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Special Study

Investigation of the Ripple Effects of Developing and Utilizing Leadership Supercomputers in Japan: The Scientific and Financial Returns from the K Computer and Possibilities from the Post-K Computer

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IDC OPINION

In Japan and other developed countries, leadership-class supercomputers have played a major role in advancing science, boosting industrial competitiveness, and improving the quality of daily life for average citizens. Japan's K computer is well known throughout the world and, as this study shows, the K computer has enabled many impressive innovations and financial returns that would not have been possible with typical, less-capable supercomputers.

During the past five years, national political leaders in the U.S., Europe, and China have recognized the ability of leadership-class supercomputers to help transform their economies, their societies, and their understanding of the natural world. As a result, these leaders have endorsed important new initiatives aimed at developing exascale computing capability in the 2020 to 2024 time frame, with pre-exascale systems entering the world in the next few years. Examples include U.S. President Obama's executive order creating the National Strategic Computing Initiative (NSCI); the EU's increased HPC funding and Action Plan to achieve exascale computing; and the incorporation of high performance computing (HPC) as a key priority in China's 13th Five-Year Plan.

Like these political leaders, IDC believes that exascale computing capability will be an important prerequisite for scientific and industrial competitiveness in the 21st century. Major economic powers, including Japan, that do not develop this capability risk losing scientific and economic ground to countries with exascale technology. IDC believes that the U.S. and Japan possess the greatest technical experience for developing exascale supercomputers and the mature vendor and user communities for effectively exploiting these advanced computers.

For the Japanese ROI accomplishments collected in this study, the overall financial return on investment averaged an extremely strong $571 dollars in revenue per dollar invested in HPC (for the K computer). On average these projects generated cost savings of an extremely high amount of $278 dollars in cost savings per dollar invested in HPC on the K computer. These results lead most other countries around the world.

IDC'S ROI definition used in this study is different from traditional ROI definitions and was developed specifically for measuring actual results of R&D programs and the contribution of HPC to these programs. The IDC ROI figure averaging $571 in additional revenue for each $1 invested in HPC is calculated on the same basis IDC used for our successful 2013 ROI study for the U.S. Department of Energy. This figure does not reflect asset costs and would be lower if asset costs were reflected. In addition, IDC's ROI figures for countries represent the totals for only the projects IDC evaluated for the present study and do not represent totals for all of the HPC projects undertaken within the countries.

This study provides 146 new financial ROI & innovation ROR examples, that were combined with previous examples around the world for this study. This study located 29 financial ROI examples and 117 innovation examples in Japan. A total of 21 different organizations and 48 different researchers were surveyed as part of this study. The combined total financial value of the K computer was an amazing $9.6 billion US dollars for the projects in this study. Looking at both the K and Post-K computers, the overall value financial values exceeds $19 billion US dollars, for the examples in this study. Note that the actual amounts are much higher, as this is only a subset of the projects on these systems.

Looking at both the K and Post-K computers, the overall value financial values exceeds $19 billion US dollars

This study confirmed that many Japanese researchers have benefitted greatly from using the K computer and are ready to advance their work and tackle even more challenging problems on a more powerful Post-K computer. We are firmly convinced that developing a more powerful successor to the K computer is well worth the investment. The K computer has demonstrated that leadership-class supercomputers can produce returns far in excess of the amounts needed to fund them.

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EXECUTIVE SUMMARY

In order to provide scientific advance and economic growth, nations around the world are increasingly investing in large, leadership-class supercomputers. These computers provide a tool that can magnify the researcher's capabilities and greatly improve their efficiency in conducting their science.

The cost to develop and build the next generation of exascale computers is very high. The top systems could exceed $1 billion US dollars, perhaps as high as $1.3 billion (excluding maintenance, staff, buildings, power, etc.). Although the costs are high, it has become the new investment level for leading edge science and innovation. When combined with advancements in application design, big data and top researchers, these systems will become the backbone for new scientific discoveries.

To provide scientific advance and economic growth, nations around the world are increasingly investing in large, leadership-class supercomputers

Project Summary

International Data Corporation (IDC) has evaluated the return-on-investment (ROI) and the return-on-research (ROR) for K and Post-K computers.

- For Strategic Programs, Post-K priority issues, and research cases which have a press release
- A total of 21 different organizations and 48 different researchers were interviewed in Japan.
- Original 721 reviewers and 68 new Japanese reviewer confirmed 117 ROR and 29 ROI cases.

K computer:

- The total revenue return on the K computer was return at least 2.7 billion US dollars – plus cost savings of 6.9 billion US dollars.
- Looking at the financial rate-of-returns, the K computer provides $571 in revenues, and $278 in cost savings for each dollar invested.
  - Cost saving ROI is much higher than that of the other flagship supercomputers around the world.
- ROR on the K computer's Strategic Programs for Innovative Research (SPIRE) generate extremely high innovation levels compared with other supercomputers in the world.
- 50% priority use of SPIRE was very efficient to generate those high level innovations.
- The ratios of priority use are smaller in other supercomputers.

NOTE: IDC'S ROI definition used in this study is different from traditional ROI definitions and was developed specifically for measuring actual results of R&D programs and the contribution of HPC to these programs. The IDC ROI figure averaging $571 in additional revenue for each $1 invested in HPC is calculated on the same basis IDC used for our successful 2013 ROI study for the U.S. Department of Energy. This figure does not reflect asset costs and would be lower if asset costs were reflected. In addition, IDC's ROI figures for countries represent the totals for only the projects IDC evaluated for the present study and do not represent totals for all of the HPC projects undertaken within the countries.

Post-K computer:

- The projected revenue is an extremely strong $5 billion – plus cost savings of $5 billion US.
  - Note that the actual return is much higher because this is only for the researchers that participated in this study. And simple comparison of actual return are in principle

impossible between future Post-K computer and present super computers like K computer.

- The ROR on the Post-K computer also generate extremely high innovation levels compared with other supercomputers in the world.
- ROI and ROR indicates Post-K computer stands out among leadership projects around the world because most other systems are used on many smaller projects than as done on the K computer.

Key Observations from the Survey on Having a Leadership Class Supercomputer

Surveyed experts cited a broad range of technical exemplars for how a K-class supercomputer has been critical to their research. Most important, a majority indicated that without such a system they simply would not have been able to generate valid results in their field of study within a reasonable time frame, if at all. Specific K-class performance features frequently mentioned were the ability to:

- Handle large three dimensional simulations
- Conduct analysis of complex physicals systems with a high degree of precision
- Perform critical calculations in real time
- Conduct advanced multiscale and multiphysics simulations
- Reduce the need for empirical testing, particularly in animal studies
- Use data sets large enough to accurately simulate physical environments with a high degree of reliability and fidelity

Benefits of Post-K Computer

Surveyed experts were in agreement that a Post-K computer would offer many benefits for their research:

- New Science. Some stressed that a more powerful system will be needed to enable new science. Areas cited as ripe for new scientific development included personalized medicine, computational astrophysics, molecular dynamics, and social simulation.
- Improved Simulations. Others stated that a larger system would drive even better capabilities in existing areas of computational studies, citing the benefits of a larger, more capable system to provide more accurate simulations, enhanced simulation resolution, reduced time to solution, and greater opportunities for advanced multiscale research.
- Less Expensive Access. A third group indicated that a larger system would allow more users to benefit from the system, thereby increasing scientific productivity and cost-effectiveness.

Surveyed experts were in agreement that a Post-K computer would offer many benefits to their research

Typical Quotes:

- With a faster computer, it is possible to reduce the computational charge [cost] of a current simulation by a factor of 100, creating a much lower simulation cost and one less expensive than an experimental counterpart.
- The economic and social costs of major earthquakes are very high, and the K computer is helping to reduce these costs in many different ways.

- In the Post-K computer, it is sufficient to expand data sets, such as expanding the area under study rather than speeding it up. There is a Nankai Trough earthquake special study of the Ministry of Education looking at ways to mitigate the damage. Evacuation simulation is also a major theme.

Financial Benefits from The K Computer and the Post-K Computer

For the Japanese ROI accomplishments collected in this study, the overall financial return on investment averaged an extremely strong $571 dollars in revenue per dollar invested in HPC (for the K computer). On average these projects generated cost savings of an extremely high amount of $278 dollars in cost savings per dollar invested in HPC on the K computer. These results lead most other countries around the world.

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This study provides 146 new financial ROI & innovation ROR examples, that were combined with previous examples to create the tables below. This study located 28 financial ROI examples and 117 innovation examples. The combined total financial value of the K system was an amazing $9.6 billion US dollars for the projects in this study. Looking at both the K and Post-K systems, the overall financial returns exceeds $19 billion US dollars, for the examples in this study. Note that the actual amounts are much higher, as this is only a subset of the projects on these systems.

As Table 1 shows, the cost savings were very impressive, at $7 billion with the K Computer and $5 billion planned for the Post-K Computer. Note that the actual amounts are much higher, as this is only a subset of the projects on these systems.

From just these projects, the total overall value of the K Computer exceeds $9.5 billion (in revenues and cost savings), and $10 billion for the Post-K Computer.

Table 1

Summary of the Financial ROI from HPC in Japan

	Total Revenues ($M)	ROI Average of Revenue $ per HPC $ Inputs	Total Cost Saving ($M)	ROI Average of Cost Saving $ per HPC $ Inputs	Total Financial Returns ($M)
Japan K computer	$2,690	$571	$6,888	$278	$9,578
Japan Post-K computer	$5,100	$398	$4,950	$234	$10,050
Total	$7,790	$423	$11,838	$251	$19,628

Source: IDC 2016

Impact on Researchers of Not Having Post-K Computer

Almost all surveyed HPC experts involved with the K computer were emphatic that a transition back to the use of regular clusters would deeply harm, and in some cases shut down, their current research activities. Many simply stated that they would have to abandon their current efforts because the jobs that are now critical to their research agendas would take too long, be too complex, or have too much data to execute effectively in a regular cluster or cloud environment.

- Other HPC experts cited concerns that reliance on regular clusters or cloud-based options would adversely affect the reliability, accuracy and even the fundamental validity of their existing simulations and significantly slow development of new ones.
- Additionally, experts stressed that such a transition would cause a loss of capability vis-a-vis foreign counterpart research efforts, a weaken ability to validate new models against empirical data, decreased opportunities to do parametric studies, and an overall slowdown in the development of advanced software for HPC systems.

Impact on Japan Itself of Not Having Post-K Computer

The bulk of surveyed HPC experts noted that in addition to the many concerns noted above, problems that would arise into the 2020-time frame should there be no Post-K computer and that the scientific community instead had to rely on regular clusters of cloud-based options include:

- A general stagnation of Japan's ability to develop leading-edge HPC hardware and software. Such stagnation is seen as resulting in Japan falling behind other world-cases HPC developers, particularly the US and China, resulting in an overall Japanese dependence on foreign capabilities to support HPC-based research.
- Many believe that Japan would lose its status as a world class HPC supplier and user nation.
- A concomitant stagnation in Japan's larger scientific and engineer capability due to a lack of indigenous HPC development. The

Many believe that Japan would lose its status as a world class HPC supplier and user nation.

Japanese research community would be forced to find new ways to conduct research that is not so reliant on HPCs.

Many experts cautioned that the negative impact of such a decision may not become apparent for the next few years, but that it could have implications well into the 2020's and beyond. Finally, some noted that such a drag on scientific and engineering developments would have a significant negative impact on many Japanese industries that are competing internationally.

Enabling Breakthrough Scientific and Industrial Research

Surveyed HPC experts pointed to a number of ways that a post-K computer would help their research. Some indicated that a new system would open up a range of new areas of scientific, while others highlighted the positive impact a new system would have on helping to improve the quality of the research they were already conducting. New scientific fields of discovery mentioned included:

- All-atom molecular dynamics simulations of more than 10 million atoms to support breakthroughs in the molecular theory of material science,
- Simulations to determine the long-term effects of various drugs on heart patients, as well as the long-term health impact of heart surgery prior to the procedure,
- High quality aerospace simulations capable of accurately modeling a wide range of take-off and landing scenarios,

Expectations of technical performance improvements for a Post-K computer included realizing performance improvements of 100X over the current K computer, reducing the time for simulations that would currently take a year down to only a few days, and facilitating the simultaneous running of 100s of versions of a code that can now only be run one at a time on the K computer.

- Many of the experts noted that without a Post-K computer, their ability to compete with other foreign researchers who had access to larger system would be hampered, and a few indicted that development of a Post-K computer could help drive innovation within Japan's semiconductor industry.

Surveyed HPC experts expressed a number of compelling - and diverse – reasons why Japan needs a world class Post-K computer. Conversely, many provided ample comments as to the overall negative effect the lack of such a system could have on Japan's overall scientific and economic prospects.

Many of the experts noted that without a Post-K computer, their ability to compete with other foreign researchers who had access to larger system would be hampered

Expert justification for a Post-K computer included:

- The critical ability to conduct sophisticated space-based simulations due to the limitations and costs of counterpart experimental studies.
- The consideration that a Post-K computer was absolutely necessary for Japan to maintain a world-class HPC capability, while indicating this will not be possible if advanced systems are purchased from overseas.
- The perception that the Post-K computer would serve not only a flagship development from a perspective of compositing power, but also as a critical driver of innovation.
- The need to develop a leading-edge HPC platform to drive human resource development and to establish a system of young researchers of education and cooperation.

Likewise, many were concerned about the implications of having no Post-K class system development, and such concerns centered on Japan being unable to compete scientifically on the world stage, serious disruptions to a wide range of on-going Japanese research efforts, the chilling effect on a broad range of leading-edge scientific research going forward, and a lack of technological leadership that the industrial sector can draw on to help them compete globally.

Scientific Innovation Returns From the K Computer

The benefits of HPC usage are not limit to financial ROI, new scientific innovations are an important type of benefit for HPC users in government, academia, and industry. Japan leads the other countries in the ratio of innovations of the top class level:

- A much higher percentage of the Japanese innovations qualified in category 5, as one of the top 2 to 3 innovations of the last decade.
- A far greater percentage of the Japanese innovation examples qualified as "useful to over 50 organizations" than the other examples.
- Using the IDC innovation class ratings, Japan has a higher ratio of Class 1 innovations compared to the US, China and major European countries.

Scientific Success Stories

- The K computer has enabled multi-scale heart simulation from the protein level. This has contributed to basic medicine (elucidation of hypertrophic cardiomyopathy), and also demonstrates the effectiveness of the clinical application of a simulation model developed for heart surgery.
- The K computer enabled the simulation of the formation process of galaxies that requires very large-scale calculations.
- In order to simulate an entire virus with all atoms, it is necessary to deal with environments of over 10 million atoms, a capability available only on the K computer.
- Highly accurate molecular simulation became possible, and can applied to various proteins, enabling accurate biological response simulation. As a result, the mechanism of the drug resistance of non-small cell lung cancer treatment drugs has been elucidated.

Industry Success Stories

- Simulation that supports coupled analysis of multi-physics can shorten the process of commercialization, which is very important for the international competitiveness of the coal gasification furnace process.
- The Post K computer is required for the simulation in the time scale of biological reactions in the millisecond level, a capability already achieved by the US.

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IN THIS STUDY

Methodology

Overview

The intent of this study was to determine the ripple effect of developing and utilizing leadership supercomputers in Japan. As a first step, IDC worked with Riken to develop a broad set of questions that would address the issue from multiple interrelated perspectives:

- The first perspective centered on assessing the overall ripple effect – defined as the widespread impact of the availability of a leadership class supercomputer on Japan's overall scientific, industrial, and economic sectors writ large – enabled by the availability of a single or a series of leadership supercomputers. Questions here centered on gathering qualitative data and insights highlighting the impact of currently available supercomputer developments, the opportunities associated with the development of future supercomputers, and the implications of future reliance on general-purpose cluster or cloud-based solutions.
- The second perspective centered on gaining insights into the overall financial impact of leadership supercomputers using two specific quantitative metrics; the financial return on investment (ROI) on a scientific or technological advancement achieved through the use of a leadership class supercomputer and an innovation return on research (ROR) metric that measured the innovative quality of a research effort supported by a leadership-based class supercomputer.
- A third perspective was based on information IDC gathered in Japan using the methodology IDC developed for an extensive study we have conducted for the U.S. Department of Energy (DOE). This methodology captures quantitative and qualitative information on the positive outcomes associated with investments in HPC technology—financial returns-on-investment (ROI) for private sector firms, and returns-on-research (ROR), in the form of innovations, for not-for-profit organizations in government and academia. The results for Japan can be found in the next two sections.

Additional questions were used to help draw out easy to understand yet highly illuminating case studies or related success stories that could be used to illustrate the ripple effects of supercomputer systems to both technical and non-technical readers.

- IDC research has shown again and again that such qualitative or anecdotal evidence of this kind can be extremely useful for helping readers of the study grasp the overall impact of HPC usage and to add more insights and a better contextual understanding of the ROI and ROR findings.
- Finally, IDC sought to gather a number of key quotes from those surveyed as a way to more effectively and clearly convey some of their key thoughts, insights, and concerns.

Once the series of question and related study guide had been agreed upon by both Riken and IDC, IDC conducted a series of in-person, in-depth interviews with a broad range of technical expert within the Japanese scientific and supercomputer user communities who were selected for their ability to best address these questions:

  - The survey included a total of 117 innovation project examples and 29 financial ROI examples, for a total of 146 examples (note some projects had both an innovation and an ROI example, and some had projects on both the K Computer and plans for running on the Post-K Computer).

- This included 61 current projects on the K computer, and plans for 40 future projects to be supported by the Post-K computer.
- The list of all participants and their organizations can be found in the appendix.

The Researchers Surveyed

IDC conducted a set of surveys of researchers and people using the K computer and this planning to use the Post-K computer. A total of 21 different organizations and 48 different researchers were surveyed as part of this study. In addition, IDC surveyed a set of people that could potentially use a Post-K like computer. The type people surveyed included:

- HPC researchers using the K computer:
  - For strategic programs, we surveyed all of the cases that each representative organization suggested.
  - For other programs, we surveyed all of the cases that we could find that had made a press release.
- HPC researchers that may use the Post-K computer:
  - For priority programs, we surveyed all of the cases that each representative organization suggested.
- Researchers and scientists that could potentially use a Post-K like computer:
  - This included people inside japan and around the world.

The Innovation Return on Research (ROR) Metric Used in the Study

In order to properly quantify the overall impact of leadership class supercomputers in Japan, IDC analysts used a rating system that measured both the *importance* and *impact* of each leadership class supercomputer based innovations in the existing data set, plus all of the new Japanese innovations collected in this research study. IDC developed this measurement method as part of a successful 2013 global study for the U.S. Department of Energy.

The overall innovation ranking or the present study on Japan was created based on a combination of the two complementary rankings of the innovations:

The IMPORTANCE this innovation compared to all other innovations in this field over the last ten years:

5. One of the top 2 to 3 innovations in the last decade

4. One of the top 5 innovations in the last decade

3. One of the top 10 innovations in the last decade

2. One of the top 25 innovations in the last decade

1. One of the top 50 innovations in the last decade

The IMPACT of this innovation to multiple organizations:

6. An innovation that is useful to over 50 organizations

5. An innovation that is useful to 10 to 49 organizations

4. An innovation that is useful to 6 to 10 organizations

3. An innovation useful to 2 to 5 organizations

2. An innovation only useful to 1 organization

1. An innovation that is recognized ONLY by experts in the field

Combing these measures, IDC's used these overall innovation ratings for this project

This was done to create a single innovation index scale to rank the overall value and usefulness of the innovations being studied. While all of the innovations are important, this scale helps to rank them for comparisons.

- Class 1 innovations – One of the top 2-3 innovations in a field over the last ten years PLUS useful to over 10 organizations
  - These are the top types of innovations, useful to many and clearly breakthroughs in the area of research
- Class 2 innovations -- One of the top 5 innovations in a field over the last ten years PLUS useful to over 10 organizations
  - These are also top types of innovations, useful to many and clearly breakthroughs in the area of research
- Class 3 innovations – One of the top 5 innovations in a field over the last ten years PLUS useful to at least 5 organizations
  - These are very important types of innovations, useful to a number of organizations and some of the top breakthroughs in the area of research
- Class 4 innovations – One of the top 10 innovations in a field over the last ten years PLUS useful to at least 5 organizations
  - These are important innovations, useful to a number of organizations and represent breakthroughs or new discoveries in the area of research
- Class 5 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at over 10 organizations
  - These are important innovations, useful to a number of organizations and represent useful discoveries in the area of research
- Class 6 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at least 2 organizations
  - These are important innovations, but only useful to a few organizations and represent useful discoveries in the area of research
- Class 7 innovations – One of the top 50 innovations in a field over the last ten years PLUS useful to at least 2 organizations
  - These are important innovations, but only useful to a few organizations, and are often minor innovations
- Class 8 innovations – The rest of the innovations in the study
  - These are useful innovations, but only useful to very few organizations, and are often minor or incremental innovations

The ROI and ROR Data Validation Process

In order to fully ensure that the data collected during the course of this study is correct, accurate, believable and defensible, IDC adopted a multi-layered process that harnessed a broad range of HPC-related expertise from a number of different subject matter experts:

1. Upon initial submission, forms were reviewed by IDC experts to see if all of the information was correct and the form met standards necessary to be considered for inclusion in the study.
   - In cases where the form either lacked the necessary information, or there were some other questions or concerns relating to a particular submission, IDC contacted the submitters, and then worked with them to add, change, or otherwise alter their submission to meet IDC submission criteria.
   - IDC then compared each entry to previous entries in similar fields of research to see if the results and numbers were at a similar level. There were 3 outliers that were then sent to a broader group for a more complete evaluation.
2. Once a submission was reviewed and accepted by IDC analysts, it was then turned over to members of the HPC User Forum Steering Committee (listed at: www. hpcuserforum.com) for review of accuracy and importance. Members are volunteer HPC and computational science experts representing leading organizations in government, academia, and industry (see list at www.hpcuserforum.com).
   - When required (in only a few cases), subject matter experts in the areas covered in a submission were called in for further review. These reviews were done by experts in a particular field.
   - The mix of experts that were available for this review included:
     - Education--University/Academic 216
     - Energy--and geosciences 39
     - Entertainment--Digital Content Creation & Distribution 5
     - Finance/Insurance--Economics/Financial 26
     - Government--Defense, Labs, Research Centers, etc. 123
     - Health--Bio-Sciences, pharmaceuticals, life sciences 63
     - Manufacturing--Discrete & Process – CAE, EDA/IT/ISV 105
     - Other 109
     - Transportation 8
     - Weather--Climate and Earth Sciences 27
     - In total, there were 721 experts available around the world
3. Subsequent to approval by the HPC Steering Committee, a submission was moved into consideration for both an innovation award and for inclusion in the study's economic database.

This process was developed to ensure that the comparisons are fair and neutral around the world. In the case of the Post-K system, we used estimates of future results as opposed to actual results.

SITUATION OVERVIEW

High performance computing (HPC) technology has been greatly advanced by Japanese vendors and heavily exploited by Japanese users since the dawn of the supercomputer era in the 1960s. Even before then, Japanese contributions to early computer technology development and usage were crucial for enabling the supercomputer era.

The world's most powerful computers, called leadership-class supercomputers, have contributed enormously to scientific advances, national security, economic progress, and the quality of life, Leadership-class supercomputers are indispensable for many applications that are important for the societies they serve, such as the following:

- Predicting severe storms that can devastate lives and property
- Providing accurate daily/weekly weather forecasts needed by the transportation. Agricultural, and tourism industries
- Improving the design and safety of power plants and developing technologies to exploit alternative energy sources
- Detecting sophisticated cyber security breaches, insider threats, and electronic fraud.
- Combatting crime and terrorism
- Advancing fundamental science as a prerequisite for later advancements in applied research and development, including industrial R&D
- Pioneering new computer technologies that can later transform business and consumer electronic devices

Political leaders around the world have increasingly recognized the transformational power of leadership-class supercomputers and are supporting initiatives to enable their countries to compete effectively in the worldwide race to develop future supercomputers with unprecedented speed, called "exascale" computers, in the next 5-6 years. U.S. President Obama, European Commission leaders, and Chinese leaders all have endorsed initiatives to reach this goal. Japan is the only other country with the technical ability to accomplish this. In IDC's opinion, the U.S. and Japan have the greatest experience in designing leadership-class supercomputers that are capable of supporting a broad spectrum of challenging scientific and industrial research problems. The Post-K computer would be a major milestone on the path toward exascale computing capability.

The Purpose of This Study

The purpose of this study was to gain insights and gather quantitative data related to the ripple effect of RIKEN’s existing K supercomputer and the potential benefit of a RIKEN development for a new flagship Post-K computer with a planned operational date of around fiscal 2020.

- Currently, the Post-K computer effort is supported as a development and maintenance project with a total project cost of investment 130 billion yen (among which the national fund is worth about 110 billion yen) in 2014 by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

For the purpose of this study, RIKEN and IDC jointly defined the so-called ripple effect as the widespread impact of the availability of a leadership class supercomputer on Japan’s overall scientific, industrial and economic sectors writ large.

SURVEY FINDINGS

Respondent Profiles

The survey included a total of 117 innovation project examples and 29 financial ROI examples, for a total of 146 examples (note some projects had both an innovation and an ROI example, and some had projects on both the K Computer and plans for running on the Post-K Computer).

This included 61 current projects on the K computer, and plans for 40 future projects to be supported by the Post-K computer. The list of all participants and their organizations can be found in the appendix.

Respondent Titles

As Table 2 indicates, the survey respondents predominantly consisted of senior-level university-based research scientists and other senior researchers.

Table 2

Titles of the Survey Respondents

Title	Number	Percentage of Sample
Professor	21	44.7%
Team Leader	7	14.9%
Assistant Professor	4	8.5%
Group Leader	3	6.4%
Senior Research Scientist	3	6.4%
Chief Researcher/Scientist	2	4.3%
Researcher	2	4.3%
CEO	1	2.1%
Director, Professor	1	2.1%
Principle Investigator	1	2.1%
Research Unit Leader	1	2.1%
Senior Director for Research Affairs	1	2.1%
Total	47	100.0%

Source: IDC 2016

Research Areas of the Projects

Table 3.A and 3.B show that the respondents represented a broad spectrum of scientific disciplines and focus areas, including applied research with strong potential for contributing to Japan's economy and quality of life. It was important to ensure that opinions were received from many areas of leading-edge research being conducted in Japan.

Note: These categories are as reported by the researchers during the survey interviews in Table 3.A. Table 3.B summarizes the projects into more general areas.

Table 3 A

Research Areas of the Survey Respondents

Research Areas	Number	Percentage of Sample
Molecular Dynamics/Science	11	10.4%
Tools & Library	10	9.4%
Biology, Precision Medicine, Pharma	8	7.5%
Weather Research & Climate	8	7.5%
Mathematical data assimilation	7	6.6%
Nuclear physics theory	6	5.7%
Quantum many-body problem	6	5.7%
Automotive aerodynamic simulation	5	4.7%
Battery Development	5	4.7%
Computational Fluid Dynamics	4	3.8%
Astrophysics, Astronomy, Precision Cosmology	3	2.8%
Civil Engineering and Social Simulations	3	2.8%
Computational Material Science	3	2.8%
Computational Molecular Engineering	3	2.8%
Computational neuroscience	3	2.8%
Design optimization	3	2.8%
Large-scale first principle computation	3	2.8%
Mesoscale meteorological research	2	1.9%

Table 3 A

Research Areas of the Survey Respondents

Research Areas	Number	Percentage of Sample
Solar thermal convection	2	1.9%
Other Areas	11	10.4%
Total	106	100.0%

Source: IDC 2016

Table 3 B

Research Areas of the Survey Respondents

Research Areas	Number	Percentage of Sample
General Science Areas	35	33.0%
Manufacturing/Automotive/CFD/Design Optimization	21	19.8%
Molecular Dynamics/Science/Engineering	13	12.3%
Biology, Precision Medicine, Life Sciences	12	11.3%
Tools & Library	10	9.4%
Weather Research & Climate	10	9.4%
Astrophysics, Astronomy, Precision Cosmology	5	4.7%
Total	106	100.0%

Source: IDC 2016

Importance of Having a Leadership Class Supercomputer

The importance of having access to a K-like supercomputer to their research

Surveyed experts cited a broad range of technical exemplars of how a K-class supercomputer was critical to their research. Most important, a majority indicated that without such a system they simply would not have been able to generate valid results in their field of study within a reasonable time frame, or even if at all. Specific K-class performance features frequently mentioned were the ability to:

Without such a system they simply would not have been able to generate valid results in their field of study within a reasonable time frame, or even if at all.

- Handle large three dimensional simulations
- Conduct analysis of complex physicals systems with a high degree of precision
- Perform critical calculations in real time
- Conduct advance multiscale simulations
- Reduce the need for empirical testing, particularly in animal studies
- And use data sets large enough to accurately simulate physical environments with a high degree of reliability and fidelity

In addition, researchers discussed some of the non-technical and--perhaps more far reaching--economic and social benefits such as increased global industrial competiveness, more accurate weather forecasting capabilities and climate change analysis, new discoveries in medical technology and genetics study, and greater understanding of earthquake and related geophysical dynamics.

Key Quotes:

- Before the K computer it took more than one year for a single calculation, but by using the K computer, and with the same resolution, it has become possible to run in a three-dimensional rather than two-dimensional mode.
- K computer availability is important for large atom simulation and maintaining international competitiveness.
- It is important to perform calculations in real time.
- In order to simulate an entire virus with all atoms, it is necessary to deal with environments of over 10 million atoms, a capability available only on the K computer.
- In previous supercomputers, accuracy ranged from 10 ˆ 6 to 10^7, and the reliability of the simulation had not been guaranteed. With the K computer, accuracy was in the 10^11 range ensuring simulation reliability.
- A critical application is in the field of dilated cardiomyopathy where high resolution simulation is used to evaluate the impact of new treatments.
- It is possible to express the actual phenomena that are intricately happening in the atmosphere in the computer, enabling a more realistic environment.
- To predict the future of weather conditions by using a supercomputer, numerical prediction has become a key technology of modern meteorological service. Weather phenomena study requires the ability to address various scales, and phase changes or emission of water, heat conduction etc., involving complex physical processes, such as turbulence.

- The K Computer has enabled multi-scale heart simulation from the protein level. This has contributed to basic medicine (elucidation of hypertrophic cardiomyopathy), and also demonstrates the effectiveness of the clinical application of a simulation model developed for heart surgery.
- It has enabled new discoveries that are not possible with using only animal experiments.
- The K computer is not only as a flagship supercomputer, in addition to the computing power, it is also important in terms of open innovation and human resource development.
- Since it is not practical to experiment with building structures, reliable simulations are required.
- Highly accurate molecular simulation becomes possible, and can applied to various proteins, enabling accurate biological response simulation. As a result, the mechanism of the drug resistance of non-small cell lung cancer treatment drugs has been elucidated.
- The K computer enabled the simulation of the formation process of galaxies that requires very large-scale calculations.

The importance of having access to the Post K-like supercomputer to their research

Surveyed experts were in general agreement that a Post-K computer would offer many benefits:

- Many researchers believed that a more powerful system would enable new science, and areas cited for new scientific development included personalized medicine, computational astrophysics, molecular dynamics, and social simulation.
- Others stated that a larger system would drive even better capabilities in existing areas of computational studies, citing the benefits of a larger system to provide for more accurate simulations, enhanced simulation resolution, reduced time to solution, and greater opportunities for advanced multiscale research.
- A third group indicated that a larger system would allow for more users to benefit from cheaper access to such a capable system.

Finally, a number of HPC exports mentioned the need for Japan to remain on par with foreign leading-edge HPC developments, particularly those in the US, as a way to remain at the forefront of science, but to also ensure that Japanese technology does inadvertently flow overseas in international cooperative efforts.

Key Quotes:

- The Post K computer is required for the simulation in the time scale of biological reactions in the millisecond level, a capability already achieved by the US.
- The Post K computer would enable greater capabilities in personalized medicine.
- Consistently between observation and simulation requires more accurate simulation.
- Because the current K computer is still a scarce computing resource, there is a need for further high-speed computer access.
- With a faster computer, it is possible to reduce the computational charge [cost] of a current simulation by a factor of 100, creating a much lower simulation cost and one less expensive than an experimental counterpart.
- The Post K computer could help unlock the mystery of physics by calculation, and also solve the celestial phenomenon of supernova explosions and neutron star binary star coalescence.

- In recent years, observation data has greatly increased, and because it is expected to become an increasing critical element in the future simulations, it is necessary to have high-speed computers that can accommodate these large and rapidly growing data sets
- Simulation that supports coupled analysis of multi-physics can shorten the process of commercialization, which is very important for the international competitiveness of the coal gasification furnace process.
- Simulation of 100,000 atoms cannot be absolutely done without K computer.
- Many larger jobs can only be run one at a time on the K computer. The Post-K will enable the ability to run a large number of such jobs at the same time.
- When the simulation of 100 to 1,000 million atom is made possible, the virus of HIV and influenza can be simulated entirely.
- We can simulate current scale simulation many times, improving accuracy and reliability
- It will be possible to perform the entire system simulation in the electronic and molecular level to complex a complex molecular and material process.
- By increasing the scale of simulations, more accurate simulation become possible.
- With better simulation speed, it is possible to drive an optimal solution easily, which in turn can greatly reduce development time.
- New applications of social simulation will be possible.
- In the Post-K, it is sufficient to expand data sets, such as expanding the area under study rather than speeding it up. There is a Nankai Trough earthquake special study of the Ministry of Education looking at ways to mitigate the damage. Evacuation simulation is also a major theme.
- With the Post K computer, simulations time will be deceased and calculations will be more statically valid and reliable.
- We have collaboration with The United States. When we have to use the resources of other countries in the absence in Japan, we must be concerned about the leakage of technology.

How their CURRENT research would be impacted if they had to use regular clusters

Almost all surveyed HPC experts involved with the K computer were emphatic that a transition back to the use of regular clusters would deeply limit, if not shut down, their current research activities. Many simply stated that they would have to abandon their current efforts because the jobs that are now critical to their research agendas would take too long, be too complex, or have too much data to execute effectively on a regular cluster.

- Other HPC experts cited concerns that reliance on regular clusters would adversely affect the reliability, accuracy and even the fundamental validity of their existing simulations and significantly slow development of new ones.
- Additionally, experts stressed that such a transitions would cause a loss of capability vis a vis foreign counterpart research efforts, a weakening ability to validate new models against empirical data, decreased opportunities to do parametric studies, and an overall slowdown in the development advanced software for Japanese HPC systems.
- There were underlying concerns that issues with porting existing code optimized for the K architecture to a new cluster architecture could be a long and likely unsatisfying task.

Surveyed HPC experts involved with the K computer were emphatic that a transition back to the use of regular clusters would deeply limit, if not shut down, their current research activities.

Key Quotes:

- Without a K computer we cannot be carry out calculations greater than on an order of 10^6. We cannot evaluate the structure, and we cannot be assured of the quality of our simulations. They will become sloppy simulations.
- Comparisons with observational or empirical data will becomes difficult, and we will not be able to verify the validity of the simulations.
- You will not be able to simulate the actual phenomenon without relying on using significant assumptions.
- Tailor-made medical care could not be done.
- Although there will not be much impact on the actual research, it can be calculated that jobs will take 10-100x times longer than they do currently.
- In the standard type of cluster, our jobs will not fit into the memory. Or it cannot compute in a practical time. Therefore, it cannot compare with the large simulation performed without experimentation.
- It might be possible to calculate one case, but more than one case is impossible.
- The performance hit would be roughly on a scale of 10 times.
- It would require us to use partial simulations. We will not be able to perform simulations in a realistic time, forcing us to transition to low-precision software.
- Small scale simulation running on either a cluster or a cloud would not be reliable. Or it becomes impossible.
- Since data set sizes have become huge, regular clusters are too small. It will not possible to analyze more than ten thousand cases of the genome without a Post-K computer.
- Use of regular clusters will make it difficult to continue the development of a computer math library that is matched with advances in computer architecture.
- It becomes impossible to follow the precision of the observation data.
- Theory would not keep up with the study of the experimental.

How their research would be impacted in 2020 if they had to use regular clusters

The bulk of surveyed HPC experts noted that in addition to the many concerns noted above, problems that would arise into the 2020-time frame include:

- A general stagnation of Japan's ability to develop leading-edge HPC hardware and software. Such stagnation is seen as resulting in Japan falling behind other world-cases HPC developers, particularly the US and China, resulting in an overall Japanese dependence on foreign capabilities to support HPC-based research. Many believe that Japan would lose its status as a world class HPC supplier and user nation.
- A concomitant stagnation in Japan's larger scientific and engineer capability due to a lack of indigenous HPC development. The Japanese research community would be forced to find new ways to conduct research that is not so reliant on HPCs.

Many indicate that such a decision could have a negative impact on Japanese HPC abilities that may not become apparent for the next few years, but that could have implications well in the 2020's and beyond. Finally, some noted that such a drag on scientific and engineering developments would have a significant negative impact on many Japanese industries that are competing internationally.

Long-term reliance on regular clusters would result in Japanese HPC capabilities falling behind those of the United States and China.

Key Quotes

- Long-term reliance on regular clusters would result in Japanese HPC capabilities falling behind those of the United States and China.
- If there is no K computer, we will need to find other means to conduct our research, putting additional pressure on the scientific community to find innovative solutions without HPCs.
- Multi-physics analysis becomes impossible.
- Japan's ability in software optimization is top class in the world. Since optimization research is an international issue, Japan would likely soon start to fall behind.
- Rather than being immediately obvious, the impact would become most pronounced in 10 years.
- Stagnation of computing technology will result in a drag on productivity and result in a decrease in Japanese industrial competitiveness worldwide.
- Top-level research would become more difficult without leading-edge HPCs. There are many research areas are that rely on very fast computer, and their lack would will limit the research.
- Without leading-edge HPC development, Japan will not be able to not grow young talented people.
- You will not be able to perform highly accurate simulations, and eventually Japanese efforts would lag behind in research teams from the United States and Europe.

How the Post-K Supercomputer Could Help Their Research

Surveyed HPC experts pointed to a number of ways that a Post-K computer would help their research. Some inducted that a new system would open up a range of new areas of scientific research made capable by a more powerful system, while others highlighted the positive impact a new system would have to help improve the quality of the research they were already conducting.

New scientific fields of discovery mentioned included:

- All-atom molecular dynamics simulations of more than 10 million atoms to support breakthroughs in the molecular theory of material science,
- Simulations to determine the long-term effects of various drugs on heart patients, as the long-term health impact of heart surgery prior to the procedure

- high quality aerospace simulations capable of accurately modeling a wide range of take-off and landing scenarios,
- and increased numerical modeming to ensure the lead time necessary to evacuate populations during severe weather events and hydrological disasters such as river flooding, as well as related debris flow predictions.

Expectations of technical performance improvements for a Post-K computer included performance improvements of 100X over the current K computer, reducing the time for simulations that would currently take a year down to only a few days, and facilitating the running of 100s of versions of a code that can now only be run once on the K computer.

Finally, many experts noted that without a Post-K computer their ability to compete with other foreign researchers who had access to larger systems would be hampered, and a few indicted that development of a Post-K computer could help drive innovation within Japan's semiconductor industry.

Key Quotes

- In the area of molecular dynamics calculations, the US already has access to a system 100 times the speed of K computer.
- Since it is possible to run several hundred cases with a Post-K computer, researchers will gain a better theoretical understanding of the universe.
- Current simulation that would take one year with 400 nodes on K computer will be completed in a few days on a Post-K computer.
- A Post-K computer would enable a more thorough understanding of gravity waves that are released in the coalescence process of neutron star binary stars, perhaps lending additional insights into the origin of heavy elements, such as platinum, gold and silver.
- For post-K, accurate models for beating of the heart from the motion of the particles of amino acids can be calculated, creating the ability to generate a personalized medicine plan.
- The basic concept of our research in the Post-K computer is a fusion of molecular simulation and organ simulation.
- The availability of a Post-K computer offers the possibility of a seasonal forecast incorporating the binding model of the atmosphere and the ocean. Such efforts could also help improve the prediction of El Niño.
- The Post-K computer is important to maintain international competitiveness.
- Clusters and cloud offer the potential for only limited simulations that may not be sufficiently actuate or reliable for study.
- The availability of a Post-K computer enables long-term cardiac simulation that can help predict medical outcomes prior to surgery.
- It is possible to study quasi-first-principles calculations at the time of take-off and landing.
- It will be able to perform all-atom molecular dynamics simulations of more than 10 million atoms, which can help establish the molecular theory underwriting material science.
- Japan's semiconductor industry is dying and will die without Post-K.
- Post-K numerical models can ensure the lead time necessary to evacuate populations during severe weather events or hydrological disasters such as river flooding and debris flow predictions.

The Post-K computer is important to maintain international competitiveness

- It will support the discovery of new principles, which can lead to the development of new substances material.

The importance to Japan of having a world class Post-K supercomputer

Surveyed HPC experts expressed a number of compelling - and diverse – reasons why Japan needs a world class Post-K computer. Conversely, many provided ample comments as to the overall negative effect the lack of such a system could have on Japan's overall scientific and economic prospects.

Expert justification for a Post-K computer included:

- The critical ability to conduct sophisticated space-based simulations due to the limitations and costs of counterpart experimental studies.
- The consideration that a Post-K computer was absolutely necessary for Japan to maintain a world-class HPC capability, seeming that is not possible if advanced systems are purchased from overseas.
- The perception that the Post-K computer would serve not only a flagship development from a perspective of compositing power, but also as a critical driver of innovation.
- The need to develop a leading-edge HPC platform to drive human resource development and to establish a system of young researchers of education and cooperation.

Likewise, many were concerned about the implications of having no Post-K class system development, and such concerns centered on Japan being unable to compete scientifically on the world stage, serious disruptions to a wide range of on-going Japanese research efforts, the chilling effect on leading-edge Japanese research going forward, and a lack of technological leadership that the Japanese industrial sector can draw on to help them compete globally.

Key Quotes:

- The development of a Post-K computer is absolutely necessary in order to maintain Japan's presence as a leading-edge HPC developer and user.
- Because space-based experimentation is costly and complex, many experiments can only be done computationally.
- One can could buy an advanced HPC from abroad, but to have access to the best possible systems, it is necessary to support the domestic HPC supplier base.
- The availability of a Post-K computer will lead to the strengthening of the industrial capability of the country. It is very important as the K computer and Post-K computer are not only a flagship development in terms of computing power, but it is also important in terms of open innovation and human resource development.
- The Post-K computer drives development of a wide range of leading-edge simulations critical to keeping Japanese science at the highest level. Buying from abroad would be useless.
- In order to enhance creativity and strengthen global industrial competitiveness, a cutting-edge machine is essential.
- Post-K computer development is extremely important in order to promote the Japanese technology. Having a state-of-the-art technology in their own country is important as a first-class country. It is also important in order to go to create a young researcher of human resource development.

The development of a Post-K computer is absolutely necessary in order to maintain Japan's presence as a leading-edge HPC developer and user.

- If there are scientific and economic achievements, it is good. But it is very important that the development establishes a system of young researchers of education and cooperation.
- If there is a scientific achievement in the Post-K, the ripple effect could be very large. Expectations for research in the enterprise is growing, and there is a very significant economic effect.
- If there is no post-K, we can run only jobs that anyone can do, and Japan will fall behind in the world.
- It is important to consider international competitiveness. In the West there is no such thing as a consortium targeted to build next-generation supercomputer original. And, Japan is capable of looking out over prepare for 10 years.
- In critical scientific fields using a computational approach is essential. Because other countries will have more computing resources, Japan will not be able to compete.
- In the field of molecular simulation, the influence of Post-K computer is immeasurable.
- It is important not only for simulation. Such a project has helped to human resource development, such as the education of students.
- It will lag behind that in the world. In addition, if there is no Post-K computer, there are a lot of areas that cannot be researched.
- Since the K computer and Post-K computer has a performance after 10 years of a large machine within the industrial sector, the industry can prepare in anticipation of 10 years. Rather than the now of the economic effect, there is a need to look at the results after 10 years.
- Supercomputer of ability is reflected in the national power.
- The project is important to be able to secure the human resources. If cut, researchers would have their work interrupted. Eventually Japan will lose the national power.
- In the future, if there is no Post-K computer, the science of nuclear physics and astrophysics it will not be led by Japan, but globally.
- The Post-K computer will create differentiation of in industrial design making it possible for Japan's shipbuilding industry to survive.
- A Post-K computer and the scientific results it enables will help spread Japanese technology abroad, and help to cultivate an international network of fellow researchers.

If there is no Post-K computer, we can run only jobs that anyone can do, and Japan will fall behind in the world.

FINANCIAL ROI RESULTS

World scientific leadership and innovation leadership are becoming more dependent on the use of HPC/supercomputers every year. Economic leadership increasingly directly results from a nation's or an industry's or an enterprise's application of supercomputers in innovative and productive ways. Many countries/regions (such as USA, Japan, China, Russia, Europe, and other Asian countries) are putting into place plans to gain leadership in innovation and economic progress by more broadly applying HPC/supercomputing across many different industries and segments.

IDC's HPC ROI Approach

IDC created a set of ROI models to show the impact of investments in HPC. The models include both the financial ROI (Return on Investment) returns and the innovation ROR (Return on Research) returns from projects done on supercomputers. The results of this research is published at: www.idc.com/ROI (IDC copyright study)

The pilot ROI study investigated how high-performance computing (HPC) investments can improve economic success and increase scientific innovation. This research is focused on the common good and should be useful to all HPC centers around the world. The study created two unique economic models and an innovation index:

- A *macroeconomic model* that depicts the way HPC investments result in economic advancements in the form of ROI in revenue (GDP), profits (and cost savings), and jobs.
- A *macroeconomic model* that depicts the way HPC investments result in basic and applied innovations, looking at variations by sector, industry, country, and organization size.
- A new *innovation index* that provides a means of measuring and comparing innovation levels.

Key findings of the pilot study included:

- IDC was able to collect the required data across a broad set of organizations, with enough detail to create the economic models and the innovation index.
- Early results indicate very substantial returns for investments in HPC:
  - $356.5 on average in revenue per dollar of HPC invested
  - $38.7 on average of cost savings per dollar of HPC invested
- The average number of years before returns started was 1.9 years.
- The average HPC investment per innovation was $3.1 million.
- Note that an additional outcome of this research is an expansive list of HPC success stories

The Definition Of The Investments Used In The Study

For both this study and IDC's overall tracking of ROI and ROR around the world, the "HPC Investments" are the costs to use the HPC system for just the project in each example. The overall guideline used in the study, is that the inputs are the “Actual” or “Equivalent” costs for a researcher in their country, in their industry, in their organization. For the K and Post-K computer, costs include the research budget, labor cost, and equivalent charge of use (K computer :14.53JPY per node hour).

For International researchers, most academic and government sites, such as NSF and ORNL, provide the HPC resources for free or for a very small charge, like only the operational costs – power and cooling costs. Large companies like banks, car companies or oil companies sometimes charge a full allocation of the hardware, software, power, building, etc. costs.

Revenue and Cost Savings

For this study, revenues are the value of the sales that have been (or may in the future) generated from the research project. For example, the design of a new tire, the design of a new car, creating new medical treatment, better understanding of financial instruments, etc.

Cost savings include research projects that generate a savings that would not have happened without the results of the project. These can vary greatly and include things like: better building designs to better withstand the impacts of earth quakes, hurricanes, tsunamis, etc.; better drugs to reduce the costs of healthcare; better ways to apply drugs to reduce the costs of giving costly drugs to people that it won't help, etc.

In some cases, both revenues and cost savings are generated, but in most cases its primarily either revenues or cost savings.

Overall Financial ROI Results in Japan

This study provides over 100 new financial ROI & innovation ROR examples, that were combined with previous examples to create the tables below. This study located 29 financial ROI examples and 117 innovation examples.

The combined total financial value of the K system was an amazing $9.6 billion US dollars for the projects in this study. Note that there are many other projects on the K system, so the full value would be much higher. Looking at both the K and Post-K systems, the overall value financial values exceeds $19 billion US dollars, for just the examples in this study.

As shown in Table 4:

- The total revenue return on the K Computer was a very strong $2.7 billion US dollars -- plus an outstanding amount of cost savings of $6.9 billion US dollars. This represents one of the highest returns on a supercomputer. (Note that the actual return is much higher, as this is only for the researchers that participated in this study).
- The projected revenue returns on the Post-K Computer is an extremely strong $5.1 billion US dollars – plus an outstanding amount of cost savings of $5 billion US dollars. This represents one of the highest returns on a supercomputer. (Note that the actual return is much higher, as this is only for the researchers that participated in this study).
- Looking at the rate-of-returns, the K computer provides 571 dollars in revenues (on average) for each dollar invested, and 278 dollars in cost savings for each dollar invested.
    - This is much higher than the rest of the world, which is at $356.5 on average in revenue per dollar of HPC invested, and $38.7 on average of cost savings per dollar of HPC invested
- Looking at the rate-of-returns, the Post-K computer provides an outstanding 398 dollars in revenues (on average) for each dollar invested, and 234 dollars in cost savings for each dollar invested.
    - This is also much higher than the rest of the world, which is at $356.5 on average in revenue per dollar of HPC invested, and $38.7 on average of cost savings per dollar of HPC invested

Table 4

Financial ROI From HPC in Japan

	Combined Revenue & Cost Savings ($M)	ROI Revenues ($M)	Average of Revenue $ per HPC $	ROI Cost Saving ($M)	Average of Cost Saving $ per HPC $
Japan K	$9,578	$2,690	$571	$6,888	$278
Japan Post-K	$10,050	$5,100	$398	$4,950	$234
Total	$19,628	$7,790	$423	$11,838	$251

Source: IDC 2016

SCIENTIFIC INNOVATION RESULTS

Innovation Areas

The benefits of HPC usage are not limit to financial ROI, new scientific innovations are an important type of benefit for HPC users in government, academia, and industry. Table 5 shows the major types of beneficial innovations reported to IDC by the Japanese organizations we interviewed for this study, along with the average investment needed for each innovation type. Some but by no means all innovations result immediately in "better products." As the table indicates, there were some of those, but the largest number of reported innovations were in the "created new approach" category.

Table 5

Innovation Areas: For ALL Innovation ROR Projects in Japan

Primary Innovation/ROI Area	K Computer Average of HPC $M per Innovation	K Computer Count of Accomplishments	Post-K Computer Average of HPC $M per Innovation	Post-K Computer Count of Accomplishments
Better Products	$3.61	9	$1.98	8
Cost Saving	$0.63	3	$3.75	5
Created New Approach	$2.27	34	$1.52	23
Discovered Something New	$1.11	9	$1.75	8
Helped Research Program	$1.75	1	--	--
Helped Society	$1.38	10	2.1875	7
Overall Total	$2.18	66	$1.93	51

Source: IDC 2016

Innovations by Sector

Most of the reported Japanese innovations were in the academic and government market sectors, but the HPC investment per innovation did not differ greatly for the industry examples (see Table 6).

Table 6

Japanese Innovations by Sector

Sector	K Computer Average of HPC $M per Innovation	K Computer Count of Basic/Applied Innovations	Post-K Computer Average of HPC $M per Innovation	Post-K System Count of Basic/Applied Innovations
Academic	$1.82	43	$1.08	34
Government	$2.79	18	$2.89	16
Industry	$1.75	5	N/A	1
Overall Total	$2.18	66	$1.93	51

Source: IDC 2016

Mix of Innovation Types in Japan

Table 7 shows that IDC collected a balanced mix of innovations in basic science and applied science. Not surprisingly, the basic science innovations on average required HPC investments that were nearly twice as large as those made for applied research–most likely because basic science innovations typically are more consequential and require more time and effort than their applied science counterparts.

Table 7

Mix of Innovation Types in Japan

Basic or Applied	K Computer Average of HPC $M per Innovation	K Computer Count of Basic/Applied Innovations	Post-K Computer Average of HPC $M per Innovation	Post-K System Count of Basic/Applied Innovations
Applied	$1.65	26	$2.15	19
Basic	$2.46	38	$1.58	30
Both	$2.31	2	$2.75	2
Overall Total	$2.18	66	$1.93	51

Source: IDC 2016

Innovations in the Study by Country

Table 8 shows the mix of innovations collected in this study. Note that this table shows the demographics of the surveys, and is NOT meant to show any differences in innovations or innovation capability by country. IDC has collected 389 real-world examples of HPC-supported innovation, of which 203 are in basic science and the remaining 190 in applied science. We collected 117 innovation examples in Japan, 72 in basic science and 49 in applied science. See Table 8. Note that in the table a few innovations in Japan were rated as BOTH basic and applied innovations.

Table 8

Number of Innovation Examples in the Study

Country	Count of Applied Innovations	Count of Basic Innovations	Total Count of Innovations
China	30	41	71
France	10	1	11
UK	20	53	73
US	70	32	102
Italy	6	0	6
K computer	28	40	68
Post K computer	21	32	53
Others	5	4	5
Overall Total	190	203	389

Source: IDC 2016

Rating the Importance and Impacts of the Innovations

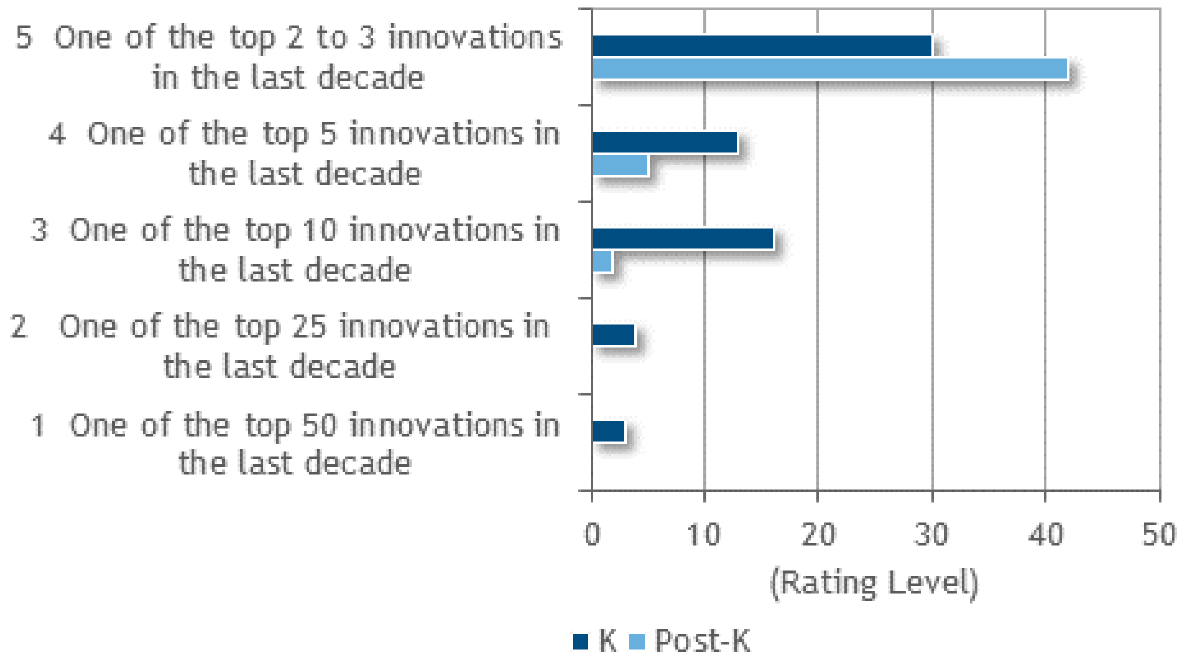
While all innovations are important, it is useful to be able to rank innovations to better understand how to increase the higher value innovations over time. IDC created two sub-scales that are then combined into an overall innovation class scale to help measure and show these differences. This is also useful in comparing the results of different research organizations around the world in applying HPC to improve innovativeness. One must always keep in mind that the primary driver of innovation comes from the researchers, and not from the tools that they use.

IDC use two scales to rate the importance (Figure 1) and impacts (Figure 2) of each innovation (and Table 9). IDC developed these measurement scales for the successful study on returns from HPC investments that we conducted for the U.S. Department of Energy (DOE). DOE was pleased with these scales and asked IDC to conduct an even larger study using them. IDC then combines these into an overall rating.

Most of the Japanese HPC-supported innovations were determined by our external review committee to be at high-importance levels. 64% of the innovations were in the highest-importance "5" category, and 96% were at levels 3-5.

FIGURE 1

Innovation Index #1 Importance (For Japan)



Source: IDC 2016

A large majority of the Japanese innovation also had very high beneficial impacts. 86% of the innovations were judged to be in the highest-impact "6" category, and a very impressive 91% of the Japanese innovations were at levels 4-6 of beneficial impact.

Table 9

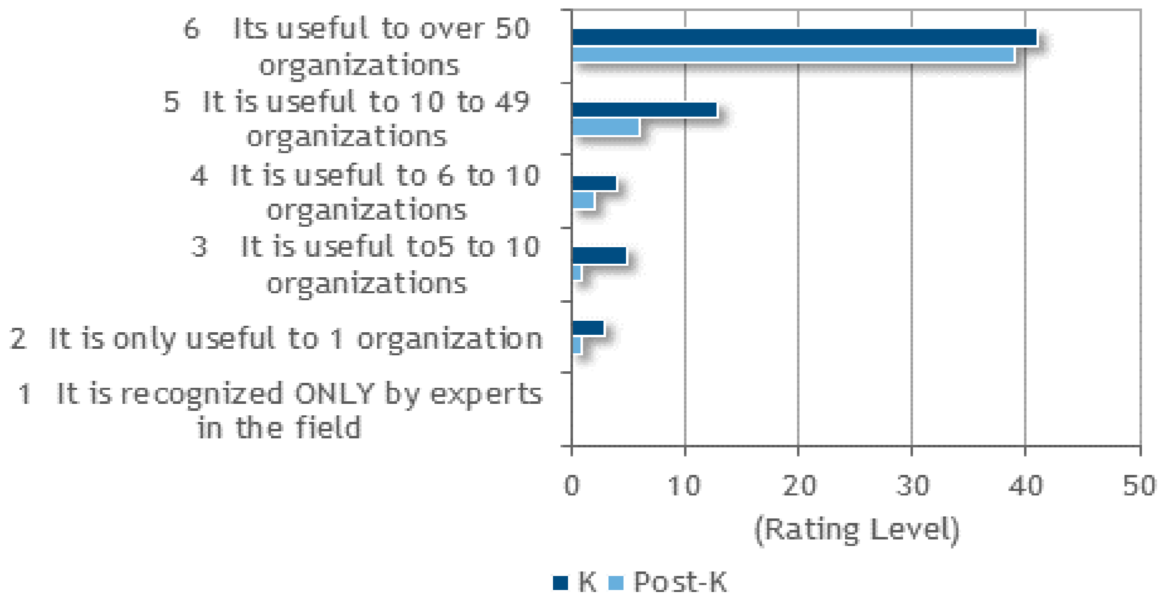
Innovation Ratings: For Japanese Innovations

Rating Level	K Computer Count of New Innovation Index #1 Importance	K Computer Count of New Innovation Index #2 No. Org's Impacted	Post-K Count of New Innovation Index #1 Importance	Post-K Count of New Innovation Index #2 No. Org's Impacted
6	N/A	41	N/A	39
5	30	13	42	6
4	13	4	5	2
3	16	5	2	1
2	4	3	0	1
1	3	0	0	0
Overall Total	66	66	49	49

Source: IDC 2016

FIGURE 2

Innovation Index #2 Number of Organization's Impacted (For Japan)



Source: IDC 2016

Rating the Overall Value Of The Innovations

The Innovation Class Levels Used in the Study

IDC has created a new HPC innovation rating system that is based on combining two sub-scales: the importance and the impact rating scales, into an over innovation class level scale. While all innovations are important and useful, innovations that are class 1, 2 or 3 are clearly the most important innovations in the world,

Rating Scale:

- Class 1 innovations – One of the top 2-3 innovations in a field over the last ten years PLUS useful to over 10 organizations
    - These are the top types of innovations, useful to many and clearly breakthroughs in the area of research
- Class 2 innovations -- One of the top 5 innovations in a field over the last ten years PLUS useful to over 10 organizations
    - These are also top types of innovations, useful to many and clearly breakthroughs in the area of research
- Class 3 innovations – One of the top 5 innovations in a field over the last ten years PLUS useful to at least 5 organizations

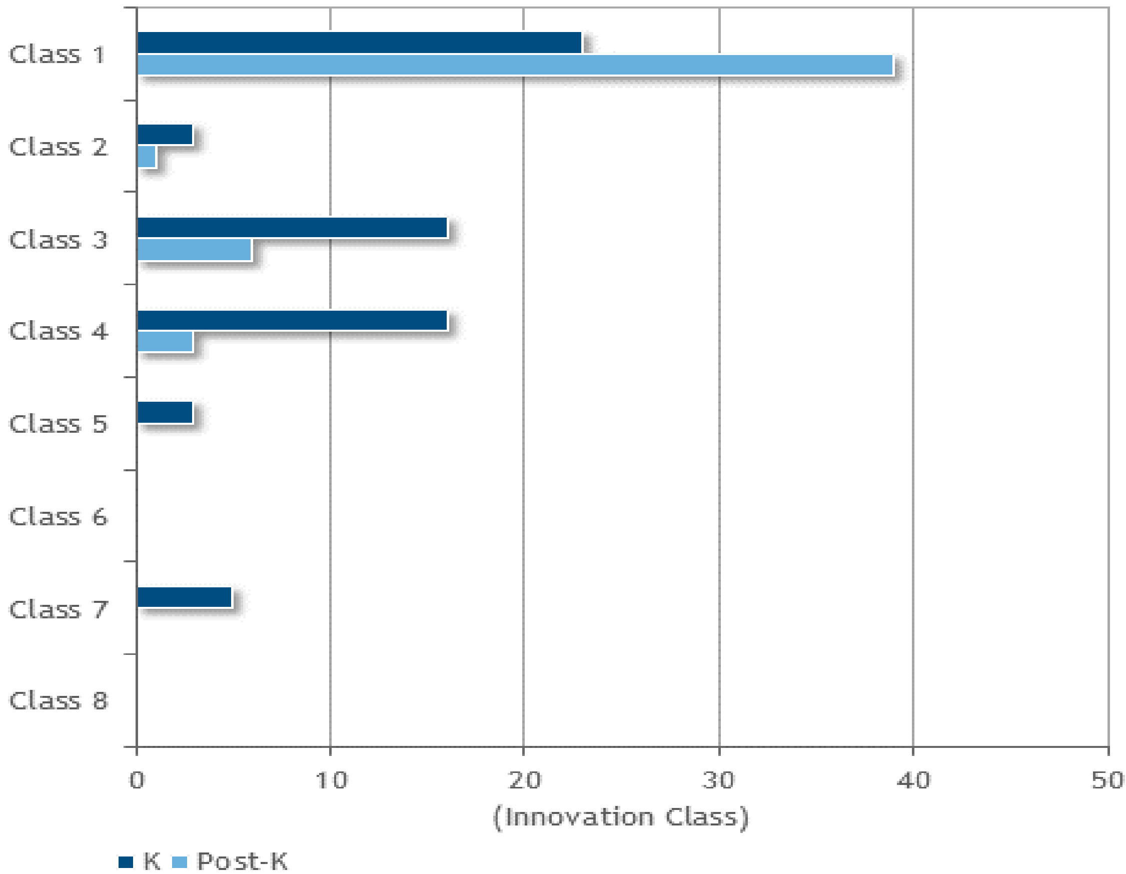
    - These are very important types of innovations, useful to a number of organizations and some of the top breakthroughs in the area of research
- Class 4 innovations – One of the top 10 innovations in a field over the last ten years PLUS useful to at least 5 organizations
    - These are important innovations, useful to a number of organizations and represent breakthroughs or new discoveries in the area of research
- Class 5 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at over 10 organizations
    - These are important innovations, useful to a number of organizations and represent useful discoveries in the area of research
- Class 6 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at least 2 organizations
    - These are important innovations, but only useful to a few organizations and represent useful discoveries in the area of research
- Class 7 innovations – One of the top 50 innovations in a field over the last ten years PLUS useful to at least 2 organizations
    - These are important innovations, but only useful to a few organizations, and are often minor innovations
- Class 8 innovations – The rest of the innovations in the study
    - These are useful innovations, but only useful to very few organizations, and are often minor or incremental innovations

Ratings of the Japanese Innovations

Figure 3 and Table 12 display the combined ratings of the Japanese innovations collected for this study, using a scale that takes into consideration both the importance and impact ratings discussed above. As Figure 3 shows, a high proportion of the Japanese examples qualified as Class 1 innovations, the most impressive category. Looking at the top three class levels, Japan has done an outstanding job at generating important innovations.

FIGURE 3

Overall Rating CLASS Levels of Japanese Innovations



Source: IDC 2016

Table 10

Overall Rating of Japanese Innovations

	Overall Count of Innovations	K Computer	Post-K Computer
Class 1	62	23	39
Class 2	4	3	1
Class 3	22	16	6
Class 4	19	16	3
Class 5	3	3	0
Class 6	0	0	0
Class 7	5	5	0
Overall Total	115	66	49

Source: IDC 2016

HOW JAPAN FINANCIAL ROI RESULTS COMPARE TO THE REST OF THE WORLD

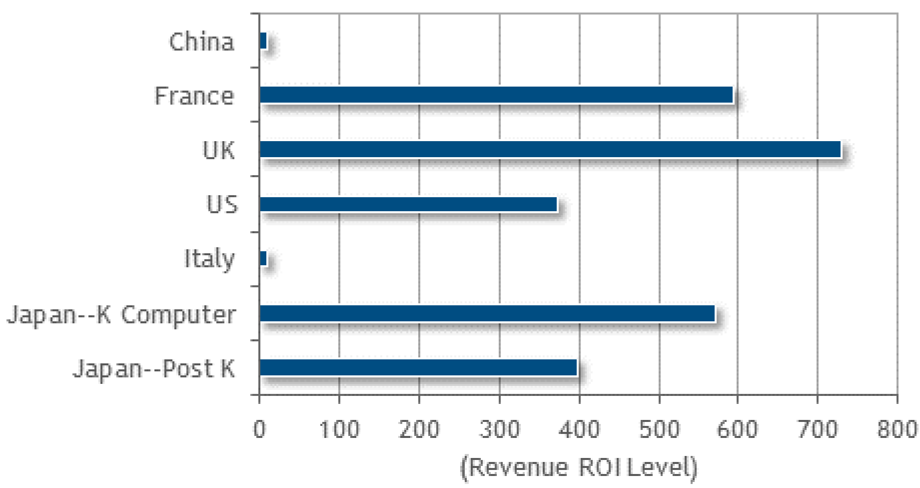
Financial ROI in Revenues

Figure 4 and Table 11 compare Japan and other countries around the world in terms of revenue ROI. The results are impressive, with the K computer and the Post-K computer exhibiting very high returns in terms of revenue generating projects. The revenue ROI is an outstanding $423 per dollar invested in HPC for both the K and Post-K computers (and from Table 1 a very high 571 per dollar invested in HPC for the K computer). The closest other countries are France at $593 and the UK at $730. Japan is over 50 times higher than China.

The results are impressive, with the K computer and the Post-K computer exhibiting very high returns in terms of revenue generating projects

FIGURE 4

Japan Compared to the Rest of the World: In Revenue ROI



Source: IDC 2016

Table 11

Financial ROI From HPC by Country: Revenues

Country	Average of Revenue $ per HPC $
China	$10
France	$593
UK	$730
US	$373

Table 11

Financial ROI From HPC by Country: Revenues

Country	Average of Revenue $ per HPC $
Italy	$10
K	$571
Post K	$398
Others	$15
Overall Total	$454

Source: IDC 2016

Financial ROI in Cost savings

Figure 5 and Table 12 shows that Japan overall exhibits the highest returns in terms of cost saving projects. The closest other country is France at $98. Japan is approximately 35 times higher than China in cost saving ROI. IDC believes that Japan's strong ROI results in cost savings category are especially high because no other country, not even the U.S., has learned how to apply HPC technology as effectively to support industry and reduces costly impacts. Japan was a pioneer in extending HPC to a variety of key business-to-business and consumer products industries, starting in the 1980s. Driven by the focus on high-impact projects of all sizes in areas like disaster research and in highly important bio-medical research projects, such as earthquake disasters, tsunami impacts on buildings, or deciding who should get very expensive anti-cancer drugs.

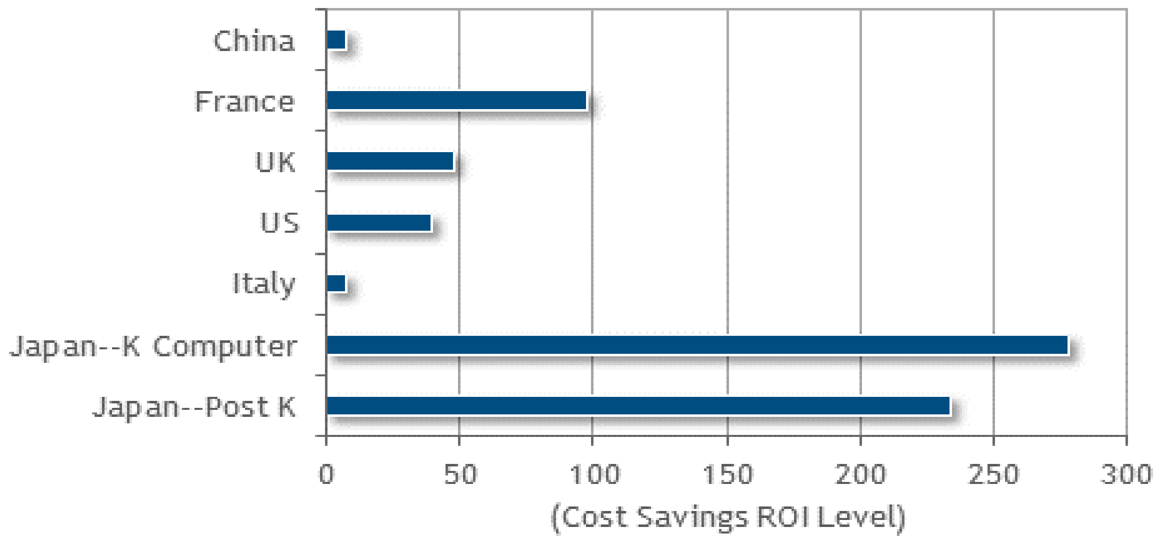
Japan's projects clearly generate the highest level of financial cost savings ROI when compared to other countries.

HPC cost savings ROI varied from a low of $10 in cost savings per dollar invested for China and Italy, to a high of $423 for the K and Post-K computers combined. Japan's projects clearly generate the highest level of financial cost saving ROI when compared to other countries. Any level above $10 to $15 dollars per dollar invested is a healthy return.

The results for Japan and all other countries confirm that investments in HPC technology typically produce strong financial returns.

FIGURE 5

Japan Compared to the Rest of the World: In Cost Savings ROI



Source: IDC 2016

Table 12

Financial ROI From HPC by Country: Cost Savings

Country	Average of Cost Saving $ per HPC $
China	$7
France	$98
UK	$48
US	$39
Italy	$8
K	$278
Post K	$234
Others	$33
Overall Total	$67

Source: IDC 2016

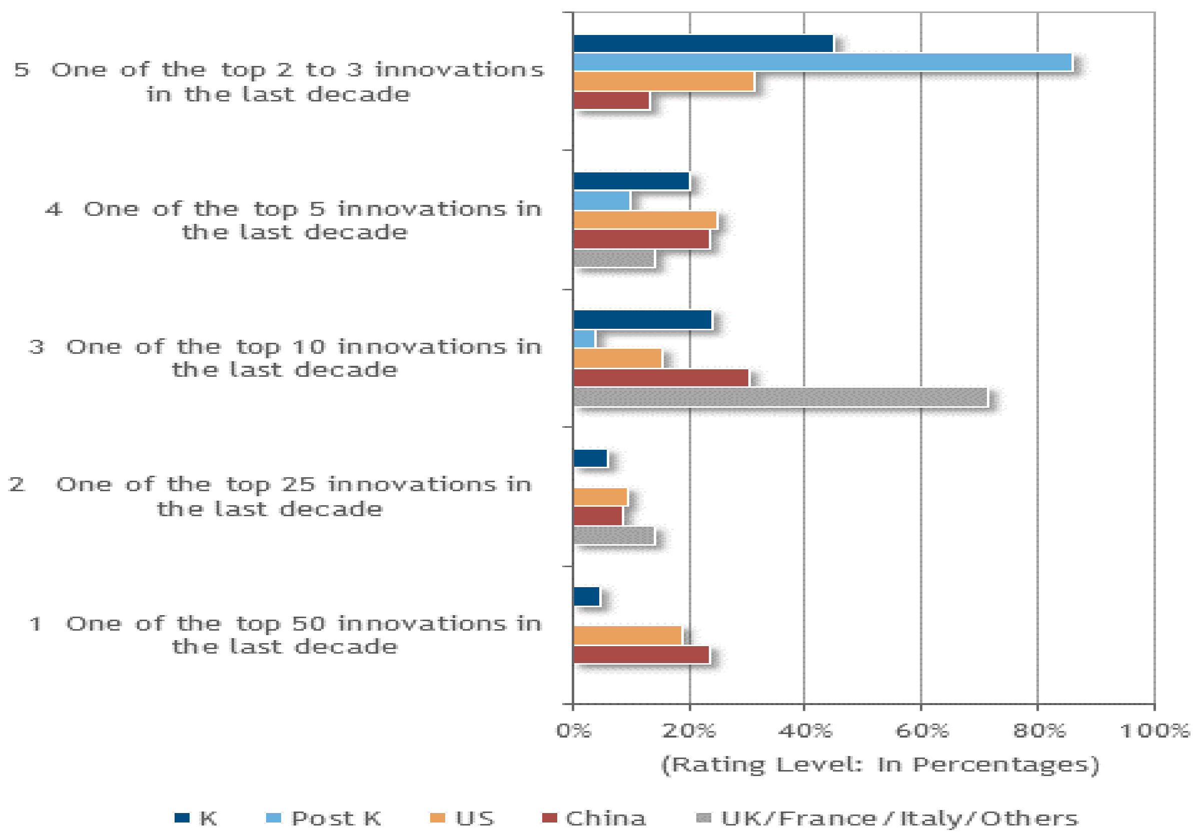
HOW JAPAN INNOVATIVENESS COMPARES TO THE REST OF THE WORLD

Where innovation is concerned, Japan also greatly outranks other countries. As Figure 6 indicates, a much higher percentage of the Japanese innovations qualified in category 5, as one of the top 2 to 3 innovations of the last decade.

Where innovation is concerned, Japan greatly outranks other countries

FIGURE 6

Japan Compared to the Rest of the World: Innovation Importance Ratings

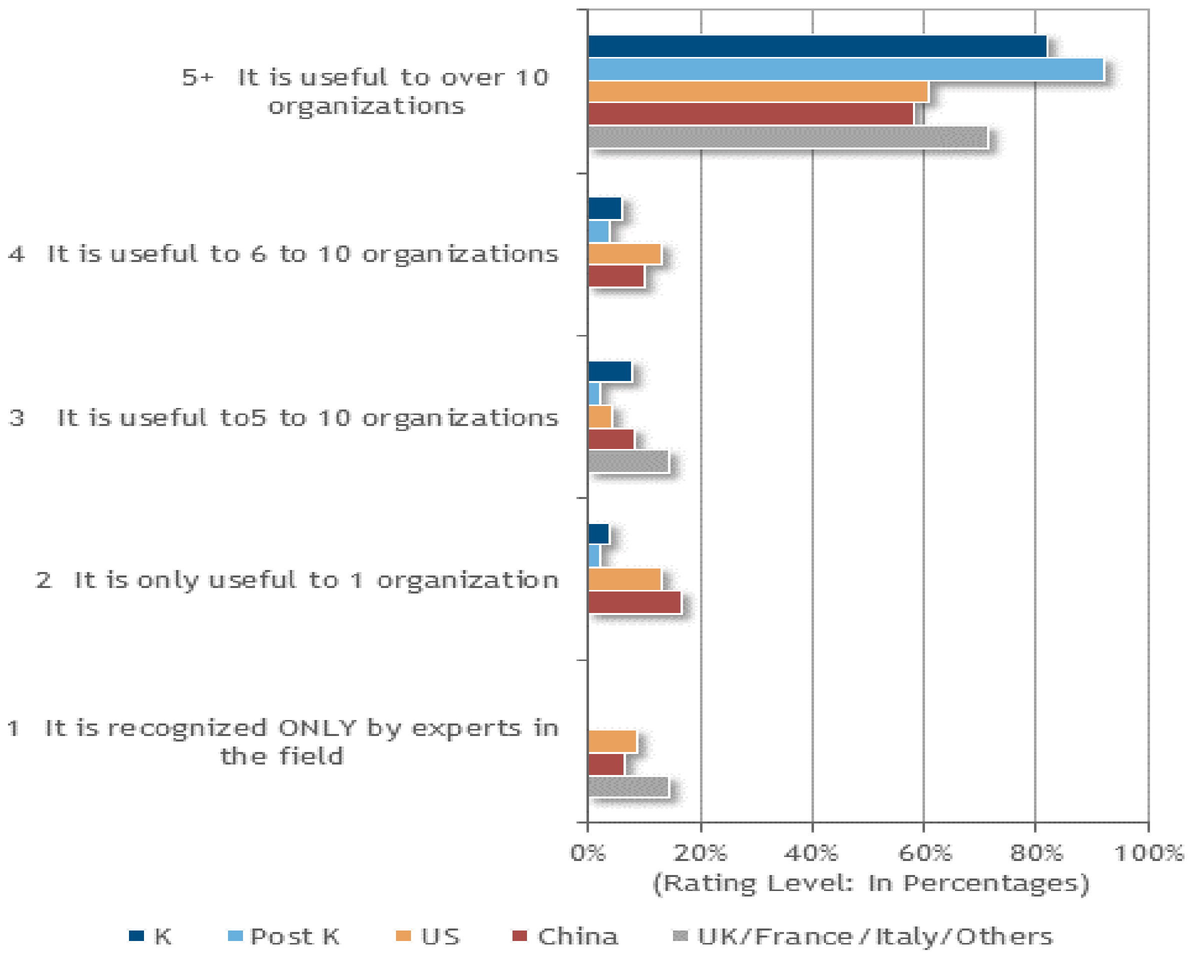


Source: IDC 2016

Japan's superior position also extends to the impact of HPC-driven innovations (Figure 7). A far greater percentage of the Japanese innovation examples qualified as "useful to over 10 organizations" than the other examples.

FIGURE 7

Japan Compared to the Rest of the World: Organizations Impacted



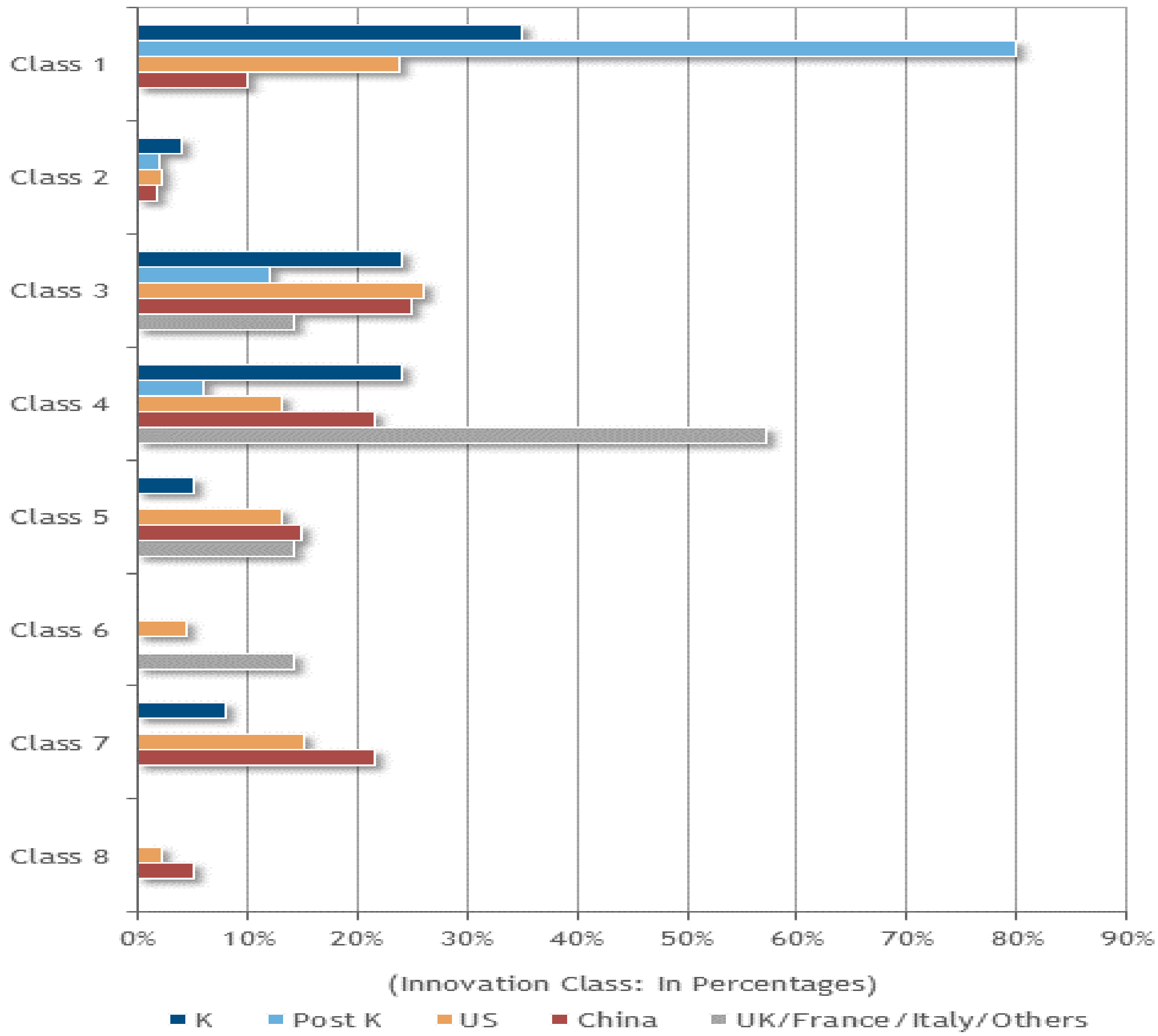
Source: IDC 2016

Figure 8 shows Japan's large advantage over the rest of the world, and China when it comes to HPC-enabled scientific innovation. Using the IDC innovation class ratings, Japan has two times the ratio of Class 1 innovations compared to the USA, and over five times China. Japan's rating using the IDC innovation class scale are truly impressive.

Japan's rating using the IDC innovation class scale are truly impressive.

FIGURE 8

Japan Compared to the Rest of the World: Overall Innovation Class Ratings



Source: IDC 2016

Notes:

IDC analyzed the reasons why the ROR of the Post-K is particularly high:

- The K and Post-K computers are targeted at solving very important and Challenging problems.
- The project is designed to provide leadership capabilities to researchers -- as a unified project with hardware development, system development, and research utilization in order to continuously advance the computational science technology developed in K computer towards the Post-K computer.

Japan Compared to China in Leadership Computing

Japan has an HPC technical community, and an HPC scientific and industrial user base, that are much more experienced than their Chinese counterparts. For this reason, Japanese leadership-class supercomputers have been much more productive, and much better able to support advanced innovation, than supercomputers in China – even in cases where the Chinese computers rank higher on the Top 500 supercomputers list.

The results of this study shows how Japan is much better at getting value from its largest supercomputers when compared to China. Japanese HPC investments produced on average over 40% times more revenue than their Chinese counterparts and more than 35 times greater cost savings.

Where innovation is concerned, Japan also greatly outranks China. A much higher percentage of the Japanese innovations qualified in category 5, as one of the top 2 to 3 innovations of the last decade. Using the IDC innovation class ratings, Japan has over 8 times as many class 1 innovations compared to China.

Summary of Key Success Stories

From the K computer

- If the development of the genomic abnormality detection kit is successful, it will be sold at about 100,000 yen per kit. If 100 million people cancer patients were tested in one year, it would generate sales of 1,000 billion yen.
- The project lead to the development of a new drug for colorectal cancer.
- This simulation software enabled the possibility of re-opening nuclear power plants that are currently stopped or shut down. Maintaining shuttered nuclear power plants costs about 1.4 trillion yen annually in Japan and through this project, it may be possible to reduce a part of that overhead.
- It takes 35 million yen per cancer patients with the treatment of the drug Nivolumab. However, because Nivolumab is only effective in about 20% of patients, the development of a genomic abnormality screening/detection kit could save hundreds of billions of yen on unnecessary - and ineffective - use of the drug.
- Generally, the development of the new drug is costs about 100 billion yen leading up to clinical trials. That cost can be reduced about 90% through the use of advanced computer simulation.
- Advanced simulations can reduce by about 20 billion yen the combined cost for wind tunnel experiment per year, or about 1.8 billion yen per wind tunnel per year.

If the development of the genomic abnormality detection kit is successful, it will be sold at about 100,000 yen per kit. If 100 million people cancer patients were tested in one year, it would generate sales of 1,000 billion yen.

Possible from the Post-K computer

- Overall drug development costs could be reduced by about 20 billion yen per drug.
- Development of advanced gasification furnaces with reduced emissions of carbon dioxide, could result in saving of about 81 billion yen in five years.
- In order to create a newly designed aircraft it typically takes five prototype models. In the case of MRJ, flight test costs were about 100 billion yen. With a new HPC, it may be possible to reduce that cost to about 80 billion yen by needing only one aircraft prototype.
- If they succeed to develop new drug, annual sales will be over 100 billion yen and it will help to reduce national health care budget.
- When the gasification furnace is realized, the construction costs will be over 140 billion yen per power plant. For five power plants the sales will be around 700 billion yen.

Selected Mini-Case Studies of Successful K computer Projects

Case Study #1 Research Area: Biology, Precision Medicine

Research Institution: University of Kyoto, Graduate School of Medicine, Department of Pathology and Tumor Biology

What the Project Accomplished: Emerging evidence of dramatic effects of immune-checkpoint blockade in many advanced cancer patients is highlighting the importance of cancer immune evasion, which is expected to be a plausible target for the development of novel cancer therapy. However, the exact mechanism of cancer immune evasion has not fully been elucidated, the understanding of which is thus one of the important issues for the development of cancer immune therapy. In the current post-K computer, we analyzed a large amount of sequencing data from more than 10,000 cancer samples using the post-K computer and successfully identified a novel mechanism by which cancer cells escape immunity. In some cancers, abnormalities of the PD-L1 gene lead to markedly elevated expression of PD-L1, through which cancer cells effectively escape anti-cancer immunity. The finding is drawing an increasing attention in the field of cancer immunity. This study has been enabled only through high-throughput computing of cancer sequencing data using the post-K computer.

How the Project Helped the World: Although found in less than 1% of all cancer patients, the relevant abnormality of PD-L1 is thought to be affecting dozens of thousands of patients overall. Because immune-checkpoint blockade is expected to be especially effective to the cancers having this abnormality, an effective use of costly immune-checkpoint antibodies will be enabled by targeting this abnormality to find those patients in whom a promising response to these antibodies is expected.

Case Study #2 Research Area: Computer Drug Discovery

Research Institution: Kyoto University, Graduate School of Medicine, Department of Biomedical Data Intelligence

What the Project Accomplished: Researcher expanded their capabilities in computational drug discovery, offering up significant saving and opening up new avenues of drug discovery research.

The pharmaceutical industry is facing soaring drug development costs and increasing difficulties with new drug discovery. The use of advanced simulations is critical to the development of innovative research methods that underwrite such drug discovery. For example, calculating the strength of the bond between the proteins for 150 amino compounds that would require more than 20 years on a general purpose machine, now takes only about a week on the K computer. Researchers estimate that computationally-based drug discovery could reduce costs by 20 billion yen for a single drug development

How the Project Helped the World: Researchers indicated that the value of the K computer is more than just its use as a flagship system with world-class computing capabilities, but that it also serves as a driver of open innovation and human resource development.

Case Study #3 Research Area: Computational Multiphysics Heart Simulation

Research Institution: University of Tokyo/UT-Heart Inc.

What the Project Accomplished: Researchers developed a multi-scale multi-physics heart simulator. The K computer supported development of a multiscale heart simulation fusing molecular and organ scales -- allowing researchers to demonstrate the effectiveness of the new simulation in clinical applications to help model patient-specific outcomes from heart surgery as well as to guide physicians' strategies on post-operative care.

How the Project Helped the World: Based on these efforts, researchers will now be better able to craft patient-specific procedures for the treatment of heart failure, as well as be able to more effectively screen for drugs that do not cause harmful, or even fatal, side effects..

Case Study #4 Research Area: Quantum Hadron Physics/Lattice QCD

Research Institution: RIKEN, Nishina Center for Accelerator-Based Science, Quantum Hadron Physics Laboratory

What the Project Accomplished: Researchers expanded the bounds of understanding on the microscopic structure of the atomic nuclei on the basis of the large scale numerical simulations of nuclear forces with elementary particles. Such a computationally intensive research effort was not possible without the computer capabilities of a K-class supercomputer.

How the Project Helped the World: The result not only extended the understanding of particle and nuclear physics, but also can be applied to wider fields such as astrophysics, so that it shed new light on the origin of matter in the Universe.

Case Study #5 Research Area: Molecular Science

Research Institution: Nagoya University, Graduate School of Engineering, Department of Applied Chemistry

What the Project Accomplished: Researchers developed a high-resolution model of both the poliovirus and hepatoma B virus in solution consisting of up to 10 million atoms in order to clarify the nature of the virus and establish a knowledge foundation that can significantly contribute to the development of more effective antiviral agents.

How the Project Helped the World: With high resolution models enabled by the availability of a K class supercomputer, researchers were able to establish a method which enables complete simulations of HIV and influenza virus structure across a number of time steps, offering the promise of improved viral research well beyond the capabilities achievable through traditional experimental studies.

Case Study #6 Research Area: Solid-Liquid Interface Of Lithium-Ion Batteries

Research Institution: National Institute of Material Science, Center for Green Research on Energy and Environmental Materials (GREEN), Interface Computational Science Group

What the Project Accomplished: High-precision first-principles calculations of electrode-electrolyte interface in Lithium-ion battery. Researchers demonstrated the structures and properties of the interface films at high resolution. The outputs will give an important insight into the control of the battery performance and reliability.

How the Project Helped the World: These microscopic understandings play crucial roles not only for the progress of fundamental electrochemistry but also for new breakthroughs in battery technology, which will strengthen industrial competitiveness in Japan.

Case Study #7 Research Area: Multi-Physics Simulation for Energy

Research Institution: University of Tokyo, School of Engineering, Department of System Innovation

What the Project Accomplished: Researchers used the computational capabilities of the K computers to develop a coal gasifier furnace simulation package that can analyze the complex coupled analysis of the multi-physics gasification process, allowing for the optimization of furnace design and subsequent operating conditions. This can result in the development of more efficient, cleaner-burning gas furnaces that through the reduction in released carbon dioxide emissions could realize a total domestic cost savings of over 80 billion yen in five years.

Potential Returns:

- Revenues (sales) -- When the gasification furnace is realized, the construction revenue will be over 140 billion yen per power plant. If in five years 5 power plants are built, revenues could reach 700 billion yen in sales.

How the Project Helped the World: The availability of the gasifier simulation software could have wide spread influence on the manufacturer of the gasifier used in electric power plants around the world that would be able to provide cleaner and cheaper coal-produced energy.

Case Study #8 Research Area: Computational Material Science

Research Institution: National Institute of Material Science, International Center for Materials Nanoarchitectonics

What the Project Accomplished: The researchers developed an advanced first-principle molecular dynamics package that supports better process analysis on next-generation semiconductor device necessary to the development of the higher performance and lower power consumption. The use of the K computer enabled the developers to explore beyond the traditional simulations that encompassed a limited model verified by experimental results and instead explore complete simulations of the true physical phenomenon.

How the Project Helped the World: New insights gained from the effort, along with the resulting software, will greatly assist researchers across a number of material science disciplines.

Case Study #9, Research Area: Weather Research

Research Institution: University of Tokyo, Atmosphere and Ocean Research Institute, Center for Earth Surface System Dynamics, Atmosphere and Ocean Research Section

What the Project Accomplished: Researchers for the first time were able to conduct long-term simulations of more than 30 years at high resolution to support near future predictions of typhoons.

How the Project Helped the World: The accuracy of predicting future changes of typhoons was greatly improved, so it now becomes possible to obtain important information such as area information where potential damage can be expected, so that it become possible to improve evacuation plans, etc.

Case Study #10 Research Area: Mesoscale (Intermediate) Research

Research Institution: Meteorological Research Institute

What the Project Accomplished: This study demonstrated the plausibility of an ultra-high precision mesoscale weather forecast that can improve the lead time required for implementing countermeasures prior to the occurrence of severe weather events. Because most severe weather phenomena that leads to a disaster are related to cumulonimbus, researchers developed prediction methods based on the cloud resolving model which can express the cumulonimbus clouds more accurately. To increase the value of the weather prediction, it is important to quantitatively estimate the forecast error due to uncertainty of the initial condition or the numerical model. These research improvements were first realized by using the K-computer.

How the Project Helped the World: Better and more reliable prediction of hazardous weathers can provide targeted information to take effective countermeasures to reduce both property damage and human causalities.

Case Study #11 Research Area: Mathematical Data Assimilation

Research Institution: University of Tokyo, Earthquake Research Institute, Division of Disaster Mitigation Science

What the Project Accomplished: Researchers developed a simultaneous simulation technique for earthquake ground motion and tsunami. With the use of the available data from ocean bottom tsunami cable recording system recently deployed across the Pacific Ocean, an efficient data analysis technique to understand the earthquake fault movement and the cause of strong ground motion and tsunami was achieved by the K computer.

How the Project Helped the World: The clarification of the cause of huge tsunami from the off the 2011 Pacific coast of Tohoku earthquake significantly improved the prediction accuracy of strong ground motion and tsunami expecting for the Nankai trough earthquake, leading to a realistic earthquake disaster prevention plan based on highly reliable simulations.

Case Study #12 Research Area: Automotive Aerodynamic Simulation

Research Institution: Kobe University, Graduate School of System Informatics, Department of Computational Science, Computational Fluid Dynamics Laboratory & RIKEN, Advanced Institute for Computational Science, Research Division, Complex Phenomena Unified Simulation Research Team.

What the Project Accomplished: Researchers developed an advanced digital automotive wind tunnel, that that can reduce costly wind tunnel testing in the design of new vehicles by a total of about 20 billion yen for all wind tunnel experiments or 1.8 billion yen per wind tunnel per year within Japan alone.

How the Project Helped the World: This project could help the Japanese car industry compete more effectively in a wider international market with more efficient, lower cost, and more reliable cars.

CONCLUSION

The K computer Has Been A Major Success

- This study confirmed that many Japanese researchers have benefitted greatly from using the K computer and are ready to advance their work and tackle even more challenging problems on a more powerful Post-K computer.
- We are firmly convinced that developing a more powerful successor to the K computer is well worth the investment.
- The K computer has demonstrated that leadership-class supercomputers can produce returns far in excess of the amounts needed to fund them—and confirms that without competitive leadership-class computers, considerable scientific competitiveness would be lost.

Impact on Japanese Researchers of Not Having Post-K computer

- Almost all surveyed HPC experts involved with the K computer were emphatic that a transition back to the use of regular clusters would deeply harm, and in some cases shut down, their current research activities.
  - Many stated that they would have to abandon their current efforts because the jobs that are now critical to their research agendas would take too long, be too complex, or have too much data to execute effectively in a regular cluster or cloud environment.
- Researchers stressed that such a transition would cause a loss of capability vis-a-vis foreign counterpart research efforts.

How Post-K computer Stands Out Among Leadership Projects Around the World

- The results of this study shows how Japan is much better at getting value from its largest supercomputers when compared to the rest of the world.
- Where innovation is concerned, Japan also greatly outranks most other countries.
  - A much higher percentage of the Japanese innovations qualified as Class 1 innovations.
  - Using the IDC innovation class ratings, Japan has over 8 times as many class 1 innovations compared to China.

Plans and Expectations for the Post-K computer

This section describes how Japanese users of the K computer plan or expect to use a more powerful successor supercomputer (called the Post-Km supercomputer).

Planned Areas of Research on the Post-K supercomputer

Japanese researchers surveyed for this study have high expectations for a new Post-K class supercomputer that spans a wide range of scientific disciplines, academic areas and industrial applications. Areas of noted interest included but were not limited to:

- Energy issues, including solar cells, batteries, and coal gasifier furnaces,
- Materials studies including high temperature superconductors
- Earth studies including magnetic field and global climate modeling
- Astrophysics including the coalescence of supernova explosions and neutron star binary star models in both long-term and high resolution
- Medical studies including multiphysics heart simulation, cancer drugs, precision medicine,
- Simulation techniques including quantum Monte Carlo techniques, molecular dynamics simulation, fluid dynamics for aircraft simulation, and social simulation.

Example Post-K computer Projects:

- Application of the tailor-made medical care with heart simulator
- Applied to the development of the fuel cell of the functional analysis approach in the composite material
- Building materials database
- Continue to develop RSDFT software for The scale, precision and time axes. Finally develop Device Simulator and Process Simulator.
- Control of solar cells of non-equilibrium state
- Control of the topological insulator
- Development of battery simulator
- Development of Coal Gasifier Furnace Simulation software
- Development of MACE (Multi-scale Ab initio scheme for Correlated Electrons) software
- Development of Next Generation of Multi-Scale Multi-Physics Heart Simulator
- Development of photosynthesis simulator
- Development of the innovative drug Discovery Infrastructure by the function control of the biological molecule system
- Elucidation of the drug-resistant mechanism of the non-small cell lung cancer therapeutic drug
- Elucidation of the nanowire properties and boundary surface structure
- Establishment of material design approach
- High accuracy of the data assimilation of the global model
- High temperature superconductors simulation of copper oxide
- Precision medicine. Such as the development of biomarkers and companion reagents.
- Improve Functionality of MODYLAS

- Improvement of the quantum Monte Carlo method program
- Calculation of the force acting between elementary particles. Determination the baryon force in the world's highest accuracy in lattice QCD calculations. Such simulations will be used to simulate the celestial phenomenon of coalescence of supernova explosions and neutron star binary star in the long-term and high resolution.
- It takes between 3-4 days in the current K computer for single simulation. Because going to be the one hundred-fold performance in "post-K", it is possible to run hundred cases in about one week.
- Molecular dynamics calculations in the high-temperature and high-pressure
- NTChem continued development
- Social Simulation
- The development of multi-scale thermoplastic CFRP molding simulator
- The development of traffic-related simulator
- The FF-VHC, which has been developed to study the era of development K computer of the core technology to realize the design and operational techniques of aircraft to develop the FF-VHC-COMP for high-speed fluid.
- The magnetic field simulation in K computer is not considered, by considering the magnetic field in the post-K, different outcomes to a new qualitative expected.
- Transition temperature change simulation
- A six-dimensional simulation with good accuracy which can reproduce Phenomenon by observation

Summary of the Expected Financial ROI Results from the Post-K computer

This study confirms that the current K computer has contributed greatly to the advancement of science and industry in Japan—the study quantified these contributions in the form of financial ROI and innovations. IDC also asked the study respondents how they might exploit a substantially more powerful Post-K computer. As the lists in the preceding section of this report indicate, nearly all of the respondents described specific projects a more powerful Post-K computer would enable them to pursue. Based on these responses, IDC is confident that a Post-K computer would be heavily utilized by researchers from a broad spectrum of disciplines, and that a Post-K computer would enable financial ROI results at least as impressive as those Japanese researchers have achieved using the current K computer.

From just these projects, the value of the K computer exceeds $9 billion (in revenues and cost savings), and $10 billion for the Post-K computer.

From just these projects, the value of the K computer exceeds $9 billion (in revenues and cost savings), and $10 billion for the Post-K computer.

For the Japanese ROI accomplishments collected in this study, the overall financial return on investment averaged an extremely strong $423 dollars in revenue per dollar invested in HPC (for the K and Post-K computers combined). On average these projects generated cost savings of an extremely high amount of $251 dollars in cost savings per dollar invested in HPC.

The total revenues generated from this sample of research projects on the K computer was very strong at over $2.6 billion, and extremely strong for the Post-K computer at over $5 billion dollars. In addition, the cost savings were equally impressive, at over $6.9 billion with the K computer and $5 billion planned for the Post-K computer. Note that the actual amounts are much higher, as this is only a subset of the projects on these systems.

Planned Innovation ROR (Return on Research) Results from the Post-K computer

Given the long list of non-financial innovation projects provided to IDC by K computer users, it is equally reasonable to assume that a Post-K computer would enable many further innovations of equal importance for Japanese science, Japanese industry, and Japanese society. Some of these innovations would be based on a continuation of researchers' work that would not be possible without a computer more powerful than the current K computer. Other innovative work could not be started on the K computer and would only become feasible on a more powerful Post-K computer.

How the Post-K computer Compares to Leadership Projects around the World

IDC has closely tracked global HPC technology and market developments for more than 25 years. We believe that today, the U.S. and Japan have the strongest experience and qualifications for developing future leadership-class supercomputers that are capable of effectively supporting a broad range of the most challenging scientific and industrial problems.

The results of this study shows how Japan is much better at getting value from its largest supercomputers when compared to the rest of the world. Where innovation is concerned, Japan also greatly outranks most other countries. A much higher percentage of the Japanese innovations qualified as Class 1 innovations. Using the IDC innovation class ratings, Japan has over 8 times as many class 1 innovations compared to China.

Here is how IDC views countries/regions that are pursuing exascale computing:

- The United States has exceptional technical skills for achieving this goal and will almost surely do so by 2023-2024 (sustained exaflop).
- Japan has a comparable high level of skills for achieving this important goal, but the Japanese government's willingness to fund this effort is uncertain.
- The European Union is determined to be a strong contender in the exascale race, because it recognizes HPC's key role for scientific and economic competitiveness, but the EU has no clear path yet for enabling the 28 member states to pool money for this effort.
- China's government seems certain to fund exascale development in order to continue China's claim to having the world's faster supercomputer, so funding should not be an issue. But China does not yet have the high level of technical skills needed to produce an exascale computer that can support a wide range of scientific and industrial problems.

Japan's advantages in the exascale race include the following:

- A long history of developing and using highly innovative, leadership-class supercomputers in a wide variety of scientific and industrial domains
- Strong, mature HPC vendor and user communities
- Holistic skills that span hardware, system software, applications software, storage, and technical support.

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APPENDIX

Participants In The Survey

Table 13

Survey Participants

Name	Organization
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Hiromu Seko	Meteological Research Institute
Jun Igarashi	RIKEN, Advanced Center for Computing and Communication, Computational Engineering Application Unit
Junichiro Makino	RIKEN AICS, Exascale Computing Project, Co-Design Team
Kazuo Saito	Meteological Research Institute
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Koji Otsuka	University of Tokyo,
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Masaru Shibata	University of Kyoto, Yukawa Institute for Theoretical Physics
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Survey Participants

Name	Organization
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Takamasa Iryo	Kobe University, Graduate School of Civil Engineering
Takashi Furumura	University of Tokyo, Earthquake Research Institute, Division of Disaster Mitigation Science
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Tsuyoshi Miyazaki	National Institute of Material Science, Nano-Theory Field, First Principles Simulation Group
Wataru Shinoda	Nagoya University, Graduate School of Engineering, Department of Applied Chemistry
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Yuichi Otsuka	RIKEN AICS, Computational Materials Science Research Team
Yuji Sugita	RIKEN, Theoretical Molecular Science Laboratory

Source: IDC 2016

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