatives markets weren't possible before the math of Black-Scholes and arbitrage-free pricing. Pricing changed dramatically as we developed insights into how these models work. None of this would have been possible without the computing infrastructure.

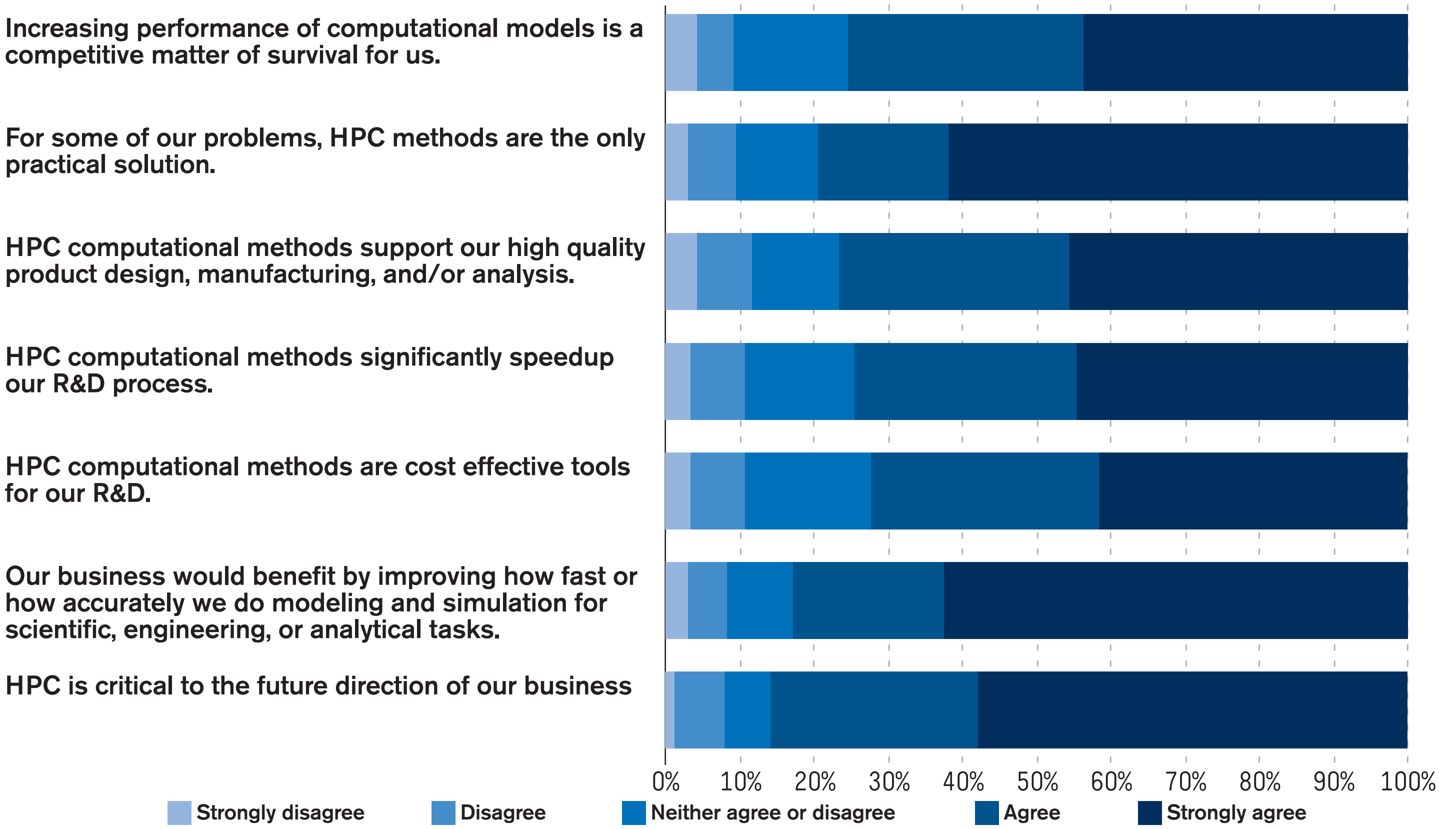
Interview 2, Financial services

We have two ways to be competitive. One is to have software that we create that does the science faster and cheaper and better. And the second is to have larger [HPC] capability [to use the] software faster and better and cheaper.

Interview 1, Oil and gas exploration

Figure 4: Importance of HPC, Agree/Disagree

N = 99-100, bars exclude "N/A" responses, 0-5 per bar



We're removing design cycles from jet engine component technology, doing full modeling of individual component of an engine: compressors, combustors, turbines, rotating elements, etc…Could we do all of those things without high performance computing? No. Could we do some of them with lots and lots of very expensive testing? Probably. It's a very cost-effective way for us to do the fundamental work.

Interview 8, Aerospace company

HPC helps us improve our products and come up with new products: protect the environment, make sure our products are safer, that they are more efficient, more durable, and that they have unique functionality. But another aspect of HPC is to help us optimize our processes through the use of data mining.

Interview 11, Automotive, industrial, and consumer manufacturing

HPC has allowed us to drive tremendous cost savings and enabled us to drive more volume, compared to the old way of doing things.

Interview 14, Satellite imaging and intelligence

We simulate every chip we make…Just like the automotive industry, the cost of building a chip is very high, both the cost in terms of design, and also in terms of market opportunity. Just like a car manufacturer can't miss having their 2014 lineup of cars, in the same way we can't miss our lineup of chips.

Interview 10, Supercomputing technology provider

Innovation is our lifeblood. We've been trying to improve daily life for over 100 years. We have a long history of hiring scientists and engineers to lead that innovation…It's the cost of prototypes that govern how many good ideas you can get into your products…We've replaced the physical learning cycles that used to be part of every scientist's and engineer's experimental routine. And the ones that we've replaced are not the last experiment, because those are still confirming the final test to make the product and see if the consumers try it. All the prototyping and all the experimentation that used to be done prior to that point which was all done physically, we now can do that virtually.

I can figure out whether a bottle will break when it drops. I can figure out how the handle will fit small hands and big hands. I can figure out whether a diaper will leak. I can figure out whether the closure on a diaper will mark a baby's leg because the elastics are too tight. Whether a formula will remove a stain and still protect a new fabric. How many washes will it take for jeans to fade? Can we smell a new perfume on laundry after it's been washed? If you think about it, we wash things to remove smell, but we want a little bit of perfume left. I can tell by the molecular structure of the perfume whether we're still going to be able to smell it or not. All of those things we now do with high performance computing.

Modeling and simulation has accounted for hundreds of millions of dollars of value over the last decade, and I can point to several products in the marketplace that would not have been there had it not been for modeling.

Interview 9, Consumer product manufacturing

It should be noted that the likeliness to agree with the statements in Figure 4 goes up with the respondent's level of HPC experience. For example, of the eight survey respondents who disagreed with the statement, "HPC is critical to the future direction of our business," six were entry-level HPC users, and two were midrange HPC users. Viewed another way, one-third of entry-level HPC users disagreed with the statement, but that number fell to about 10 percent of midrange HPC users, and no respondents that were high-end HPC or supercomputing users. (Causality must be inferred: Is it that users find HPC more valuable as it scales, or is it that users who don't anticipate the value don't invest as much? Intersect360 Research believes the answer tends more toward the latter, though both could be true.)

Despite the apparent value in HPC as indicated in Figure 4, it can be difficult for industrial organizations to justify the investment in HPC on an ongoing basis. Users rated how challenging it is to justify HPC investments on a five-point scale (1 = not a challenge; 5 = significant challenge). (See Figure 5.)

Figure 5 measures the degree to which justification is challenging, and therefore every response greater than a 1 is at least some level of challenge, and an “average” score of 3 still represents at least a moderate challenge. Sixty-seven percent of respondents rated the justification challenge a 3 or higher, and 10 percent gave it a 5.

As with Figure 4, we notice the most significant segmentation difference in the level of HPC experience the end user has. If we view Figure 5 with this segmentation, we see that entry-level HPC users perceive a far greater challenge in justifying HPC investment than the supercomputing users at the far end of the spectrum. (See Figure 6.) One interview respondent explained:

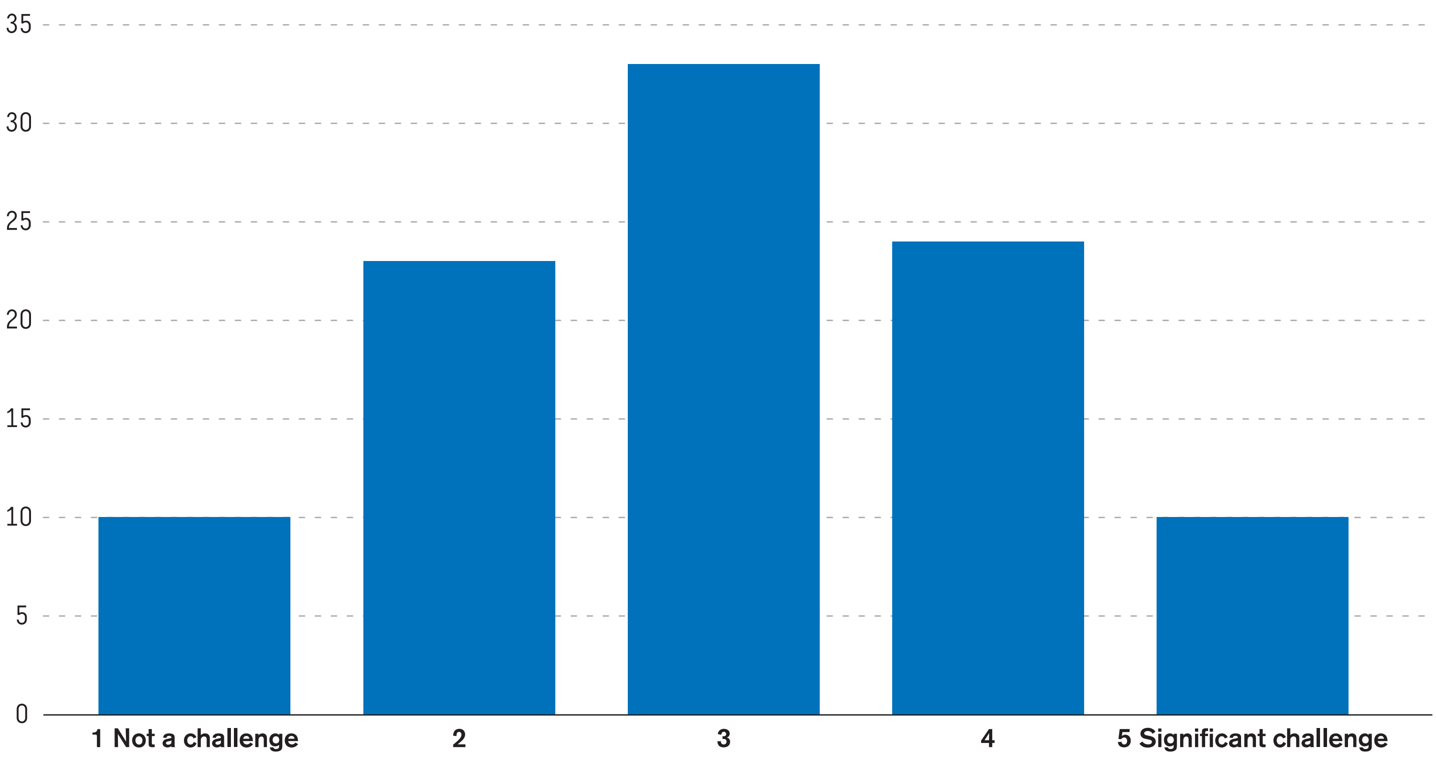
> *The big guys have the stuff, and the little guys don’t, and there’s getting to be more separation between the big and the little.*
>
> **Interview 12, Consulting services for industrial supercomputing adoption**

Given the challenges in justifying HPC expenditures, it is also important to look at what means HPC users employ in order to make that justification. Users were asked to pick the single most effective metric to justify HPC investment from the following. (See Figure 7.)

- Time to solution
- Inability to solve the problem by any other means
- Utilization rate
- Improvements in quality or features
- Reduced costs compared to physical methods
- Return on investment (ROI)
- Other

“Time to solution” (24 percent) and “Inability to solve the problem by any other means” (23 percent) were the top two responses, but what is more instructive is to look at the distribution. There is not any response that is dominant. That is, there is not a single “silver bullet” metric that is viewed as the best across industry. Furthermore,

Figure 5: Justification of HPC. "How challenging is it to justify investment on HPC within your organization?"
N = 100



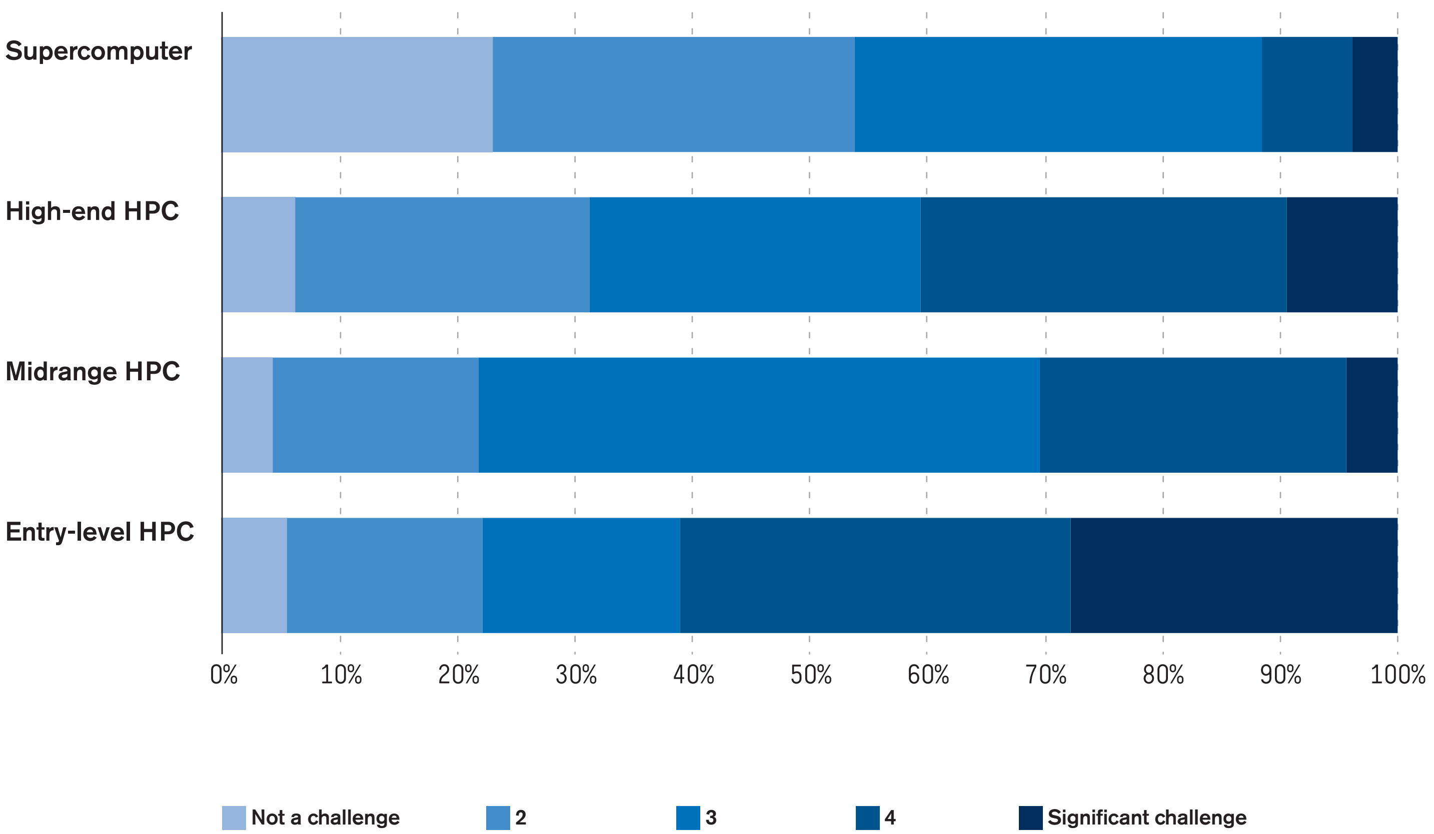
certain responses, such as "ROI," might have significantly different implementations depending on the industry or the specific organization. Finally, there is not any significant pattern to the responses by industry or by the level of HPC experience. HPC justification is individual to the organization measuring it.

> *If I look at the top ten supercomputers in the world, they're not entirely out of reach of certain corporations. But if I get this machine, will we really see the benefits in our design process? And that has become a chicken-and-egg problem, because management can be skeptical, and of course they want a justification for such a large investment.*
>
> **Interview 11, Automotive, industrial, and consumer manufacturing**

> *You cannot come to me and say, 'Here's a problem I want to do, and I don't have the computational resources to do it,' because we will go get them. If that means substantially more cores in the company, if that means buying a bigger computer, if that means buying additional software, the return on this investment is easy for us to justify.*
>
> **Interview 8, Aerospace company**

Many of the survey respondents also provided optional long answers describing the internal justification of HPC investment. The diversity of these comments illustrates that corporate HPC investments are justified by varied or multiple reasons particular to that firm. The following are samples from those responses.

Figure 6: Justification Challenge Rating, by HPC Experience



Bio sciences

There are many factors that contribute to the justification of HPC. I could push four of the above buttons. But it always seems to come back to ROI. I once justified a large-scale purchase by showing how we could pay for an entire new HPC cluster with savings from power/cooling costs and maintenance contracts on our old cluster. Net cost of the new cluster over three years was zero dollars for a 6x increase in capacity. It got funded.

Primarily used for bioinformatics, next-generation sequencing, and virtual screening, which cannot be accomplished efficiently without HPC services. These technologies are core to our research pipelines and as such required to maintain competitiveness. Time to market is our main driver. Using HPC lets us get to market quicker.

Chemical manufacturing and engineering

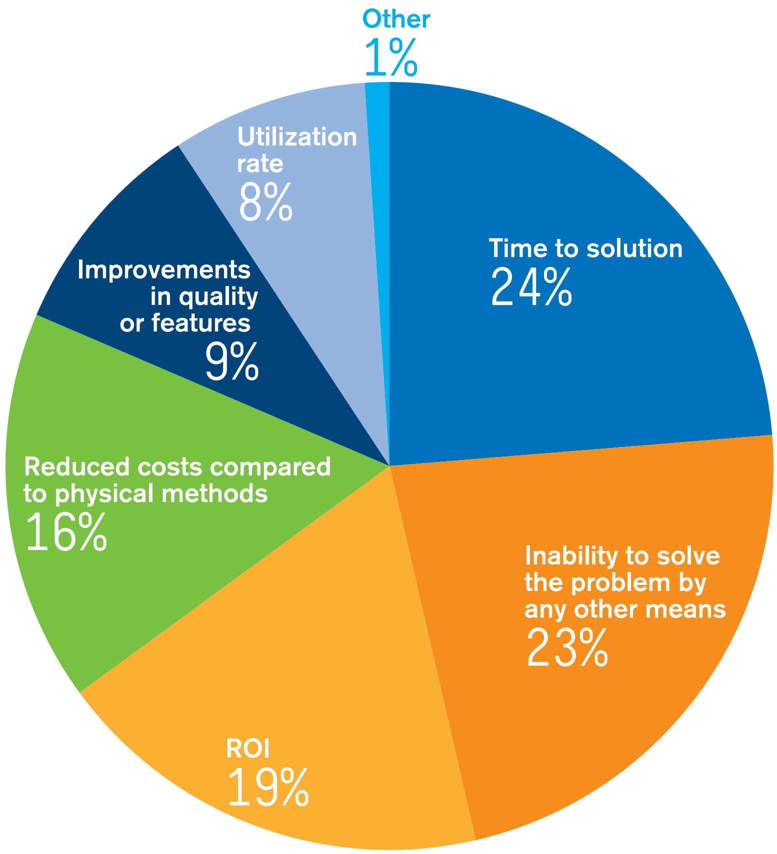
Even though our Company is in reality an R&D / Engineering and Manufacturing Company, our organization is under a Corporate / Enterprise IT umbrella, and that makes it very difficult to compete for funding with the Enterprise and ERP. We are highly scrutinized on all of our spending, operations and services we offer. That makes it a real challenge to justify what we do in the big picture and very difficult to show real value up the management chain. If we didn't have really strong support from our clients, we would not be able to function at all.

Alternative would be physical modeling that would be much more expensive.

Development time is reduced using HPC.

Figure 7: Best Metric for Justifying HPC Investment

N = 97



Consumer products manufacturing

Time is money and virtual prototyping is faster than traditional physical models.

We reduce costs by performing options analysis …before settling on a final design that moves forward for physical testing.

Electronics

Without HPC, [we] would not be able to design, develop and produce complex circuits in a timely manner.

Time and risk reduction of getting to market is main benefit.

Energy

Seismic imaging is critical for oil and gas exploration. There's not a really good way around it.

We are always looking for ways to increase the efficiency and core utilization so that we spend less on each job.

Financial services

HPC is the key to all strategies we develop. It is the secret sauce that makes us money.

HPC would only work for our company if users could work faster, thus bill more per unit of time.

Time to market and achieving competitive advantage are critical factors for us.

Large product manufacturing

I wish I could answer "inability to solve the problem by other means," because it is the right answer and 100 percent true; however, management has not yet been willing to swallow that pill, despite its truth.

It is very difficult to claim value based on issues we avoided, since we don't really know if it will happen. This is related to the culture (test data is right, simulation data is artificial). I believe we will see this change dramatically.

Time to solution, utilization, and reduced costs all apply when considering increases in HPC investments.

We collect detailed metrics, and use these utilization metrics to determine the need for additional compute capacity.

Professional services

It is only possible to solve large CFD problems within a real-time engineering design cycle timeframe by using HPC.

ROI and ROC must pass the "accountant's" tests first.

[We are a] small company, so [it is] difficult to justify investment.

The ability to shrink the development time down by even a month is critical for time to market.

Future Scalability Requirements and Limitations

Users were asked to consider their most demanding HPC applications, as well as their complete HPC workflows in total, in order to project their inclination to consume additional resources over the next five years. These were presented as agree/disagree statements, with respondents looking at whether they foresaw any need for additional capacity, and whether that capacity could be 2x, 5x, 10x, 100x, or 1,000x their current usage. (See Figures 8 and 9.)

Only 11 percent of respondents felt that their most demanding applications would not require any increases in size, fidelity, or accuracy; the figure was approximately the same—13 percent—for the entire HPC workflow.

Conversely, over 60 percent of respondents agreed that their most challenging applications, as well as their total HPC workload, could use 2x, 5x, or even 10x increases in performance over the next five years, showing a standing, immediate demand for more use of HPC simulations.

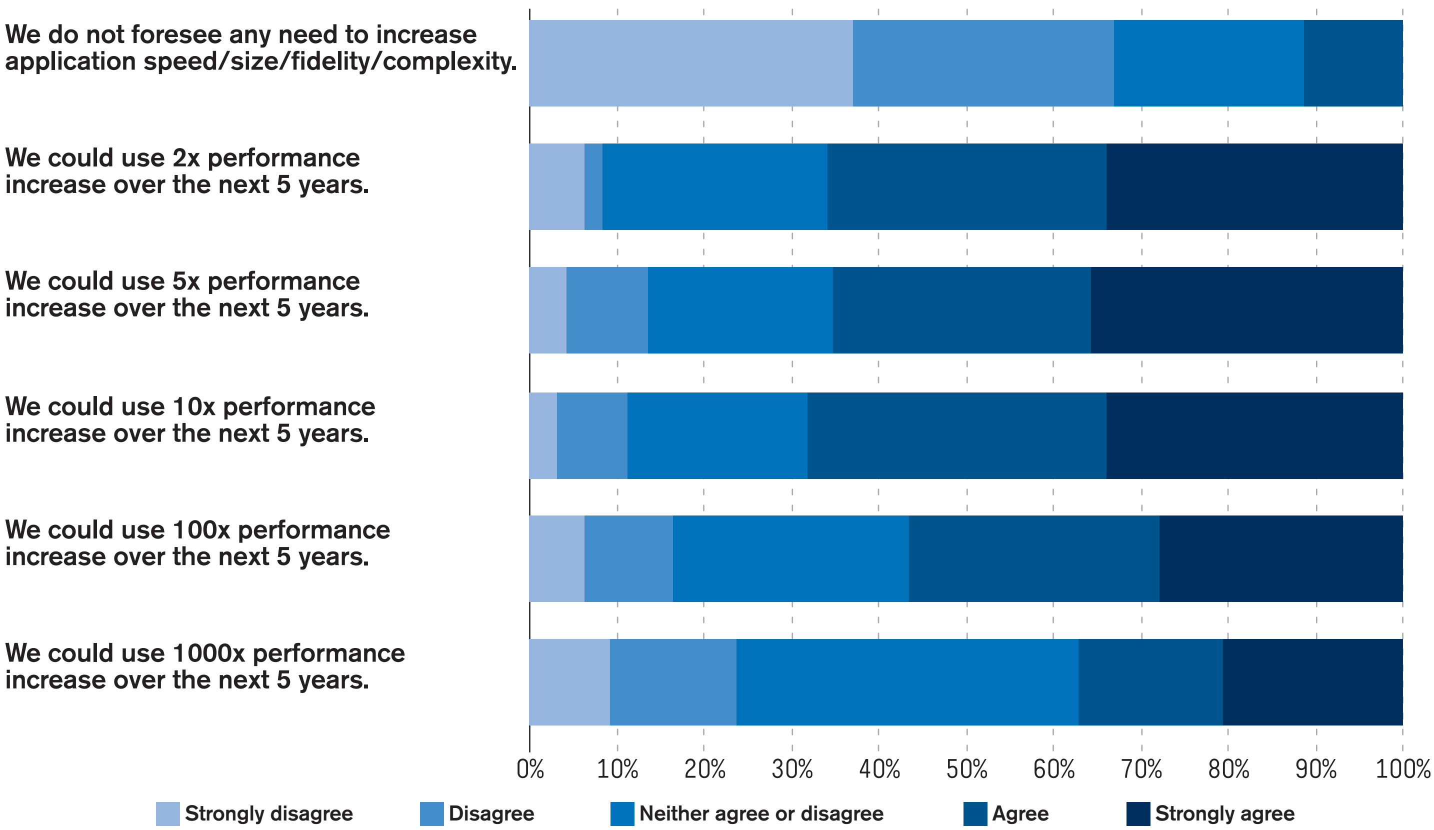
Remarkably, this latent demand stays high as the statement scales out to 100x and even 1,000x. Fifty-seven percent agreed (of which 28 percent strongly agreed) that their most demanding applications could use 100x more performance in five years. Thirty-seven percent agreed (of which 21 percent strongly agreed) that their most demanding applications could use 1,000x more performance in five years. These percentages drop off only slightly for users with smaller HPC systems. Twenty-two percent of entry-level HPC users felt their most demanding applications could use 1,000x improvement in performance in five years.

> *My internal challenge is to get people to think about the problems that are relevant for us at the teraflop-petaflop level, and then when and how do I provision to do those. I don't get up in the morning feeling like my competitive situation is challenged because I don't today have an exascale machine. I get up in the morning thinking, 'Are my engineers and scientists thinking about how to adequately use the computational resources just beyond what they have now?'*
>
> **Interview 8, Aerospace company**

> *If I think about [the] Blue Waters [supercomputer at the National Center for Supercomputing Applications], I think we could use that. If we go two or three orders of magnitude beyond that, I can dream, but is there a practical need right now? I struggle with that one. What I see in exascale is that we need to push the boundaries, so that Blue Waters can sit on my desk someday.*
>
> **Interview 7, Large equipment manufacturing**

Figure 8: Projected Five-Year Needs for Most Challenging Applications

N = 95-97



37 percent of respondents say their most demanding applications could use a 1,000x increase in performance within five years.

The fastest benefit that exascale is going to have is that the petaflop will become extremely inexpensive, so that every midsize company will be able to have a petaflop supercomputer. But industry doesn't adopt the leading edge of HPC; they're usually several ticks behind.

Interview 10, Supercomputing technology provider

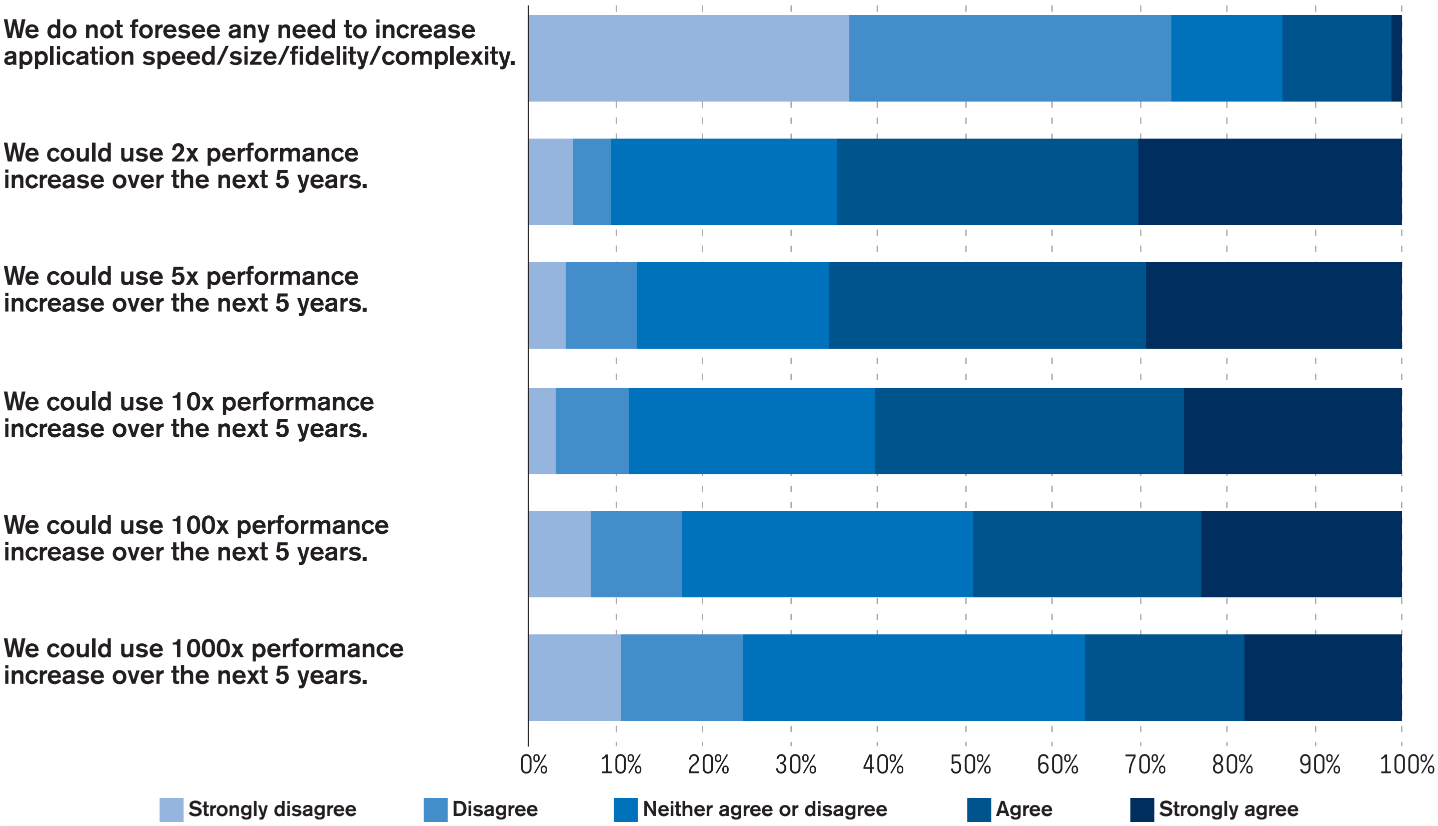
What would be nice is to run reverse time migration 10 times faster than we can now.

Interview 1, Oil and gas exploration

Demand for scalability might be driven not only by existing application needs, but also from new applications that require great performance in order to be practical. Fifty-three percent of respondents said that new applications are coming up that will require significant increases in HPC performance. (See Figure 10.)

Figure 9: Projected Five-Year Needs for Total HPC Workload

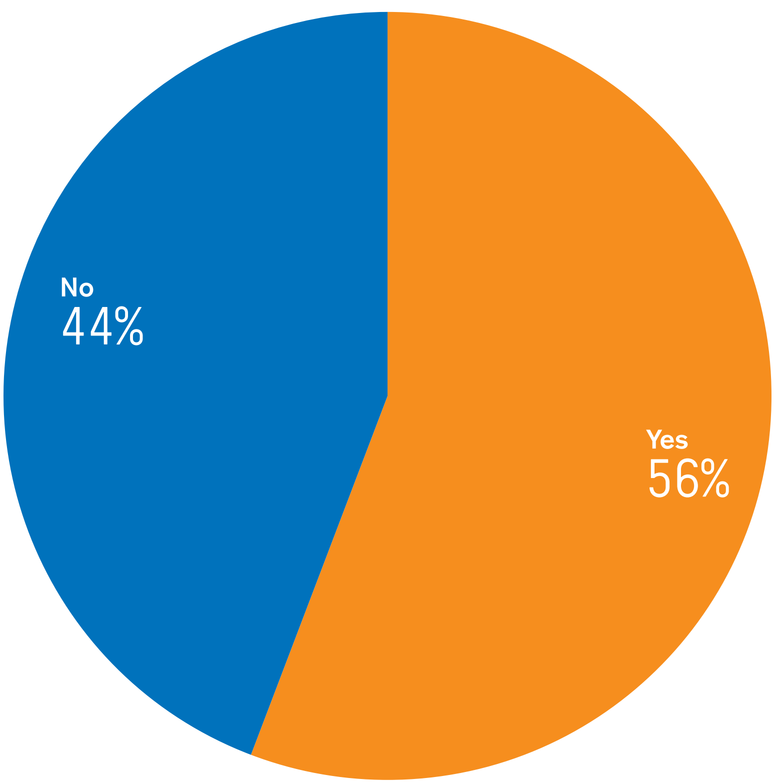
N = 94-96



Respondents indicated that scalability needs for new applications varied, with answers ranging from “about 20 percent” to “six orders of magnitude” (i.e., a million times greater). Some of the specific comments from the quantitative survey included:

> *Hard to quantify this, but to take just one significant metric, we need to reduce a task from a six-hour run to less than one minute. This has been proven possible in a test environment, so we know it can be done!*
>
> *10 times maybe, depends on the cost to obtain. We will take as much as we can afford.*
>
> *Data I/O speeds from disk is current bottleneck; network and data I/O [improvement of] 2x-5x would be great.*
>
> *I tend to think in terms of 100x. However, if I view today's compute power to what we used for modeling and simulation just a couple of decades ago, I have to believe that 1,000x will be needed. I just can't get my head around this yet.*
>
> *It's difficult to say until the new applications are available. However, we would prefer to see at least a 5x performance improvement.*
>
> *We anticipate that we need 2-3x both performance and scale improvement to fully realize the capabilities of new screening and modeling applications.*
>
> *Unknown. New applications are always coming in the door as old applications leave. Net growth is about 200 percent a year but we do have spikes. Genomics is a spike but we're not sure how big. Could be 5x, could be 100x.*
>
> *We have an almost infinite appetite for computing power.*

Figure 10: New Applications That Will Require Greater Scalability
N = 95



These comments are amplified by the qualitative interviews:

> *We're a Big Data company…As we grow our data and information, the complexity of the algorithms having to operate on that larger data set goes up. And these are not often linear relationships. We see an exponential increase in complexity.*
>
> **Interview 14, Satellite imaging and intelligence**

> *I don't think anybody can exactly articulate the extent to which it's going to change how we do product development, but it could be radical. It could take our development time to less than half, perhaps, if you don't have to build prototypes and have systems in the field and do all of the testing virtually. Who knows?*
>
> **Interview 3, Large equipment manufacturing**

> *Enterprise risk is essentially doing distributed processing over multiple processors…It's one of the areas we're selling into. Second-tier and third-tier broker-dealers need risk analytics more and more as regulations keep ramping up. They're not going to build it themselves, and we feel we can do a better job of it, building out analytics …to be able to run value-at-risk calculations every night, with 20,000 deals in a portfolio and needing to run thousand of computations on each position, it's a tremendous amount of computation.*
>
> **Interview 2, Financial services**

> *In a research mode, we can evaluate a [single] design, but to put it into full production and try to evaluate the [entire] product line, it's impossible at that level. We can impact things at a research level—to try to understand the benefit, can we go in this direction—but to really have a broad impact on the whole product group, it's prohibitive. We're going to need somewhere between 10x and 100x in order to achieve that.*
>
> **Interview 7, Large equipment manufacturing**

> *As opposed to a national laboratory, we are less driven by the one heroic calculation that I have to do, the one engine simulation, [such] that I'm going to get as much computation as I can, let it turn for hours, days, weeks, and I get one answer. It's much more important to us, particularly in product design, [to] look at very large numbers of complementary simulations. I need to be able to run thousands of case studies, not just one case study.*
>
> **Interview 8, Aerospace company**

> *There are two Holy Grails at exascale that I am just dying for. One of them is computational steering, taking the engineer, the scientist, the doctor, the accountant, putting them in the chair, give them the joystick, basically running through the application and continuously optimizing to whatever state they want to be at. The other Holy Grail is being able to do digital holography, where I can truly create virtual objects, which is the ultimate VR [virtual reality]…To me, that unlocks human creativity, and we have another Renaissance period, a scientific Renaissance.*
>
> **Interview 12, Consulting services for industrial supercomputing adoption**

It's extremely unproductive to develop a product and then go do ship tests with it, where we literally have to make the product and then ship it around the country, go retrieve it, see if it's okay, and if it's not, how do you fix it? That's a very slow way to innovate. That's one of our grand challenge problems [for HPC].

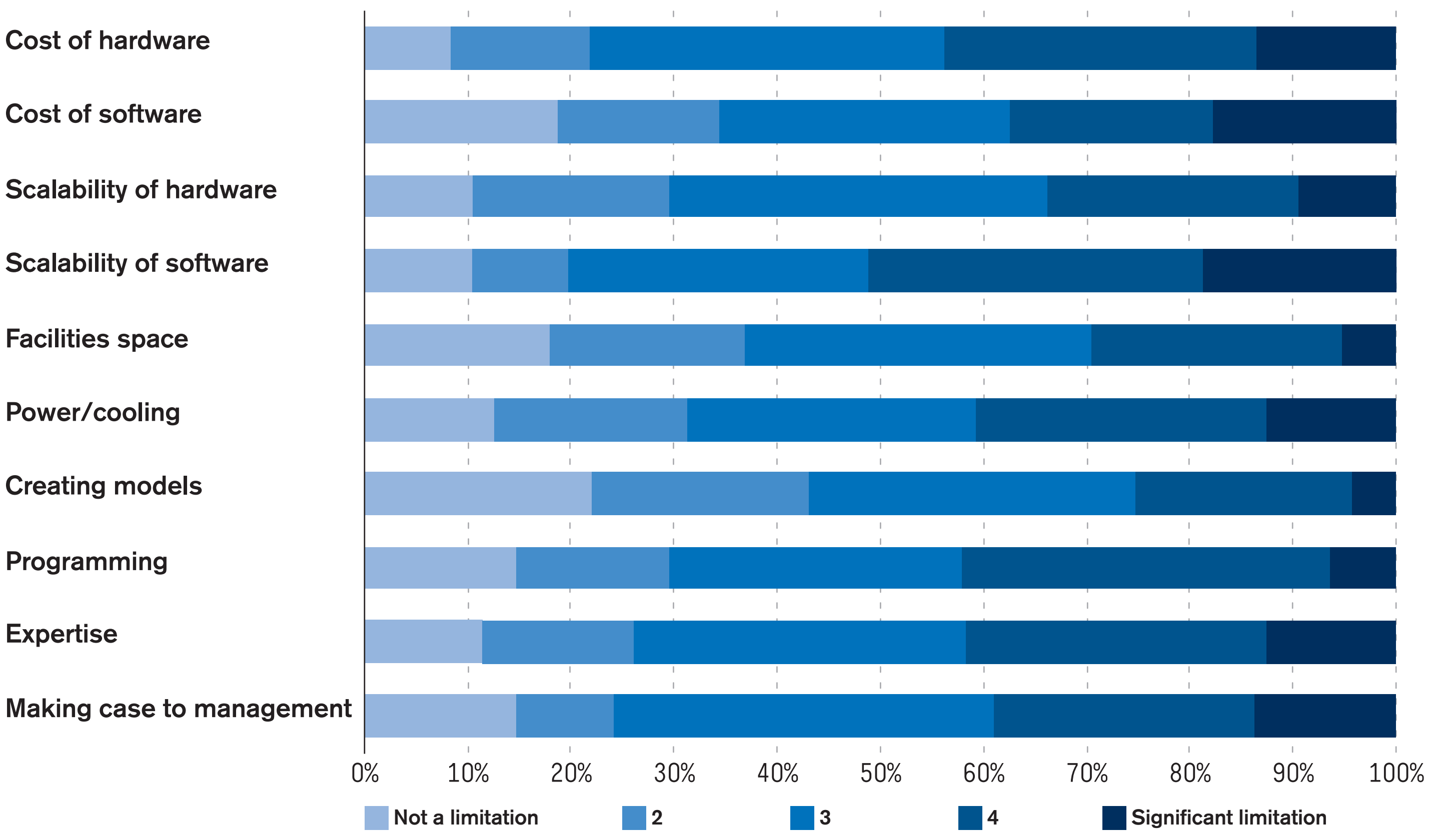
Interview 9, Consumer product manufacturing

With so much apparent demand, it is relevant to look at the limiting factors. The survey asked respondents to rate the barriers to achieving 10x and 1,000x more scalability on a five-point scale (1 = not a limitation; 5 = severe limitation). (See Figures 11 and 12.)

Cost is, of course, a significant barrier for a large percentage of respondents at any level, but these figures illustrate the tremendous challenges perceived in software scalability. "Scalability of software" is perceived as the top barrier for 10x scalability, whether measured as an average score or as the percentage of respondents rating it at least a 3, at least a 4, or a 5 on the scale.

Figure 11: Barriers to Achieving 10x Greater Scalability

N = 95-96



As users rate the barriers of scaling out to 1,000x, it seems natural that "cost of hardware" becomes a dominant factor, but even then, "scalability of software" has the highest percentage of respondents rating it a 3 or higher, at 92 percent. "Power and cooling" and "programming" also become significant perceived barriers for 1,000x scalability.

Still it seems evident that in both the short term and the long term, there is a need for focused investment in software scalability. HPC users have a need for immediate greater scalability, as well as an appetite for large improvements in performance going forward, that are inextricably linked to competitive advantage. Software scalability is the most significant barrier to achieving it.

> *Probably my biggest issue right now is with software, not with hardware, simulating long timescale events.*
>
> **Interview 9, Consumer product manufacturing**

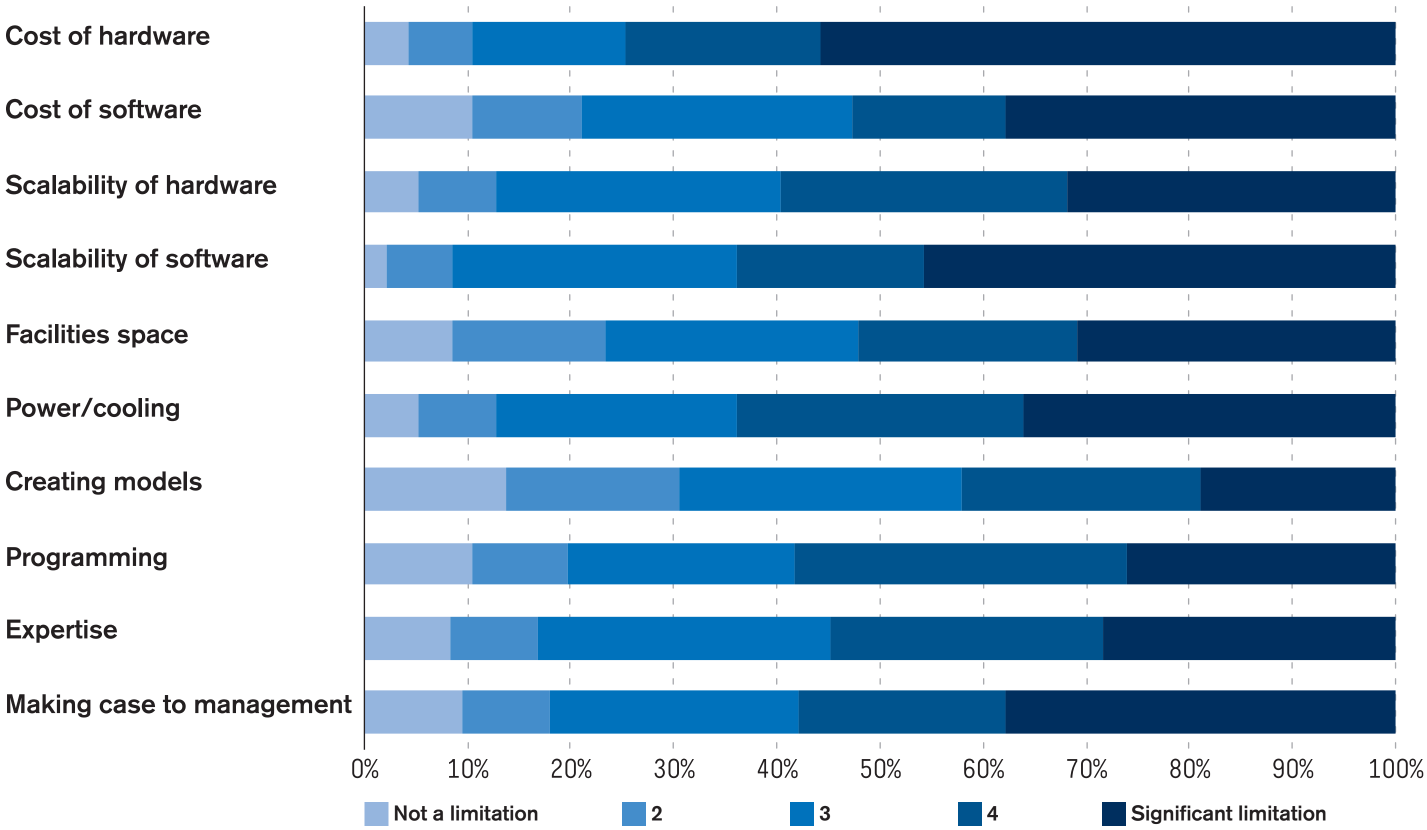
> *We don't want to be in the business to know how to do parallel computing and exascale computing and how to scale software. No.*
>
> **Interview 3, Large equipment manufacturing**

> *Once the technology exists, an equal emphasis has to be placed on algorithms that leverage that technology.*
>
> **Interview 14, Satellite imaging and intelligence**

> *It's all around software. How do I get my workflow—not workload, [but] workflow—through this thing. How do I get this piece of software talking to that piece of software? Global name spaces on file systems. Security across multiple firewalls. And then all these rigid pieces of codes that are barely running at terascale now, let alone petascale.*
>
> **Interview 12, Consulting services for industrial supercomputing adoption**

Figure 12: Barriers to Achieving 1,000x Greater Scalability

N = 94-96



It's a software-integration and a data-integration challenge…It's a tough question, because you have different strategies from different companies, as to whether they use third-party or proprietary [software], …and in some instances open-source software.

Interview 5, Oil and gas exploration

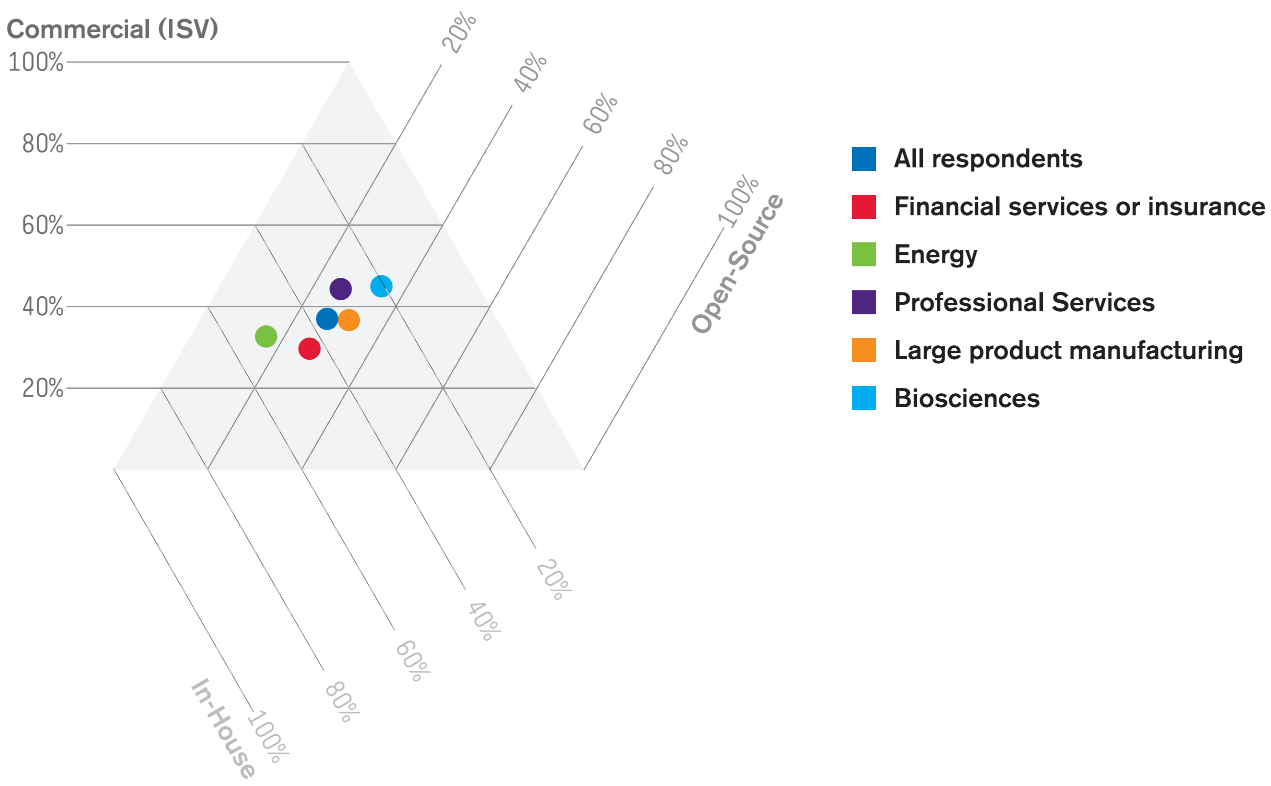
This is a particularly vexing problem because of the many different software approaches available. Some organizations rely predominantly on purchased, licensed applications from independent software vendors (ISVs). Others will deploy a wide range of open-source applications (which may be modified internally), and still others will primarily use applications and algorithms written in-house, strictly for their own use.

The survey measured this mixture of purchased, open-source, and in-house applications by organization. For ease in surveying, users were not asked for exact percentages, but rather, how much of their workflow relied on each category, on a seven-point scale: None, Very little, Some, About half, Most, Almost all, or All. For the analysis, we translate these responses into approximate percentages—0 percent, 10 percent, 30 percent, 50 percent, 70 percent, 90 percent, 100 percent—and then we normalize the answers such that they add to 100 percent. (For example: If a respondent said his organization used "very little" purchased software, "some" open-source software, and "most" in-house applications, these figures translate to 10 percent, 30 percent, and 70 percent. Since these add to more than 100 percent, we then scale the individual figures proportionally to 9.1 percent, 27.3 percent, and 63.6 percent, to create an approximation for that respondent.)

Figure 13 presents averages for the entire base, as well as for selected vertical markets. In this figure, we can see that on average, there is close to equal reliance on purchased commercial ISV software, in-house software, and open-source software, but there is noticeable difference by vertical markets. In this study, we see a higher reliance

Figure 13: Mix of Commercial, Open-Source, and In-House Software, by Vertical

N = 100 (see Demographics for Vertical distribution)



on in-house applications and algorithms among financial services and energy companies, whereas engineering-related areas like manufacturing and professional services depend more on commercial software. Biosciences tend to have the highest proportion of open-source mixed into the workflow.[4]

This is an important observation, because if software scalability is perceived as the most important limitation to scalability, we must be aware that this means different things in different vertical industries. The scalability challenge in some markets, such as energy and financial services, will trend more toward providing environments and expertise in which end users can scale their own applications. In other markets, such as manufacturing, there must be a greater emphasis on the packaged, licensed software that comes from the ISV community.

> *We use standard codes as a starting platform …but then customize them by utilizing our expertise and knowledge to give them capability that is applied to our models.*
>
> **Interview 11, Automotive, industrial, and consumer manufacturing**

> *On the computational science side, we've hired about seven graduates in the last three years. Most are Ph.D. applied mathematicians or computer science majors. That's a longer-term investment. They'll become fully capable over the next three to five years.*
>
> **Interview 6, Oil and gas exploration**

> *It's really the programming effort that drives innovation.*
>
> **Interview 2, Financial services**

> *Many of our core simulation codes are part and parcel of the deep intellectual property of the company. We continue to look at those and how to scale them onto big machines. It's an issue, but it's an investable, fixable issue. There's a bigger issue in that the software vendor models, for which the [license] model scales with cores, is going to be unworkable over time. My incentive to run that code on tens and hundreds of thousands of cores runs directly up against a business model in which someone wants to charge me based on the number of cores. So there's a significant issue that we'll be facing in the industry in the business model for which software licensing is done.*
>
> **Interview 8, Aerospace company**

> *The thing we struggle with [in scalability] with is the [ISV] licensing. If we look at open source or some of the internally developed codes we're okay, but otherwise, the licensing just kills it.*
>
> **Interview 7, Large equipment manufacturing**

> *Most of the independent software vendors, they haven't evolved their models for how to entice people to use more parallel computing.*
>
> **Interview 3, Large equipment manufacturing**

> *We've developed a whole series of unique algorithms on the GPU platform…The critical piece to manage when you have ISV codes is to have a tight dialogue with them about your growth plans and your scale needs. The ISVs really rely on us to provide them with that information to drive their roadmap and to understand where the industry is going. It's critical to have a close relationship with those ISVs and to be very open about where you're heading and what scale you expect. Without that market feedback we tend to see divergence between where they think the market is going and where it actually is.*
>
> **Interview 14, Satellite imaging and intelligence**

But as they recognize the software scalability challenge, many end users also recognize a shortage in skilled talent for creating more scalable software.

> *There are not very many people coming out of school as specialists in parallel computing. I don't think we're unique in the fact that we don't have any people who are exactly that…Eventually we'll collaborate with some institutions who say, 'we're the only ones have these resources.' …We're not going to be hiring [students with these skills] any time soon.*
>
> **Interview 3, Large equipment manufacturing**

4 This observation is consistent with historical HPC application data collected by Intersect360 Research.

If you talk to smaller companies, they definitely will not have the capability to do both physics method improvements and computer science. Even for a larger company, it can be very, very difficult.

Interview 11, Automotive, industrial, and consumer manufacturing

If you focus on exascale, the creation of a thing, you've failed. Building a thing in our industry does nothing for American competitiveness, because the parts come from an international supply chain, the software comes from an international supply chain, and whatever thing gets built, the guys who built it will immediately sell it into a country that's competitive with the United States. To me the only things that pursuit of exascale creates that have lasting value are development of people with skills who know how to do programming at scale, and secondly the development of algorithms that know how to take advantage of scale processors. If you have a program that focuses on the development of skills, those are people, right? 90 percent of those people will stay in the U.S. Some will go, but the vast majority will stay in the United States.

If you have a program centered on developing skills, that is a value that has legs. It's going to last for a long time. And those people are going to make innovations that will drive the development of system technologies that will be quite natural in terms of the value that gets produced for the economy. Launch a strategic program on the development of algorithmic skills. Bring in captains of 25 or 30 industries to sit with you and tell you about the compelling problems their industries face in the future. Orient the algorithmic program to tie into those problems and start pumping money into the universities to create those people developing that set of skills to work on that class of problems. Everything else will fall out naturally.

Interview 13, Supercomputing technology provider

It's hard to find talent in the world today that has the math, the science, and the computer science ability to work on these problems. We participate with Sandia and Oak Ridge and the Swiss supercomputing center on exascale activities …and they understand that problem set, but even with our corporation, the conversation is a much tougher road. The education part is a big obstacle, not only to explain to people why these problems are important, but also to source the talent.

Interview 4, Oil and gas exploration

The Role of Government

According to the June 2014 list of the world's Top500 fastest supercomputers, the United States accounts for 232 of them. Industry accounts for 152 of the U.S. systems, or 66 percent. Government-operated or government-funded systems, however, dominate the leading edge—accounting for 14 of the fastest 15 systems. Looking at roughly the top 10 percent of U.S. systems (23 supercomputers), 78 percent are operated or funded by the federal government. In reality the government skew at the top of the list is probably even higher, as the Top500 does not include classified systems or those that choose not to be listed.

The federal government invests in supercomputing primarily to achieve national security, energy, and basic science missions—but this investment also generates economic competitiveness returns and programs exist that enable industry to pay or compete for access to government systems. As government advances the HPC ecosystem (e.g. hardware, software, skills), the survey asked industry representatives how they view and benefit from government's role at the leading edge.

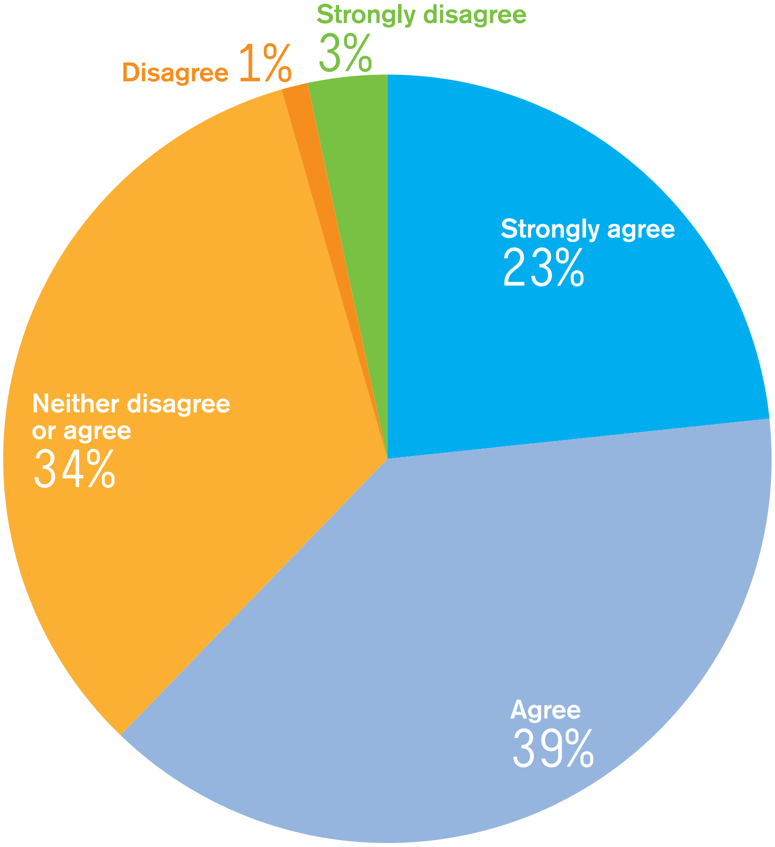
Industry is bullish on the effect government can have. Survey respondents were asked to what extent they agree or disagree with the statement, "Past government investments in new generations of supercomputing have had a benefit on your company/industry." 62 percent of respondents agreed (or strongly agreed), while only 4 percent disagreed, a ratio of over 15-to-1. (See Figure 14.)

Although there is strong agreement that government investment benefits industry, end users have a difficult time quantifying that benefit. When asked if the benefits could be quantified, some of the comments from the survey include:

> *Not really, but there ALWAYS has to be a first adopter to fund research. I believe that what the national labs did one to two decades ago has in some way strongly impacted our ability to have the compute platforms we have today.*
>
> *Can the benefits of ARPAnet and the Internet be quantified?*
>
> *I don't think so…But MPI, OpenMP, TCP/IP all came from government programs, and we'd be dead in the water without them.*
>
> *Quantified, no, but it's clearly produced huge leaps in knowhow across the board. Large-scale R&D is in my view NEVER a bad thing.*
>
> *Difficult to quantify, but I strongly believe that NSF and other funding of national labs or universities with HPC capabilities (TACC, SDSC, etc) has had a positive effect on industries that require cost-effective HPC. The Top500 "race" or "competition" has delivered ripple-down effects of providing cost-effective supercomputing technologies for the masses (e.g., #1 systems are typically very experimental, high-risk and perhaps unaffordable to the average commercial entity, but in a few years' time many of these systems find their way into commodity systems that are affordable and deployable).*

Figure 14: Agree/Disagree: "Past government investments in new generations of supercomputing have had a benefit on your company/industry."

N = 90



These sentiments were echoed in some of the qualitative interviews.

> *I could probably come up with a dozen analogs where there was an investment made by the national labs, or the Department of Defense, or an NSF kind of activity that's directly found its way at least into our business.*
>
> **Interview 4, Oil and gas exploration**

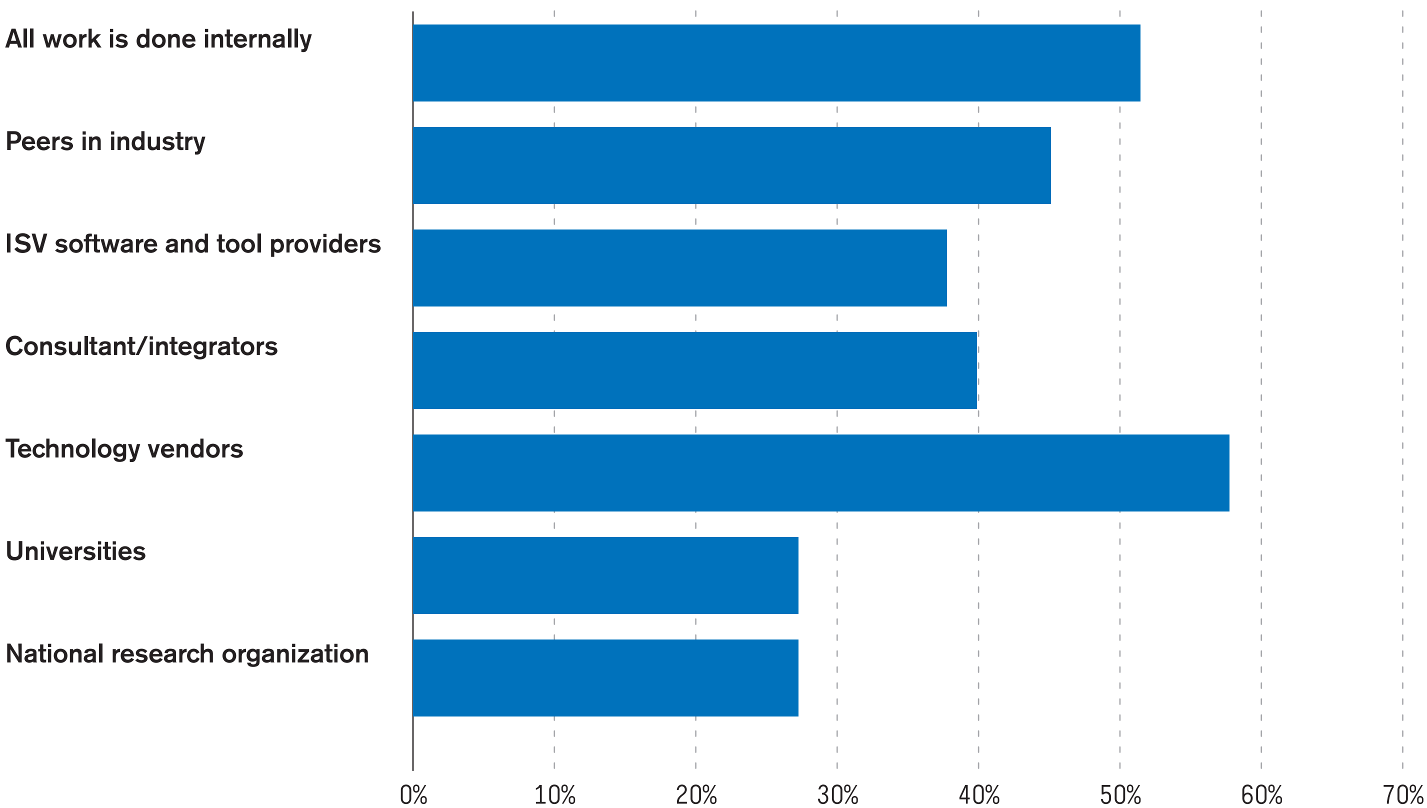
> *[Academic and government labs] are willing to do some things that are much more experimental at big scale. We need to feel like it's going to work before we make that kind of investment. But we're not very far behind most of the things that they're doing…We're probably more aggressive than just about any other commercial site, but we don't want to be quite at the same bleeding edge as the national labs.*
>
> **Interview 6, Oil and gas exploration**

Despite these assertions, most commercial organizations do not look directly to government to extend the scalability of their applications. More commonly, they look to technology vendors, industry peers, or simply seek to do the work in-house. Nevertheless, 28 percent of industry respondents do look to government directly through national research organizations, and a similar share engage universities, many of which operate government-funded systems. (See Figure 15.)

> *The strength of coupling how you write software for this type of computing resource, I don't think it's to be found anywhere else but at the national labs.*
>
> **Interview 3, Large equipment manufacturing**

Figure 15: Resources for Extending Scalability of Systems or Applications

N = 94 (Multiple selections permitted)



> *We look at the nexus of national labs and academia, and what ultimately become spinoffs from those, for where the next general purpose code's going to come from. Those have to come from somewhere, and they tend to start in academia and national labs.*
>
> **Interview 8, Aerospace company**

> *I'm not that close to the national labs. Most of the consortia that we're involved with are academic.*
>
> **Interview 6, Oil and gas exploration**

> *We work really closely with Stanford, which has a center for industrial and research partnerships, and those are the kinds of things that really help collaboration and dissemination of HPC.*
>
> **Interview 10, Supercomputing technology provider**

Since a large majority of industry respondents values government investment but a smaller share partners with government directly, there is the question of what benefits industry perceives in government investment. The survey asked respondents to rate on a five-point scale, "In general, how might the work done by national research organizations (e.g., DOE National Labs, NASA, NOAA, DOD HPC MOD, NSF, DARPA, NIST, etc.) affect your organization's ability to increase the performance of your most demanding applications?" (See Figure 16.)

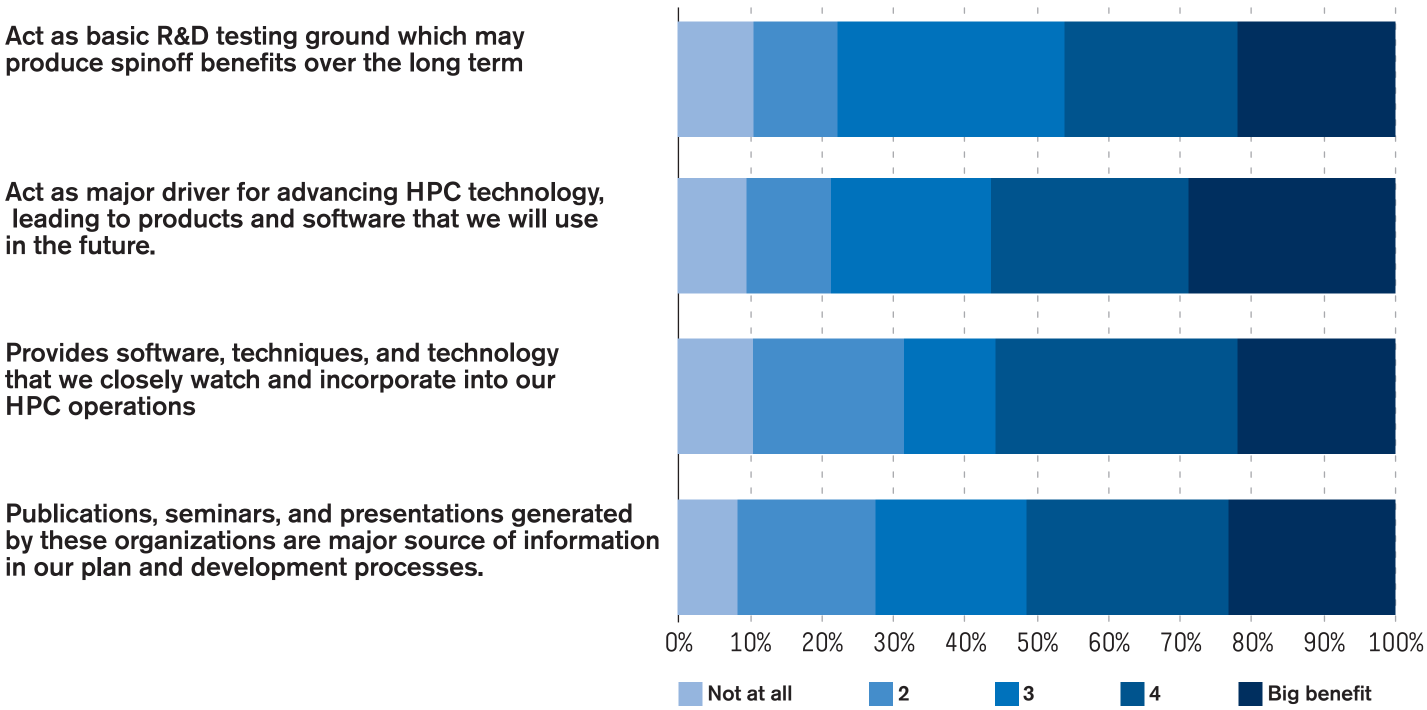
Here then we see the true perceived benefits of government investment at the level of national research organizations. More than three-quarters of respondents see at least a moderate benefit (rated 3 or higher) in labs acting as "basic R&D testing grounds," as well as acting as a "major driver for advancing HPC technology." Fifty-six percent of respondents see a significant benefit (rated 4 or 5) in labs providing "software, techniques, and technology that we closely watch and incorporate into our HPC operations."

One interview respondent cited national lab investment in helping fuel supercomputing innovation:

> *I think in terms of keeping competition alive and creating innovation, I think it works well.*
>
> **Interview 5, Oil and gas exploration**

Figure 16: Ratings of Benefits of Government Investment in HPC

N = 94-95



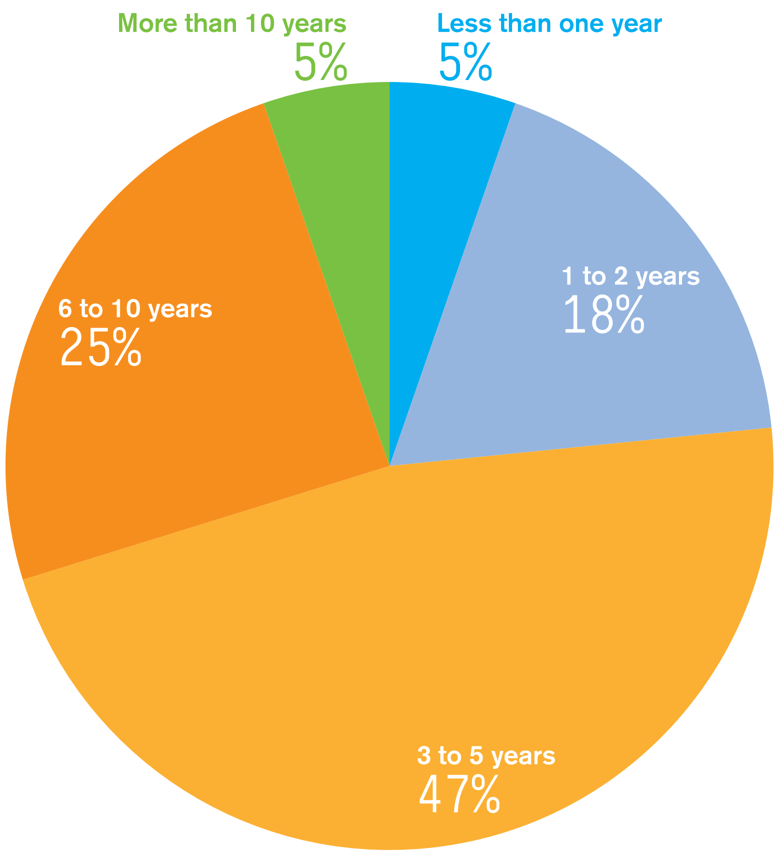
And yet, respondents believe that federal investments in HPC could yield greater economic benefits for the nation. The in-depth, qualitative interviews revealed that many industry experts feel this is an area that still needs significant improvement.

> *There's encouraging stuff along the way. National labs …have become a lot more open and willing to collaborate with companies, and as a result of that openness, the barriers of collaborating with national labs have decreased. And there are many barriers. One obvious one would be cost, but there are other barriers such as the legal requirements, dealing with intellectual property. I like this trend; I think it's a positive trend. The only point I want to make is that I think these are first steps. I think a lot more can be done, and a lot more should be done to have larger investments, a number of these larger machines that can be dedicated to joint work between national labs and industry.*
>
> *And there's a tremendous amount of expertise at the national labs …which would then be able to convince corporations to invest in high performance computing within the company itself…*
>
> *[There is] an opportunity to have a program to offer access to large-scale government machines, where companies could be assigned time as a proof-of-concept, and if you showed the results to management they'd be willing to invest.*
>
> **Interview 11, Automotive, industrial, and consumer manufacturing**

> *The smaller ISVs seem not to be engaged, anyone smaller than a large multinational. Every time [ISVs] show up to the labs, they just want to sell them stuff; they don't show up to the labs to do collaborative research and development. And I hear whining from both sides; I'm*

Figure 17: Time Lag from National Labs Scalability to Industry Scalability

N = 94



not going to fix blame…On the ISV side, all they hear is that the labs don't understand commercial engagement and are not very forthcoming with intellectual property that they can make a business out of.

Interview 9, Consumer products manufacturing

The little guys can hardly even play. It's very hard for them to spin up to do a CRADA, for example. It's costly, because you have to have a procurement officer that can talk government-speak to them, not business-speak. There's a disconnect there, at best…

There's a lot of people that are just going to ride out the technology wave. People just aren't going to put in the effort to rewrite code. That's where I believe the U.S. government and the labs ought to get into this. They ought to be writing the next generation of libraries. I'm not a Big Government fan, but maybe what the government should get back into is doing some fundamental open-source projects and allow the little guys to connect up to that.

Interview 12, Consulting services for industrial supercomputing adoption

If we learned one thing, it's that we need a more synergistic relationship between private sector and the government.

Interview 3, Large equipment manufacturing

The technology transfer piece is quite weak. As I visit industrial customers, one of the biggest complaints I hear about is the lack of good HPC programmers…We've not done a good job as a community in the education moving to industry in creating the next crop of engineers.

Interview 10, Supercomputing technology provider

The national labs, this is a lot of men and women who talk to themselves all the time, and they need to talk to us more. We ought to be getting a lot more direct industry feedback. I'd like to see them showing up at industry events.

Interview 1, Oil and gas exploration

The government has to wade into it. Industry's behavior is to focus on short-term impact. And by the way, if they did it, they could make a better argument for why investment in STEM makes sense, because now you could connect the investment in STEM to this strategic development of skills that depend on having a good fountain of potential players to choose from. You need a bunch of [students] who have taken a little bit of math who you can train.

Interview 13, Supercomputing technology provider

Respondents also offered a sense of the time it takes between government laboratories driving and adopting new levels of scalability and the private sector running at that new horizon. Sixty-five percent of respondents said that they make the transition within 1-5 years, with roughly half of the respondents indicating that the lag is between 3-5 years. At the ends of the spectrum, 5 percent of respondents say it takes less than one year and an equal share say that it takes more than 10 years. (See Figure 17.)

There is room for further optimism as well. Compared to the past, 28 percent of respondents feel this time lag is decreasing—that is, that the gap between national labs and industry is lessening—while only 12 percent feel it is lengthening.

The data also shows that awareness of government programs tends to be fairly good, though adoption rates are significantly below awareness rates. Whereas over 60 percent of respondents have at least heard of programs such as the Energy Department's Advanced Scientific Computing Research (ASCR) Leadership Computing Challenge, Cooperative Research and Development Agreements (CRADAs), Non-Federal Work for Others (NFWFOs), and the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program, the usage of these programs tends to be below 20 percent. (See Figure 18.)

Industrial HPC users assert that their partnerships are useful, whether they are within industry consortia, with academia, or with government research organizations. Industry consortia are seen as the most useful overall, but generally, all are rated highly. More than half of users with government research partnerships rated them a 4 or 5 in usefulness, on a five-point scale. (See Figure 19.)

I am extremely excited about my engagement with national laboratories in the Department of Energy…Our engagement with these national laboratories has been extremely productive. This is collaboration that has delivered over a billion dollars in value.

Interview 9, Consumer product manufacturing

Figure 18: Awareness and Usage of Government HPC Programs

N=94

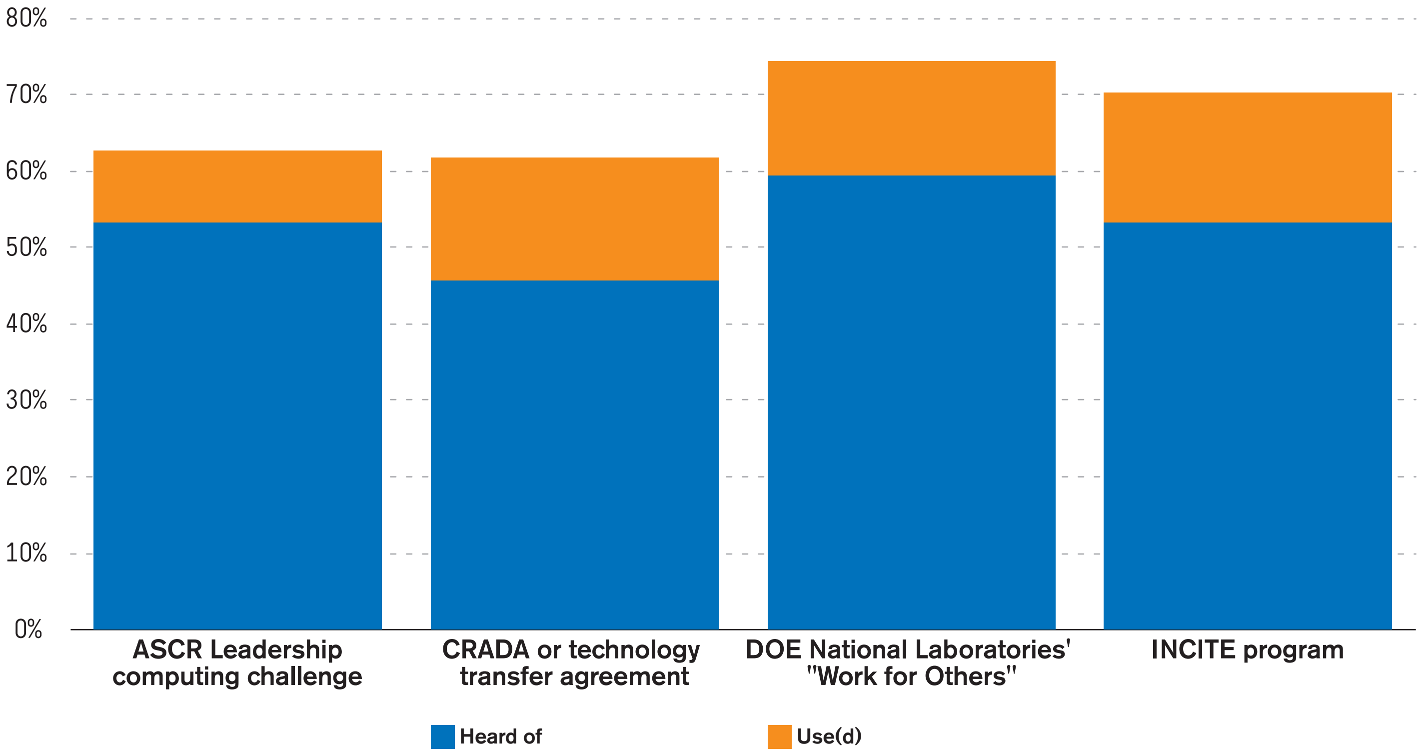
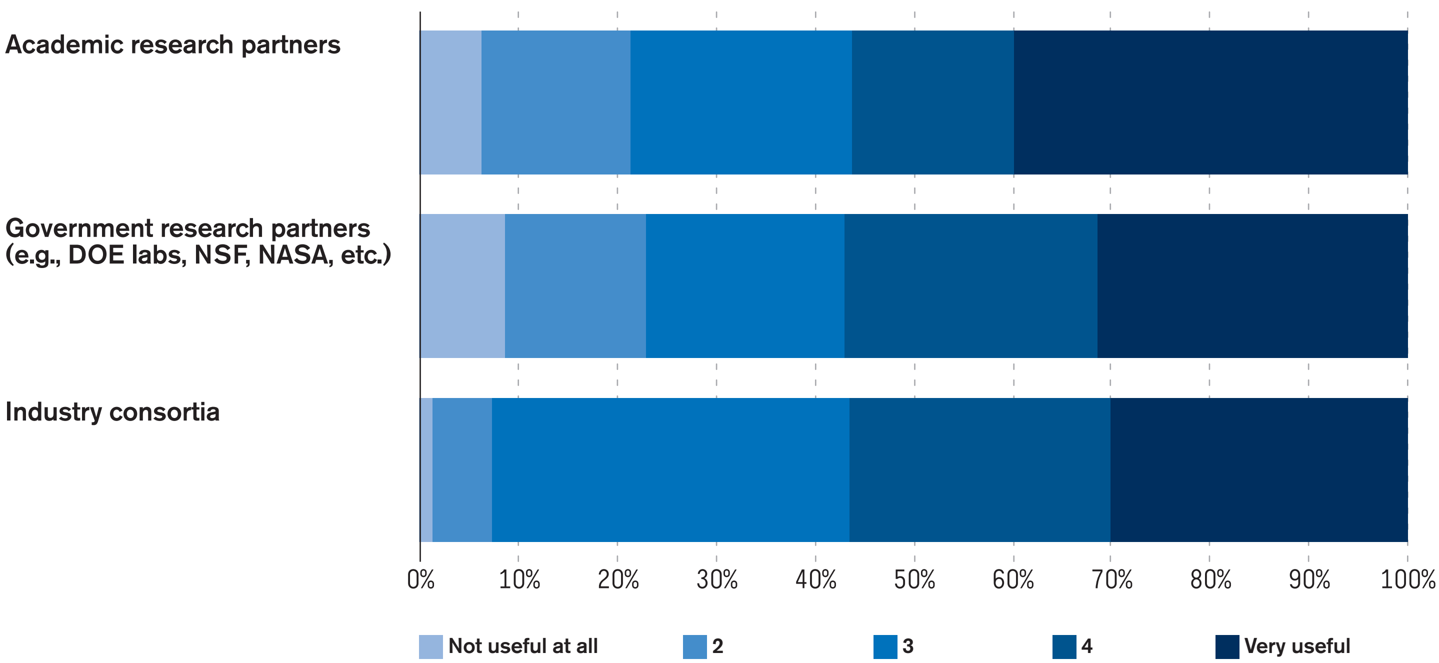


Figure 19: Usefulness of Partners in Academia, Government, Industry

N = 80 for academic partnerships, 70 for government partnerships, 83 for industry consortia



> *We look to …TACC, NCSA, a few people at the national labs. Intel has really helped us with MPI; they've helped us with some of the library issues. We've worked really well with Arista growing networks. We're making a pretty serious test with Mellanox on InfiniBand.*
>
> **Interview 6, Oil and gas exploration**

Finally, in assessing the overall U.S. industry outlook on U.S. government investment in next-generation supercomputing, and its ability to have a positive effect on industrial competitiveness, the survey presented the question directly and specifically, as follows:

The U.S. Government has announced an initiative to work with U.S. vendors and research institutions to accelerate and influence the next generation high performance computing with a goal of 1000x more compute capability (exascale) at only 4x more power (20MW). If successful, this R&D effort would be expected to also enable petascale racks within budget of science and engineering departments at most U.S. research universities.

Please rate the U.S. supercomputing/exascale initiatives based on the following factors: Effectiveness, relevance to industry, importance to the country. [Five-point scale: 1 = Poor/Low; 5 = Excellent/High.]

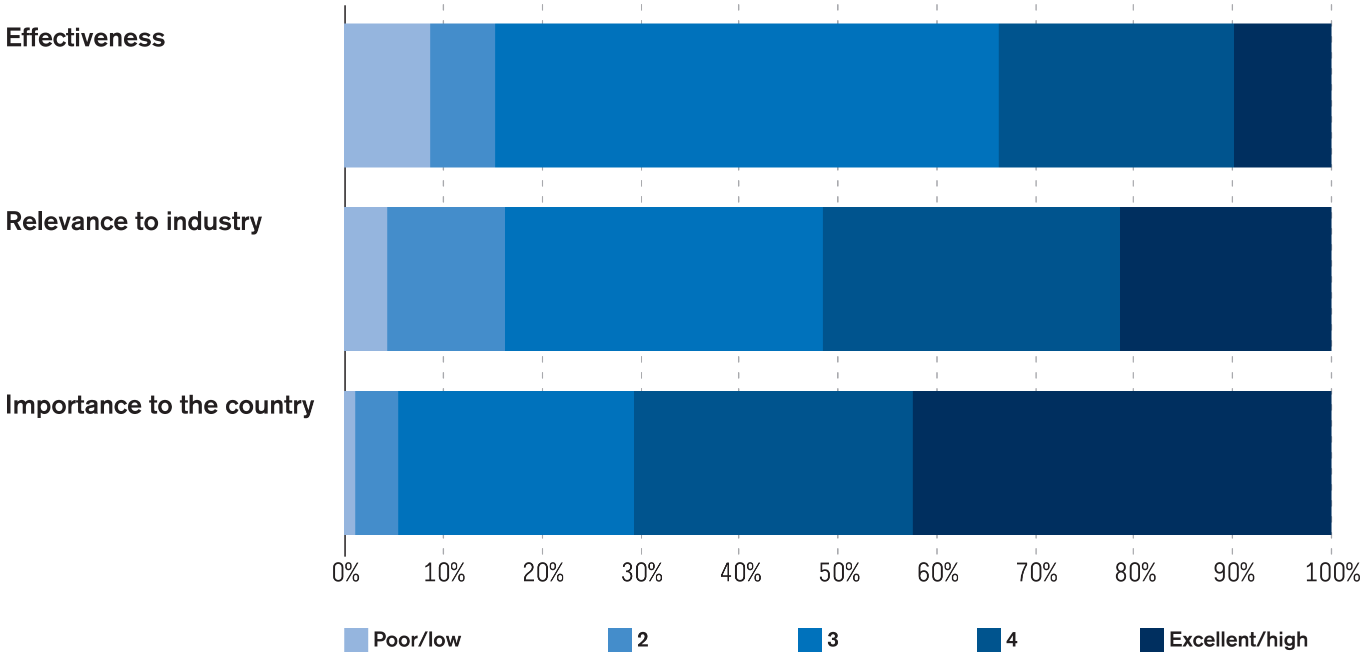
As shown in Figure 20, respondents see this as extremely relevant work, though not always as effective as it might be. Seventy percent of respondents rated "Importance to the country" a 4 or 5, and 52 percent gave a 4 or 5 to "Relevance to industry." However, only 34 percent rated these initiatives a 4 or 5 in "Effectiveness." These scores were more positive than negative, but they illustrate that a significant share of industry representatives believe that the drive toward exascale computing could be conducted more effectively and with greater promise for industrial competitiveness.

One interview respondent summed up well, as follows:

> *I think exascale is a milestone that's a cool road mark in front of us, and having the government drive those projects is absolutely valuable for industry. If it brings a technology a year or two years earlier, it has a huge value for us.*
>
> **Interview 6, Oil and gas exploration**

Figure 20: Industry Ratings of U.S. Exascale Initiatives on Effectiveness, Relevance to Industry, and Importance to the Country

N = 93-94



SECTION 6

The Path Forward

There is an immediate and enduring benefit to U.S. industry in increased HPC scalability and capability, which is directly linked to economic leadership and competitiveness. Companies rely on the U.S. government to steer the path of HPC innovation through its investment in new technologies and partnership with commercial and academic organizations. However, there is more work to be done in building and strengthening the bridges that transition technology and expertise from lab research to industry effectiveness. The U.S. government should strive not only to advance technology and computing architectures, but also to invest in partnerships around software and talent that would help achieve public missions and bolster American competitiveness.

In particular, there is an acute need for the development of software that will leverage increases in hardware scalability. This is the greatest gap in efficiency for industrial HPC users today, and it promises to remain a significant concern throughout the path to exascale.

> *I've been thinking about what I call my 'two-by-four strategy,' where I hit people over the head with a two-by-four until they start working together. The three main players, industry, academia, and government, have to get their act together.*
>
> **Interview 12, Consulting services for industrial supercomputing adoption**

> *Clearly the large national labs are taking a leadership role, definitely in terms of hardware investment. But the leadership also has to come in terms of software and algorithms. This is where more work needs to be done…*
>
> *Most government labs …have training programs and programs for outreach. I just don't think they are as well done and as well staffed as they could be. Part of the challenge is industrial partners. It comes down to programming. They still have to port their applications to take advantage of these large-scale systems.*
>
> **Interview 10, Supercomputing technology provider**

> *It's impossible for a corporation to be on the leading edge of algorithmic development when it doesn't have access to the hardware.*
>
> **Interview 11, Automotive, industrial, and consumer manufacturing**

Models of parallelism

There are multiple factors that make the software scalability issue particularly challenging. As described in the research results, HPC users are reliant on a combination of in-house, open-source, and commercial, licensed ISV software. (See Figure 13.) This implies a wide pool of developers, all of whom have their own motivation—or perhaps lack of motivation—to invest in more scalable software.

The underlying problem is that software applications generally do not run faster simply by being introduced to a "faster" computer. Though this seems counterintuitive, it is germane to consider what makes a computer faster. As discussed earlier[5], evolutions in computer architecture, such as multi-core, many-core, and lightweight processors, have introduced increasing levels of parallelism in order to achieve higher peak performance.

This is not a truly new dynamic, but rather another step in the continued move toward the economics of commodity components. However, one aspect has changed that has a significant impact on software development. The speed of processors (generally measured in gigahertz, or GHz) has plateaued, and individual processors now get faster through the incorporation of more cores, the individual

5 Key Findings, #2: Software scalability is the most significant limiting factor in achieving the next 10x improvements in performance.

computational elements that now make up a processor. In other words, a four-core processor is really like four separate processors, dividing work between them.

For small tasks that only take fractions of a processor's capacity—loading a web page, typing a report, virus-checking a download—this works well, but for HPC applications which leverage all the work of multiple processors, the effect is challenging. The application programmer is not dealing with faster computing elements, but rather more computing elements. The onus is on the programmer to distribute the application to run efficiently across more cores.

It must be stated that there are strong reasons in favor of the movement toward multi-core and many-core systems. Leveraging the economies of scale of volume markets, they typically offer more processing cycles per dollar, per watt, and per square foot than competing technologies. It is incumbent on the HPC industry to devise software applications that will take advantage of these advancements.

Software Business Models

The ISV arena for HPC is highly fragmented, as HPC applications tend to be specialized to very particular need sets. Although there is certainly overlap in broad categories such as molecular modeling or computational fluid dynamics, the ISV market is in actuality a form of limited competition, similar to say, the restaurant industry. (There may be millions of restaurants, but there might only be one that serves my favorite tofu curry.)

Consider then the motivation for the ISV to invest in greater scalability. To be sure, it is something that a portion of the ISV's customer base would like, but the ISV—more often than not a small or medium-size company itself—must also address bug fixes and patches, new features, and support for a large and ever-changing combination of operating system environments (Windows, Linux, UNIX), distributions within those operating systems (e.g., RedHat Enterprise Linux 4.5.2), microprocessors (Intel, AMD), and a wide range of possible middleware environments.

Against this complicated backdrop, it is also rare to find an HPC user that desires to pay more for software. In fact, in engineering-driven application areas that are heavily reliant on ISV applications, the common sentiment is that software is too expensive. As hardware prices have fallen, and more of the burden of scalability has shifted from the hardware designer to the application programmer, software has grown overall as a percentage of spending.[6] This is often blamed on pricing models—if a user is charged for usage on a per-socket or per-core basis, then the cost for scalability is quite high—but to blame the pricing model itself is to miss the larger point that the end user doesn't want to pay so much for more scalability, regardless of how the licensing is structured.

Looking Ahead

Government investment in supercomputing is vital to U.S. industry, and the technologies developed will permeate the national landscape, improving U.S. competitiveness and leadership. In particular, investment must focus on the application software that will allow new generations of technologies to be used effectively.

But beyond the general concept of "software," in order to be effective, any programs or investment must be targeted, with specific goals in mind. Entry-level HPC users have different needs than high-end users; in-house, open-source, and ISV development models have distinct benefits; and achieving a 10x gain requires a different mindset than achieving a 1,000x gain.

6 Intersect360 Research survey data, HPC User Budget Map, 2014.

This research study found that while there have been improvements in partnerships that benefit U.S. industry, there is still a lot of room for improvement, and companies would see significant benefits in expanded partnership opportunities. Based on industry feedback and the findings of this study, the government may consider creating an assortment of targeted programs that can benefit different segments of the commercial space.

- **Programs for in-house software:** For companies with critical in-house software, we can look to a direct partnership model, matching companies and their applications to national resources (hardware and expertise), in order to help them scale. This could be a continuation or expansion of programs currently in place.
- **Programs for ISVs:** This is similar to the in-house case in engagement, but also may need to provide the business incentive for investment in scalability. Work may need to be done to determine viable pricing models for application software at scale.
- **Programs for open-source:** In these cases, government may be able to identify a priority list for open-source application software and designate teams for working directly with the open-source community, taking care to understand how competition is influenced by the engagement.
- **Programs for entry-level HPC:** HPC usage and adoption at the low end remains a critical issue, and these users have different need sets than established supercomputing experts. At the lower end of the market, the ability to integrate HPC into the workflow is a bigger challenge than scalability.

For any type of government investment or partnership incentive, a significant question is whether the market will act efficiently to produce the desired result without intervention. For hardware development, the presence of a government buyer has been sufficient to drive providers to develop more scalable computers, year after year, via multiple waves of innovation. But ultimately, the measure of a supercomputer is what can be done with it. The development of application software capable of that level of scale has been problematic. The level of investment is high, the target markets are narrow, and the business model is uncertain. As industry moves into the exascale era, the real leaders in supercomputing will be those who focus on the applications that the supercomputers are meant to run. Targeted programs to develop more scalable application software are needed to keep U.S. industry at the forefront of innovation through its ability to leverage high performance computing.

APPENDIX A

Discussion Guide for Qualitative Interviews

How does your company use HPC today, and how does it relate to competitiveness?

- Types of applications
- Scale of applications
- What can you do with HPC that you couldn't do otherwise? How does HPC help you achieve your organizational goals?
- Where does your use of HPC put you on the competitiveness scale: keeping up with everyone else, or using HPC to get ahead?
- How has your usage of HPC evolved over time? What new capabilities have been unlocked with previous generations?
- What to you wish you could do with modeling and simulation that you can't do today? How much more capability/capacity would you need in order to do that?

How would exascale computing (or a computer 1,000 times more powerful) contribute to your organization's strategy, capability, and competitive advantage?

- How would modeling and simulation at that level change your competitiveness, or the way you do business? (Cite examples; prompt as necessary)
- How would you use such a machine?
- What are the limiting factors that prevent you from doing that?
    - Technologies
    - Facilities
    - Expertise
    - Software / applications
    - Complexity of models
    - Investment
- What indirect benefits are there that you think there would be to your company, or to society at large, from the scientific advancements driven by exascale computing? Are there any areas of general scientific research that could have a significant positive effect on your business?

Where do you see leadership in new HPC scalability coming from?

- Who are the leaders in your industry?
- Who are your primary influencers?
- How do you view the flow of technology or expertise from government and academic research into industry?

APPENDIX B

Council on Competitiveness HPC Study

Welcome

Thank you for taking a few minutes to complete our survey. The objective of this survey is to better understand the requirements for future HPC scalability. Intersect360 Research will aggregate the data and will not identify individuals or their organizations as participants in this study.

For the purpose of this study, we define HPC as:

High Performance Computing (HPC) is the use of servers, clusters, and supercomputers plus associated software, tools, components, storage, and services for scientific, engineering, or analytical tasks that are particularly intensive in computation, memory usage, or data management. HPC is used by scientists and engineers in research and development, by the military in simulations and training exercises, and to a growing extent in business applications in such areas as business intelligence, complex event processing, virtual environments (e.g. online games), and ultrascale computational facilities. HPC applications are found across industry, government, and academia. Within industry, HPC can frequently be distinquished from general business computing in that companies generally will use HPC applications to gain advantage in their core endeavors e.g., finding oil, designing automobile parts, or protecting clients' investments as opposed to noncore endeavors such as payroll management or resource planning

In this study, we will ask you to respond to a few of questions about your current IT infrastructure and then focus the remainder of the survey on your requirements and limitations for future scaling, and resources that may ease or help in increasing scalability at your site. Finally,we ask for some demographic information to complete the survey.

Please contact Addison Snell at Addison@Intersect360.com if you have any questions or comments. Thank you again for your help.

Click the NEXT button below to begin.

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Qualifier #1

*1. Do you work for a US-based commercial company or a multi-national company with HPC operations in the US?**

- ◯ Yes
- ◯ No

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Qualifier #2

*2. Does your organization run any type of HPC applications?**

- ◯ Yes
- ◯ No

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Job Description

Please answer a few questions on your job description.

***3. What is name of company/institution/organization?**

If company name is confidential, please enter NA. All survey responses are kept anonymous.

***4. What is your job title?**

5. Which of the following tasks do you perform or have management responsibilities for in your organization? (Check all that apply)

- ☐ Overall management
- ☐ Systems administration
- ☐ Facilities operations/management
- ☐ Systems engineering/planning
- ☐ Systems specifications/purchasing
- ☐ Software specifications/purchasing
- ☐ Applications software development/optimization/maintenance
- ☐ Systems software development/tuning/enhancing/maintenance
- ☐ Workflow software development/maintenance
- ☐ Used services/training/consulting
- ☐ Other (please specify)

Other (please specify)

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IT Infrastructure

For the system used to run your <u>most demanding applications</u>, please answer the following:

6. Please choose the size category for the largest system used for your most demanding applications. (Choose only one)

- ◯ **Entry-level HPC System** – Generally small clusters under $50,000, used to support individuals, small groups, or for dedicated applications.
- ◯ **Mid-range HPC System** – Generally single rack clusters under $250,000, used to support small organizations or projects.
- ◯ **High-end HPC System** – Generally a full rack or multi-rack cluster under $1.5 million, used to support larger organizations, often with several independent subgroups. These systems can also be dedicated to supporting large ongoing (often mission-critical) applications.
- ◯ **Supercomputer** – Multimillion-dollar, multi-rack systems, designed or configured to address problems that cannot be effectively addressed by general-purpose systems. Although generally seen as scientific and engineering systems, supercomputers can be used for any application that requires extraordinary capabilities in such areas as computational power, I/O performance, or scalability.

7. How much of your workflow depends on application software that is purchased (commercial applications), versus open-source, versus in-house (written internally)

	None	Very little	Some	About half	Most	Almost All	All
Commercial (purchased) applications:	◯	◯	◯	◯	◯	◯	◯
Open Source applications:	◯	◯	◯	◯	◯	◯	◯
In-house (internally developed) applications:	◯	◯	◯	◯	◯	◯	◯

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Importance of HPC to the Organization

8. To what extent do you agree/disagree with the following statements as they apply to your organization.

	Strongly Disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree	N/A
HPC is critical to the future direction of our business.	◯	◯	◯	◯	◯	◯
Our business would benefit by improving how fast or how accurately we do modeling and simulation for scientific, engineering, or analytical tasks.	◯	◯	◯	◯	◯	◯
HPC computational methods are cost effective tools for our R&D.	◯	◯	◯	◯	◯	◯
HPC computational methods significantly speed-up our R&D process.	◯	◯	◯	◯	◯	◯
HPC computational methods support our high quality product design, manufacturing, and/or analysis.	◯	◯	◯	◯	◯	◯
For some of our problems, HPC methods are the only practical solution.	◯	◯	◯	◯	◯	◯
Increasing performance of computational models is a competitive matter of survival for us.	◯	◯	◯	◯	◯	◯

9. How challenging is it to justify investment on HPC within your organization?

1: Not a challenge	2	3	4	5: Significant challenge
◯	◯	◯	◯	◯

10. Which of these metrics work best for justifying HPC in your company? (only one answer allowed)

- ◯ Time to Solution
- ◯ Inability to solve the problem by any other means
- ◯ Utilization rate
- ◯ Improvements in quality or features
- ◯ Reduced costs compared to physical methods
- ◯ ROI
- ◯ Other

11. Please elaborate on the justification of HPC investment within your company.

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12. What is the planning horizon for HPC purchases?

- ◯ Less than 1 year
- ◯ 1 to 2 years
- ◯ 3 to 5 years
- ◯ More than 5 years
- ◯ Don't know

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Requirement for future scaling

13. Considering requirements to run your <u>most demanding applications</u> to what extent do you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Disagree or Agree	Agree	Strongly Agree
We do not foresee any need to increase application speed/size/fidelity/complexity.	◯	◯	◯	◯	◯
We could use 2x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 5x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 10x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 100x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 1000x performance increase over the next 5 years.	◯	◯	◯	◯	◯

14. Considering requirements to run your <u>total HPC workload</u> applications to what extent do you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Disagree or Agree	Agree	Strongly Agree
We do not foresee any need to increase application speed/size/fidelity/complexity.	◯	◯	◯	◯	◯
We could use 2x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 5x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 10x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 100x performance increase over the next 5 years.	◯	◯	◯	◯	◯
We could use 1000x performance increase over the next 5 years.	◯	◯	◯	◯	◯

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15. Are there new applications coming on line that will require significant increases in systems performance?

- ◯ No
- ◯ Yes

If yes, how much performance increase over current applications will be required?

16. For your most demanding applications, what is the level of maximum scalability you can currently achieve based on cores, processors, or nodes?

Can use maximum of:

Units of measure (e.g., cores, processors, nodes)

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Limiting factors to scalability

17. To what extent are each of the following limiting factors to achieve 10x more scalability?

	1: Not a limitation	2	3	4	5: Severe limitation
Cost of hardware	◯	◯	◯	◯	◯
Cost of software	◯	◯	◯	◯	◯
Scalability of hardware	◯	◯	◯	◯	◯
Scalability of software	◯	◯	◯	◯	◯
Facilities space	◯	◯	◯	◯	◯
Power/cooling	◯	◯	◯	◯	◯
Creating models	◯	◯	◯	◯	◯
Programming	◯	◯	◯	◯	◯
Expertise	◯	◯	◯	◯	◯
Making case to management	◯	◯	◯	◯	◯

18. To what extent are each of the following limiting factors to achieve 1000x more scalability?

	1: Not a limitation	2	3	4	5: Severe limitation
Cost of hardware	◯	◯	◯	◯	◯
Cost of software	◯	◯	◯	◯	◯
Scalability of hardware	◯	◯	◯	◯	◯
Scalability of software	◯	◯	◯	◯	◯
Facilities space	◯	◯	◯	◯	◯
Power/cooling	◯	◯	◯	◯	◯
Creating models	◯	◯	◯	◯	◯
Programming	◯	◯	◯	◯	◯
Expertise	◯	◯	◯	◯	◯
Making case to management	◯	◯	◯	◯	◯

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External Resources

19. In extending the scalability of your systems and/or applications, what resources or groups do you look to: (Choose all that apply)

- [ ] All work is done internally
- [ ] Peers in industry
- [ ] ISV software and tool providers
- [ ] Consultant/integrators
- [ ] Technology vendors
- [ ] Universities
- [ ] National research organizations
- [ ] Other

Please specify:

20. For the following statement, to what extent do you agree or disagree:

Past government investments in new generations of supercomputing have had a benefit on your company/industry.

Strongly Disagree	Disgree	Neither Disagree or Agree	Agree	Strongly Agree
○	○	○	○	○

21. Can this benefit be quantified?

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22. In general, how might the work done by national research organizations (e.g., DOE National Labs, NASA, NOAA, DOD HPC MOD, NSF, DARPA, NIST, etc.) affect your organizations ability to increase the performance of your most demanding applications.

	1: Not at all	2	3	4	5: Big Benefit
Act as basic R&D testing ground which may produce spin-off benefits over the long term	◯	◯	◯	◯	◯
Act as major driver for advancing HPC technology, leading to products and software that we will use in the future.	◯	◯	◯	◯	◯
Provides software, techniques, and technology that we closely watch and incorporate into our HPC operations	◯	◯	◯	◯	◯
Publications, seminars, and presentations generated by these organizations are major source of information in our plan and development processes.	◯	◯	◯	◯	◯

23. To the extent that national research organizations effect your computing strategy, what is the time lag (best guess) between a U.S. lab running at a new level of scalability (e.g. petascale, exascale) and your company running at that level?

- ◯ Less than one year
- ◯ 1 to 2 years
- ◯ 3 to 5 years
- ◯ 6 to 10 years
- ◯ More than 10 years

Comments

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24. How has that time lag changed?

- ◯ Lengthening
- ◯ Consistent with the past
- ◯ Decreasing
- ◯ Don't know

Comments.

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The path forward

25. For each working relationship you have, how useful has it been?

	1: Not useful at all	2	3	4	5: Very useful	No partnership for our company
Academic research partners	○	○	○	○	○	○
Government research partners (e.g., DOE labs, NSF, NASA, etc.)	○	○	○	○	○	○
Industry consortia	○	○	○	○	○	○

26. Have you heard of or used the following:

	Heard of	Use or Used
ASCR Leadership Computing Challenge	☐	☐
CRADA or Technology Transfer agreement	☐	☐
DOE National Laboratories' "Work for Others"	☐	☐
INCITE program	☐	☐

Other (please specify)

27. The U.S. Government has announced an initiative to work with U.S. vendors and research institutions to accelerate and influence the next generation high performance computing with a goal of 1000x more compute capability (exascale) at only 4x more power (20MW). If successful, this R&D effort would be expected to also enable petascale racks within budget of science and engineering departments at most U.S. research universities.

Please rate the U.S. supercomputing/exascale initiatives based on the following factors:

	1: Poor/Low	2	3	4	5: Excellent/High
Effectiveness	○	○	○	○	○
Relevance to Industry	○	○	○	○	○
Importance to the country	○	○	○	○	○

28. What types of partnerships or investments would you like to see and would take advantage of?

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Demographics

Please answer a few questions on demographics.

***29. Please select the category below that best describes your organization.**

- ◯ Biosciences (pharmaceutical, genomics, medical device mftg. etc.)
- ◯ Chemical manufacturing and engineering (e.g., polymers, plastics)
- ◯ Consumer products manufacturing
- ◯ Large product manufacturing (aerospace, automotive, etc.)
- ◯ Electronics (semiconductors, electronic components, etc.)
- ◯ Energy (oil/gas exploration, alternative energy)
- ◯ IT Systems and software manufacturing
- ◯ Professional Services (engineering consulting, cloud service provider, etc.)
- ◯ Utilities (power generation, distribution, telecommunications, pipeline management)
- ◯ Financial services or insurance
- ◯ Media/Entertainment
- ◯ Online Gaming
- ◯ Retail
- ◯ Transportation
- ◯ Ultrascale computing
- ◯ Other commercial segment

Please specify other commercial segment:

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***30. What percent of IT spending is devoted to HPC?**

- ◯ None (0%)
- ◯ Very little (1% to 10%)
- ◯ Some (11% to 33%)
- ◯ About half (34% to 66%)
- ◯ Most (67% to 89%)
- ◯ Almost all (90% to 99%)
- ◯ All (100%)
- ◯ Don't know

31. What is your organization's annual budget for HPC, including servers, software, storage, and services?

- ◯ Less than $50,000
- ◯ $50,000 to $99,999
- ◯ $100,000 to $499,999
- ◯ $500,000 to $999,999
- ◯ $1,000,000 to $1,999,999
- ◯ $2,000,000 to $4,999,999
- ◯ $5,000,000 to $9,999,999
- ◯ $10,000,000 and higher
- ◯ Not available

32. Going forward (over the next 2 years), what change do you anticipate for your HPC budget:

- ◯ Up by more than 20%
- ◯ Up by 10% to 20%
- ◯ Up by 5% to 10%
- ◯ Up by 1% to 5%
- ◯ No change(0%)
- ◯ Down by 1% to 5%
- ◯ Down by 5% to 10%
- ◯ Down by 10% to 20%
- ◯ Down by more than 20%

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33. Which department owns the HPC budget?

- ◯ Production engineering
- ◯ IT
- ◯ R&D
- ◯ Share responsibility
- ◯ Other (please specify)

Other (please specify)

APPENDIX C

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WHO WE ARE

The Council's mission is to set an action agenda to drive U.S. competitiveness, productivity and leadership in world markets to raise the standard of living of all Americans.

The Council on Competitiveness is the only group of corporate CEOs, university presidents and labor leaders committed to ensuring the future prosperity of all Americans and enhanced U.S. competitiveness in the global economy through the creation of high-value economic activity in the United States.

Council on Competitiveness
1500 K Street, NW, Suite 850
Washington, D.C. 20005
T 202 682 4292
F 202 682 5150
www.compete.org

HOW WE OPERATE

The key to U.S. prosperity in a global economy is to develop the most innovative workforce, educational system and businesses that will maintain the United States' position as the global economic leader.

The Council achieves its mission by:

- Identifying and understanding emerging challenges to competitiveness
- Generating new policy ideas and concepts to shape the competitiveness debate
- Forging public and private partnerships to drive consensus
- Galvanizing stakeholders to translate policy into action and change

APPENDIX D

About Intersect360 Research

Intersect360 Research is a market intelligence, research and consulting advisory practice focused on suppliers, users and policy makers across the High Performance Computing (HPC) ecosystem. Intersect360 Research provides deep insight and perspective around the dynamics of the current and emerging HPC market segment, including trends and influences affecting customer behavior and technology adoption. Intersect360 Research draws heavily on close interaction with the HPC user community, leveraging its HPC500 user group spanning High Performance Technical Computing and High Performance Business Computing use cases worldwide.

Research Qualifications

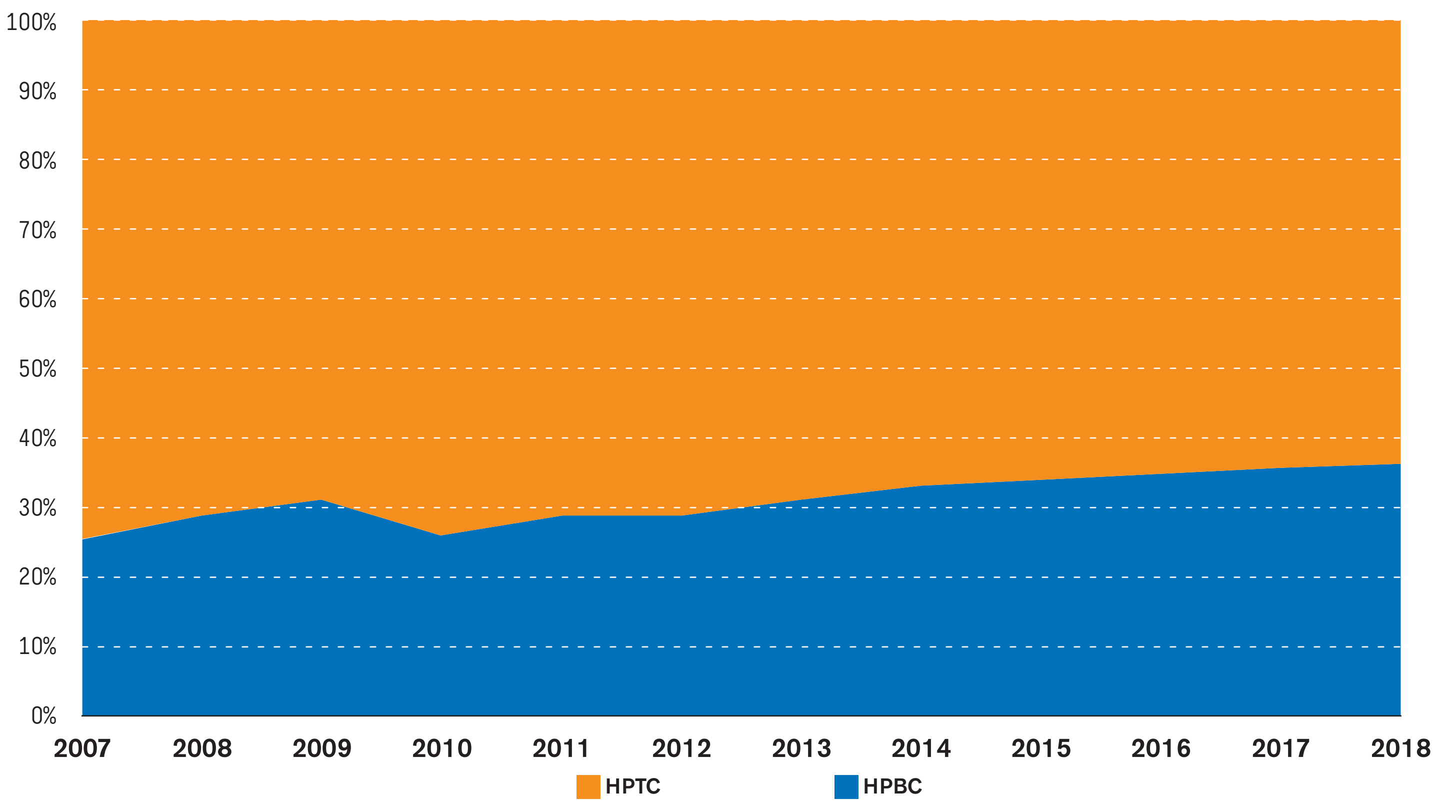
Since our founding, Intersect360 Research has described a broad set of industrial use cases for HPC. This foundational tenet is manifested in two "supersegments" in our market models and forecasts: High Performance Technical Computing (HPTC) and High Performance Business Computing (HPBC). (See Figure C1.)

HPTC is our supersegment representing scientific and engineering applications of HPC, including industry, government, and academia. It is important to stress that industry represents over 40 percent of HPTC revenue, as

Figure D1: HPBC vs HPTC Revenue Share of HPC Market by Year

2007-13 actual, 2014-18 forecast

Source: Intersect360 Reseach Total HPC Market Model and Forecast, 2014



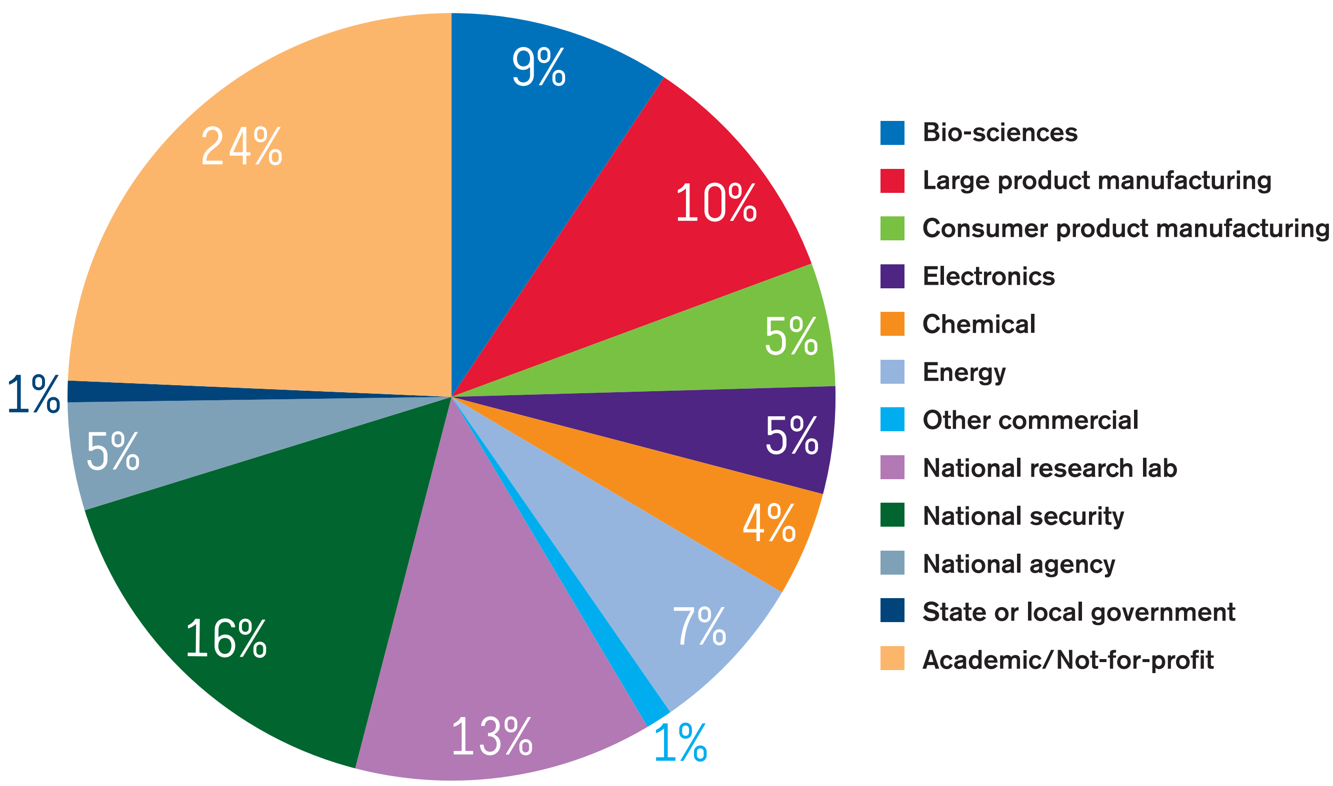
there are many for-profit commercial segments that rely on R&D advancements, including manufacturing, pharmaceuticals, chemical engineering, and oil exploration. (See Figure C2.)

HPBC is our supersegment representing the application of HPC to non-scientific business applications. Financial services is the largest vertical market here (as large as all of manufacturing combined), where we track applications in trading, risk management, pricing, and analytics. Beyond finance, we find applications in logistics, content delivery, and data mining across multiple industries. It is important to note that many of these users might not associate themselves with the term HPC, even if they rely on applications that are compute-intensive, memory-intensive, or data-intensive to achieve or maintain competitive advantage. (See Figure C3.)

Our HPC market advisory service is anchored by two major surveys that are conducted annually. Our HPC User Site Census survey tracks the adoption of HPC technologies across all application segments, geographies, and budget sizes, and based on this data, we have published regular trend reports on systems, processors, storage, interconnects, operating systems, middleware, application

Figure D2: HPTC Vertical Markets, by Revenue Share, 2013

Source: Intersect360 Research, HPC Total Market Model and Forecast, 2014



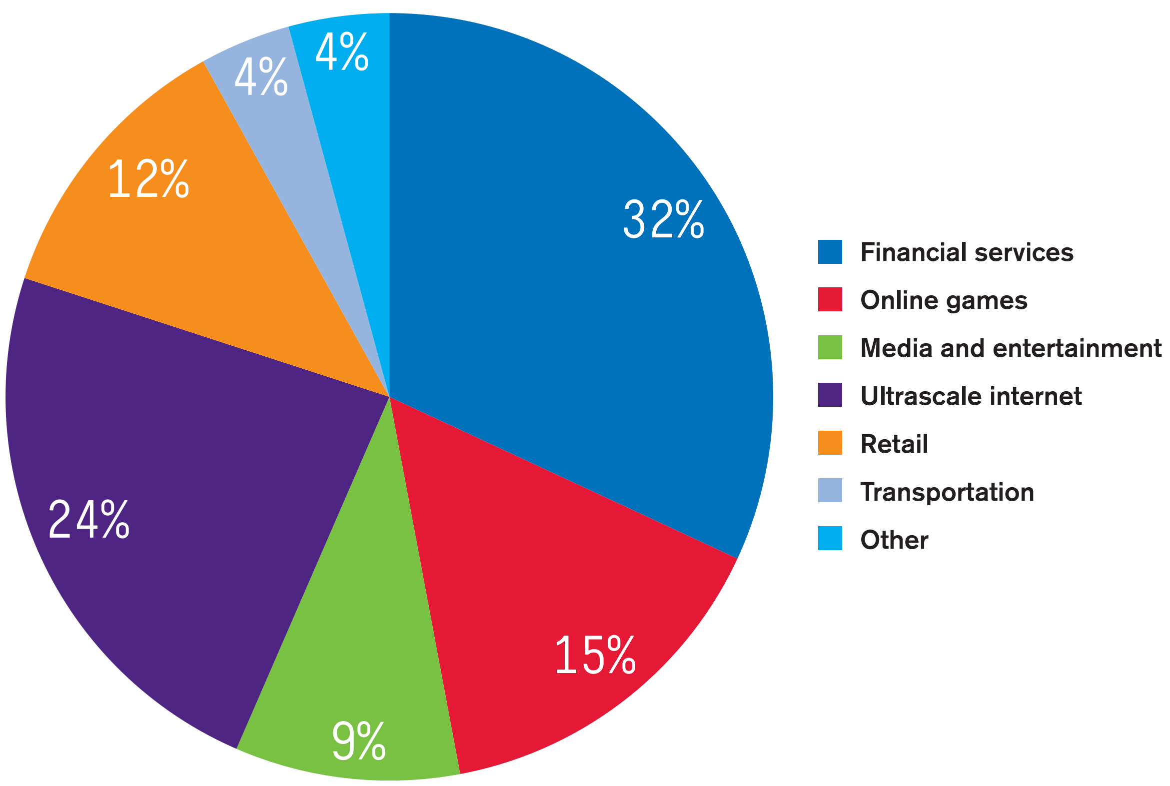
software, and cloud computing. Our HPC User Budget Map survey tracks spending on HPC, both as a whole and as it gets divided into top-level categories (hardware, software, staffing, facilities, services, cloud) and subcategories (such as, for software: operating systems, developer tools, middleware, storage software, and application software).

Beyond our anchor surveys, we conduct additional quantitative research into topical trends. Recently completed special study topics include the application of HPC technologies to Big Data workflows[7]; the adoption of digital manufacturing technologies among U.S. manufacturers; and users' forward-looking views on emerging technologies, such as cloud computing and GPU acceleration.

7 Conducted in 2012 and again in 2013, in partnership with Gabriel Consulting, the survey spanned over 300 respondents representing both HPC and non-HPC enterprise profiles.

Figure D3: HPBC Vertical Markets, by Revenue Share, 2013

Source: Intersect360 Research, HPC Total Market Model and Forecast, 2014



Our qualitative research projects help specific clients craft their messages to targeted industry segments. We work collaboratively with clients to establish a discussion guide and use our end-user contacts to capture actionable insights, and we interpret these for our clients.

HPC500 User Group

Further extending our reach and ability to conduct broad-based HPC research, in 2012 Intersect360 Research announced the formation of the HPC500 user group.[8] The HPC500 is a bellwether group comprised of leaders who bring HPC technology to bear on challenging problems across all application and geographic segments. Participants learn from each other's best practices, benefit from our research, and help steer the course of development in HPC by participating in Intersect360 Research studies.

Membership in HPC500 is controlled to be demographically balanced by industry and predicated on participation in research. The HPC500 includes leaders in manufacturing, energy, bio sciences, chemical engineering, finance, and other industries, and its membership continues to grow according to our goals. In addition to our traditional HPC research base, the HPC500 gives Intersect360 Research unmatched reach in addressing a wide range of forward-thinking industrial leaders.

8 http://www.hpc500.com

Council on Competitiveness
1500 K Street, NW, Suite 850, Washington, D.C. 20005 T 202 682 4292
Compete.org

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