SC20 Virtual Market Update

November 2020

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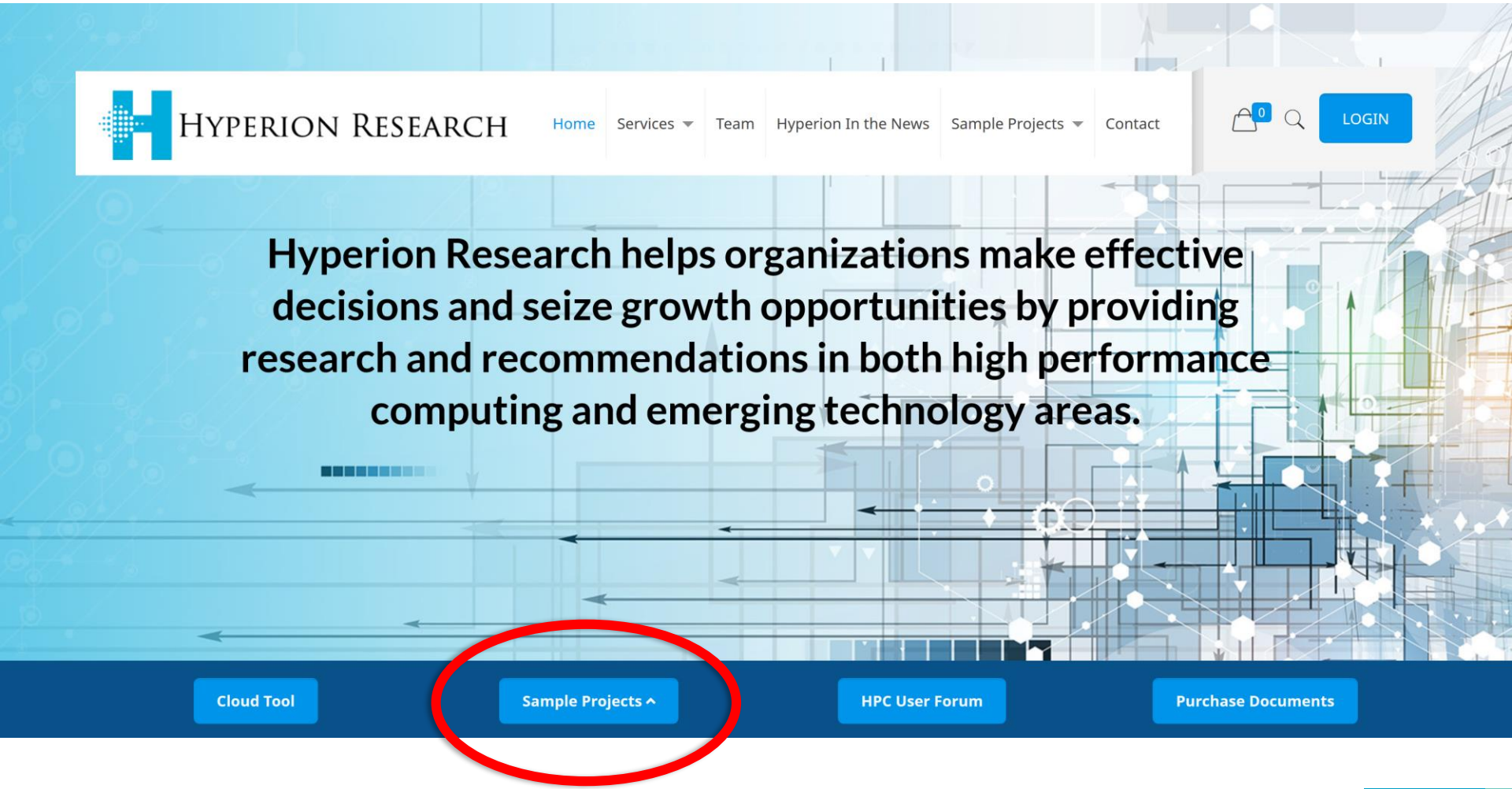

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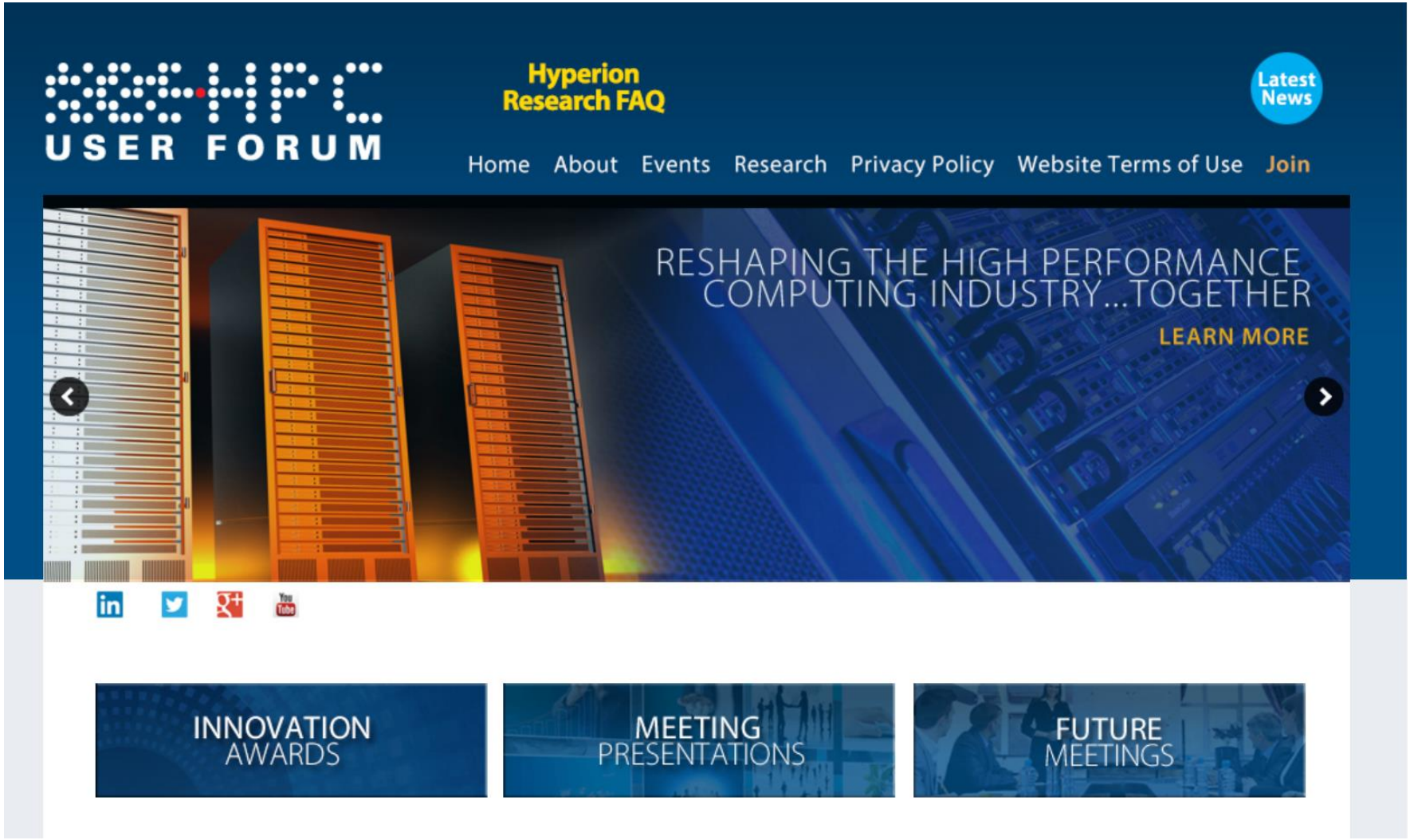
Hyperion Research HPC Activities

(www.HyperionResearch.com & www.HPCUserForum.com)

- **Track all HPC servers sold each quarter worldwide and by 28 countries**
- **4 HPC User Forum meetings each year**
- **Publish 85+ research reports each year**
- **Visit all major supercomputer sites & write reports**
- **Assist in collaborations between buyers and vendors**
- **Assist governments in HPC plans & strategies**
- **Maintain 5-year forecasts in many areas/topics**
- **Track the ROI from HPC**
- **AI, ML, DL & HPDA tracking**
- **Track HPC cloud spending and usage**
- **Future architectures and technologies**
- **Quantum computing**

The HPC User Forum:
www.hpcuserforum.com



SC20 HPC Market Results, And New Forecasts

November 2020

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Earl Joseph

Covid-19's Impact on the HPC Market

Major shipment delays

Based on developments to date and discussions with HPC vendors around the globe, we believe several impacts are affecting the market:

- ***Delayed product shipments.*** HPC vendors report that worker illnesses and related precautions reduced output and temporarily shut down some factories at HPC component suppliers, especially in Q1 2020
- ***Delayed revenues*.** Delayed product shipments have resulted in delayed revenues. However, most vendors expect customers to spend their annual HPC budgets once the covid-19 threat subsides

Covid-19's Impact on the HPC Market

Now forecasting a decline of ~14% for 2020

- ***Delayed orders.*** Vendors' inability to meet customers and prospects in person or to attend sales-supporting conferences and industry meetings have reduced the new business pipeline temporarily
  - The lower end of the market is likely to have a number of difficult years (under $100K HPC servers)
- ***Potential growth areas:***
  - *New HPC demand to combat covid-19*
  - *Public cloud computing for HPC workloads may grow faster than previously predicted*
- ***The net for the first half of 2020 was a decline of 11.5%***

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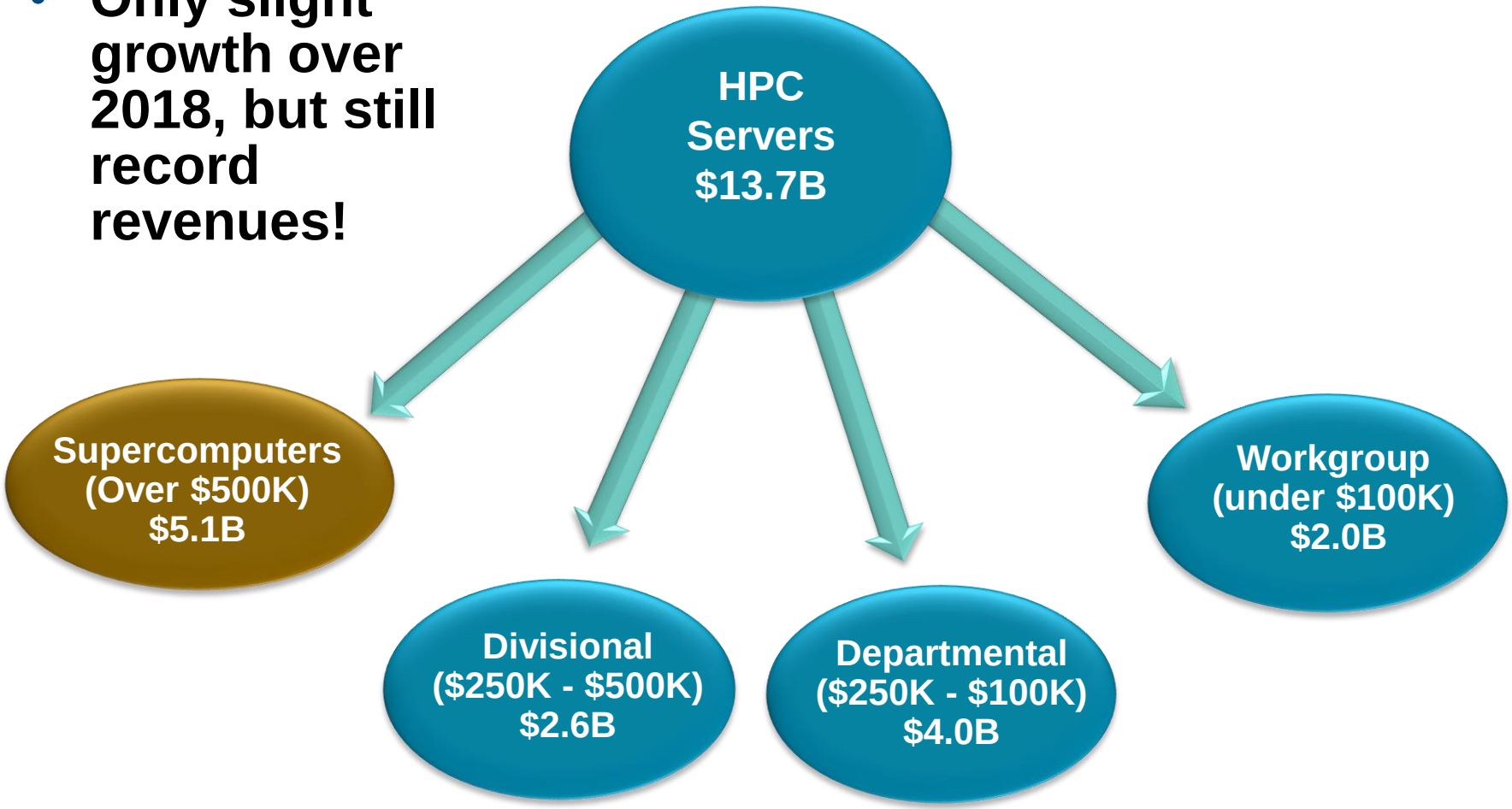
2019 Market Results

The 2019 Worldwide On-Prem HPC Server Market: $13.7 Billion

- **Only slight growth over 2018, but still record revenues!**



2019 HPC Market By Verticals ($ Millions)

	2019
Bio-Sciences	$1,457
CAE	$1,721
Chemical Engineering	$170
DCC & Distribution	$825
Economics/Financial	$710
EDA / IT / ISV	$822
Geosciences	$969
Mechanical Design	$052
Defense	$1,472
Government Lab	$2,418
University/Academic	$2,301
Weather	$639
Other	$155
Total Revenue	$13,710

Source: Hyperion Research, November 2020

Worldwide HPC Vendor Server Market Shares 2018 & 2019 ($ Millions)

($M)	2018	2019		2019 Shares
HPE	4,766	5,095		37.2%
Dell Technologies	2,833	3,012		22.0%
Lenovo	957	891		6.5%
Inspur	781	860		6.3%
IBM	970	498		3.6%
Sugon	462	442		3.2%
Atos	270	398		2.9%
Fujitsu	269	295		2.1%
Penguin	244	249		1.8%
NEC	201	216		1.6%
Cray	313	106		0.8%
Other	1,612	1,650		12.0%
Total	13,679	13,710		
Source: Hyperion Research, November 2020				

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Updated On-Prem HPC Forecasts

HPC On-Prem Server Forecast
($millions)

The overall CAGR is now 6.8%, down from 8.7%

- **2020 is projected to decline by ~14%**
  - We are now adjusting the forecasts quarterly
- **The market will be down by ~$1.8 billion in 2024**

New HPC Forecasts Compared to Previous Forecasts ($M)							
($M)	2019	2020	2021	2022	2023	2024	CAGR 19-24
November 2020 Forecast (with covid impacts)	13,710	11,846	13,295	15,817	17,942	19,044	6.8%
July 2020 Forecast (with covid impacts)	13,710	10,860	12,313	14,793	16,810	18,262	5.9%
May 2020 Forecast	13,710	14,484	15,658	18,457	19,940	20,844	8.7%
Source: Hyperion Research, November 2020							

HPC On-Prem Server Forecast By Competitive Segment ($millions)

Workgroup segment is impacted the most (0.4% CAGR)

Updated HPC On-Prem Server Forecast By Competitive Segments (November 2020) $M							
($M)	2019	2020	2021	2022	2023	2024	CAGR 19-24
Supercomputer	5,741	5,050	6,215	7,185	8,554	9,375	10.3%
Divisional	1,916	1,685	1,863	2,322	2,560	2,682	7.0%
Departmental	4,236	3,583	3,669	4,526	4,946	5,132	3.9%
Workgroup	1,817	1,528	1,548	1,785	1,882	1,856	0.4%
Total	13,710	11,846	13,295	15,817	17,942	19,044	6.8%
Source: Hyperion Research, November 2020							

The Exascale Market (System Acceptances)

~30 systems and over $10 billion in value

Exascale and Near-Exascale Systems (2021 to 2026)							
28 - 38 Systems, ~$10-$15B in Value							
Year Accepted	**China**	**EU & UK**	**Japan**	**US**	**Other Countries***	**Total Systems**	**Total Value**
2021	1 or 2 near-exascale systems ~$400M each	1 pre-exascale system ~$150M	1 exascale system Fugaku ~$1B	--	--	3-4	$1.6B-$2.0B
2022	1 or 2 exascale systems ~$350M - $400M each	2 pre-exascale systems ~$150M each	1 near-exascale system ~$200M	2 exascale systems ~$550M each	--	6-7	$2.0B-$2.4B
2023	1 or 2 exascale system ~$350M - $400M each	1 or 2 exascale systems ~$375M	1 near-exascale system ~$150M	1 exascale system ~600M	--	4-6	$1.5B-$2.3B
2024	1 exascale system ~$350M - $400M each	1 or 2 exascale systems ~$375M	?	1 or 2 exascale systems ~$500M each	1 exascale system ~$250M	4-6	$1.5B-$2.4B
2025	2 exascale systems ~$350M - $400M each	1 exascale systems ~$375M	1 exascale system ~$150M	1 or 2 exascale systems ~$500M each	1 exascale system ~$200M	6-7	$1.9B-$2.5B
2026	1 or 2 exascale systems ~$350M - $400M each	1 or 2 exascale systems ~$375M each	?	2 exascale systems ~$500M each	1 or 2 exascale systems ~$200M each	5-8	$2.0B-$3.0B
Total	**7-11**	**7-10**	**4+**	**7-9**	**3-4**	**28-38**	**$10B-$15B**

- S. Korea, Singapore, Australia, Russia, Canada, India, Israel, Saudi Arabia, etc.

Source: Hyperion Research, July 2020

On-Prem Forecasts For The Broader Market Areas ($millions)

Storage is expected to grow the most at 8.3%

Revenues by the Broader HPC Market Areas							
($M)	2019	2020	2021	2022	2023	2024	CAGR 19-24
Server	$13,710	$11,846	$13,295	$15,817	$17,942	$19,044	6.8%
Storage	$5,427	$4,772	$5,410	$6,519	$7,577	$8,099	8.3%
Middleware	$1,613	$1,402	$1,576	$1,902	$2,171	$2,317	7.5%
Applications	$4,689	$4,062	$4,455	$5,258	$5,862	$6,111	5.4%
Service	$2,239	$1,899	$2,040	$2,366	$2,587	$2,643	3.4%
Total Revenue	$27,678	$23,981	$26,774	$31,862	$36,138	$38,214	6.7%

Source: Hyperion Research, November 2020

HPC On-Prem Server Forecast By Application Area ($millions)

The overall CAGR is now 6.8%, down from 8.7%

	2019	2020	2021	2022	2023	2024	CAGR 19-24
Bio-Sciences	$1,457	$1,239	$1,226	$1,536	$1,739	$1,850	4.9%
CAE	$1,721	$1,468	$1,492	$1,859	$2,110	$2,242	5.4%
Chemical Engineering	$170	$145	$154	$185	$209	$220	5.2%
DCC & Distribution	$825	$696	$681	$857	$970	$1,017	4.3%
Economics/Financial	$710	$608	$623	$818	$924	$972	6.5%
EDA / IT / ISV	$822	$702	$696	$918	$1,037	$1,091	5.8%
Geosciences	$969	$815	$843	$1,010	$1,151	$1,231	4.9%
Mechanical Design	$052	$044	$049	$057	$065	$068	5.6%
Defense	$1,472	$1,284	$1,317	$1,692	$1,916	$2,027	6.6%
Government Lab	$2,418	$2,161	$3,352	$3,314	$3,759	$4,127	11.3%
University/Academic	$2,301	$1,993	$2,141	$2,647	$2,981	$3,053	5.8%
Weather	$639	$553	$570	$724	$819	$866	6.3%
Other	$155	$139	$151	$202	$261	$279	12.5%
Total Revenue	**$13,710**	**$11,846**	**$13,295**	**$15,817**	**$17,942**	**$19,044**	**6.8%**

Source: Hyperion Research, November 2020

HPC Application Areas Definitions

Definitions of the Vertical/Application Segments	
Vertical/Application Area	Abbreviated Description
Biological sciences	Bioscience tasks e.g., genomics, proteomics, pharmaceutical research, bioinformatics, drug discovery
Chemical engineering	Chemistry applications not directly related to biosciences e.g., molecular modeling, computational chemistry, process design, chemical analysis
Computer-aided engineering (CAE)/manufacturing	Manufacturing workloads e.g., finite element analysis, mechanical computer-aided engineering, civil engineering, structural analysis, computation fluid dynamics (CFD)
Digital content creation and distribution (DCC&D)	Digital media tasks e.g., rendering, animation, video editing and production, high-end gaming servers
Economic and financial modeling	Economic analysis e.g., portfolio management, economic modeling, forecasting, financial analysis, back office trading analysis, insurance analysis
Electronic design and analysis/IT (EDA/IT)	Electrical/electronic tasks e.g., chip design, all forms of IT system design, ISV and software design, system modeling, system development and testing
Geosciences and geoengineering	Earth resources-related applications e.g., seismic analysis, oil services, reservoir modeling, mining, natural resource management, GIS, mapping, pollution modeling
Government laboratories and research centers	Government-funded research and development institutions that do not offer degree programs for students
Mechanical design	Mechanical design applications e.g., finite element analysis, mechanical computer-aided engineering, civil engineering, structural analysis, computation fluid dynamics
National defense	National security applications e.g., surveillance and signal processing, encryption, homeland security, military applications, C3I, geospatial, classified codes
University and academic	Scientific research and engineering efforts conducted at public or private institutes of higher education
Weather forecasting and climate modeling	Weather-related tasks e.g., atmospheric modeling, meteorology, weather forecasting, climate modeling
Other	Any technical computing workloads not otherwise specified by the previous definitions
Source: Hyperion Research, 2020	

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Key Buying Requirements For HPC

#1 = price/performance (for running their specific applications) and performance on their specific applications

Top Criteria For Next Purchase	
Price	83%
Application Performance	61%
Security	25%
Faster CPUs	25%
AI-Big Data Capabilities	22%
Interconnect Performance	16%
Quality	15%
Accelerators	14%
Storage	11%
Memory Bandwidth	10%
Compatibility with Current Systems	10%
Source of Open Source Software	4%
Other	3%
Source: Hyperion Research 2020	

Barriers For Buying More On-prem

#1 = budgets

Top Barriers to Expanding Purchases	
Financial barriers — budgets, system costs, other costs	81%
Power & cooling cost	43%
Space limitations	30%
Difficulties related to scaling/moving our work up to an HPC server	29%
Lack of knowledge, or skilled HPC/Technical computing support staff	25%
Lack of support by management	21%
Ease-of-use issues: e.g. lack of system management software	21%
3rd party applications costs	18%
Programming hurdles with hybrid environments	16%
Lack of application availability	7%
Other	9%
Source: Hyperion Research 2020	

SC20 Briefing: Using Clouds For HPC Workloads

November 17, 2020

www.HyperionResearch.com
www.hpcuserforum.com

Alex Norton and Mark Nossokoff

2020 HPC Cloud Forecast

HPC cloud spend projected to reach ~$9B by 2024

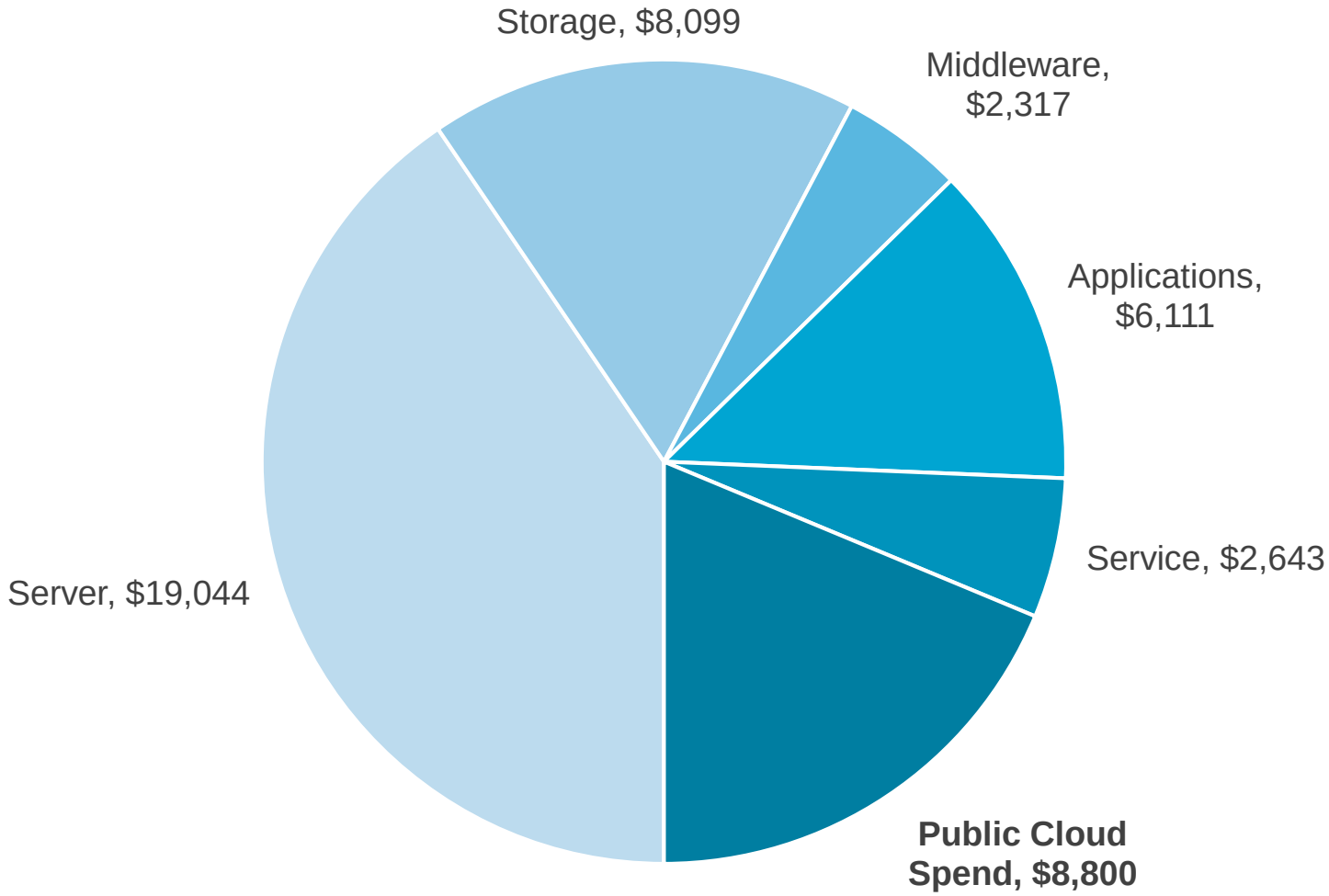
($M)	2018	2019	2020	2021	2022	2023	2024	CAGR '19-'24
NEW 2020 HPC Cloud Forecast	2,466	3,910	4,300	5,300	6,400	7,600	8,800	17.6%
2019 HPC Cloud Forecast	2,466	3,910	4,262	5,135	6,182	7,418	-	24.6%

- **This forecast includes covid-19 impacts, which has accelerated cloud adoption even more**
- **HPC in the cloud is expected to grow more than 2.5 times faster than the on-prem HPC server market**

This forecast is for public cloud computing, and is from the perspective of end-user spending in the cloud

2024 Total HPC Market with Cloud

Cloud spend brings 2024 HPC forecast to $47 billion

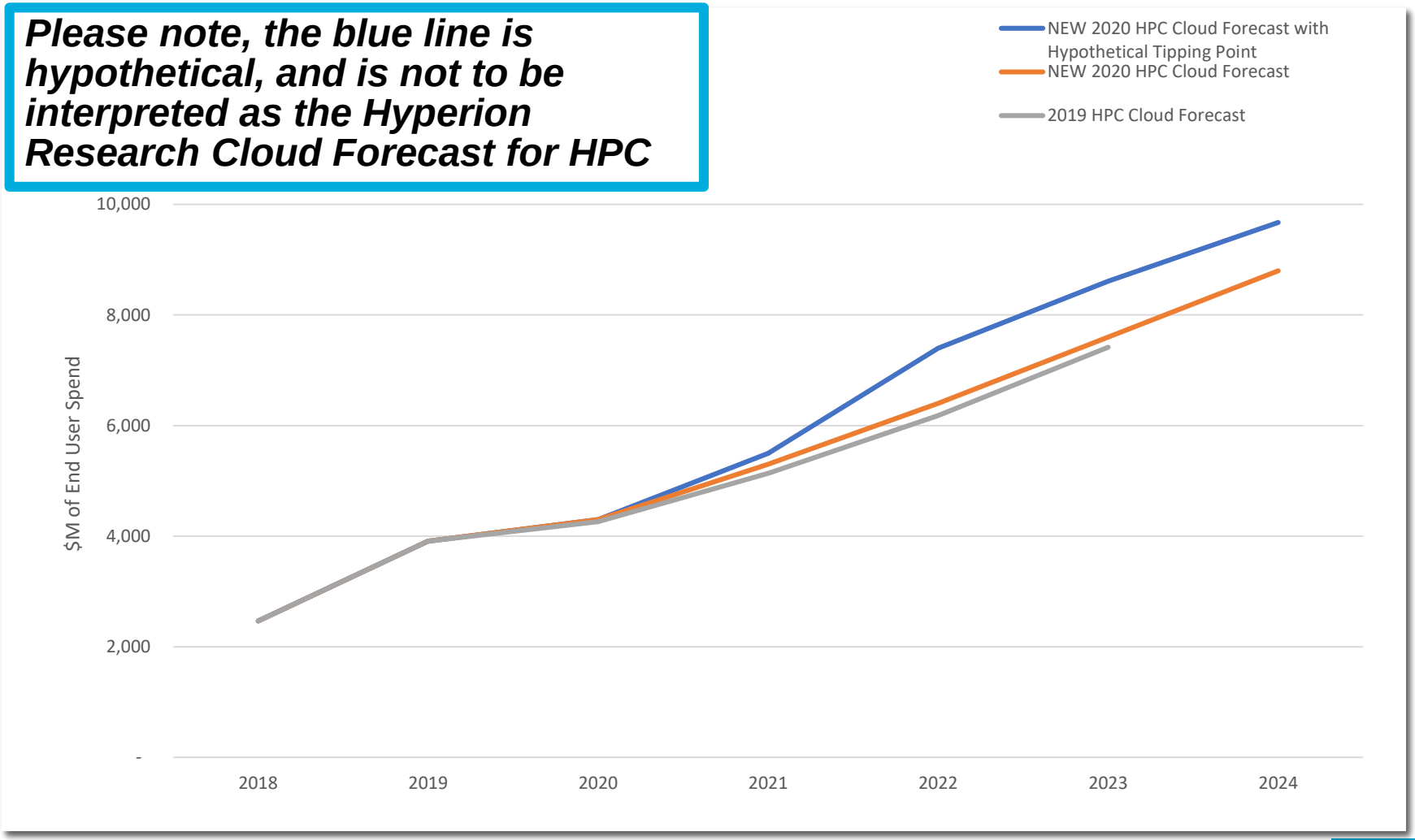


Note: All values are in millions

Cloud Forecast Scenarios

An example showing a potential new tipping point

Please note, the blue line is hypothetical, and is not to be interpreted as the Hyperion Research Cloud Forecast for HPC

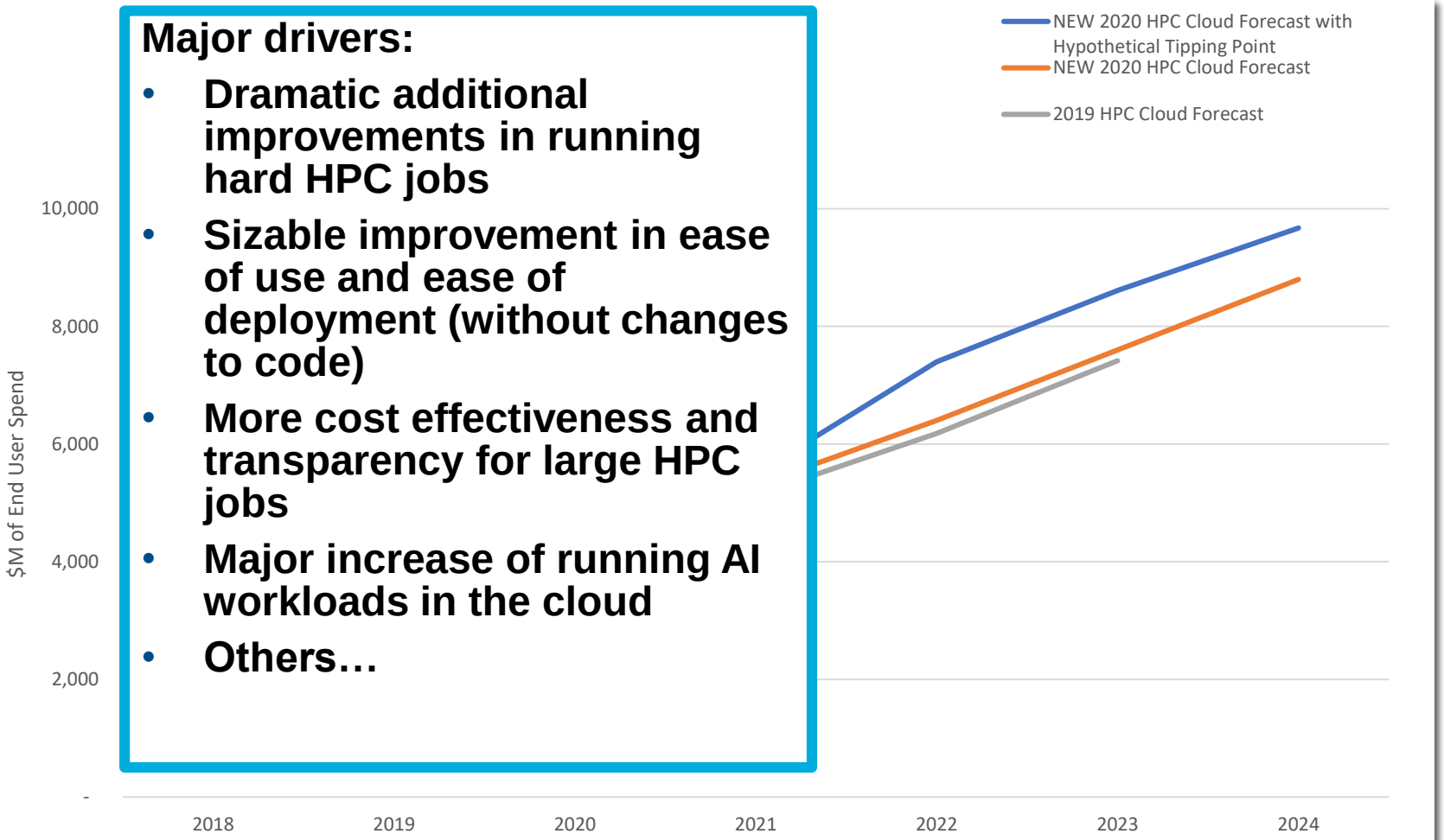


Cloud Forecast Scenarios

An example showing a potential new tipping point

Major drivers:

- **Dramatic additional improvements in running hard HPC jobs**
- **Sizable improvement in ease of use and ease of deployment (without changes to code)**
- **More cost effectiveness and transparency for large HPC jobs**
- **Major increase of running AI workloads in the cloud**
- **Others…**



Cloud Forecast by Vertical

Bio-sciences and CAE early cloud adopting verticals

($M)	2018	2019	2024	2019-2024 CAGR
Bio-Sciences	$778	$1,230	$2,453	14.8%
CAE	$469	$733	$1,540	16.0%
Chemical Engineering	$62	$98	$211	16.6%
DCC & Distribution	$141	$222	$519	18.5%
Economics/Financial	$123	$195	$430	17.2%
EDA	$178	$285	$677	18.9%
Geosciences	$148	$240	$660	22.4%
Mechanical Design	$12	$20	$44	17.5%
Defense	$185	$296	$705	18.9%
Government Lab	$173	$274	$625	17.9%
University/Academic	$123	$197	$528	21.8%
Weather	$26	$42	$220	39.0%
Other	$49	$79	$188	18.9%
Total	$2,466	$3,910	$8,800	17.6%

Vertical Spending Propensities

Fast cloud adopters separate from high on-prem revenue sectors

	Percent of 2019 HPC Cloud Spend	Percent of 2019 On-Prem Revenue
Bio-Sciences	31.4%	10.6%
CAE	18.7%	12.6%
Chemical Engineering	2.5%	1.2%
DCC & Distribution	5.7%	6.0%
Economics/Financial	5.0%	5.2%
EDA	7.3%	6.0%
Geosciences	6.1%	7.1%
Mechanical Design	0.5%	0.4%
Defense	7.6%	10.7%
Government Lab	7.0%	17.6%
University/Academic	5.0%	16.8%
Weather	1.1%	4.7%
Other	2.0%	1.1%
Total	100.0%	100.0%

Workgroup User Cloud Adoption

Sizeable adoption increase over past few years

- **Workgroup users (machines under $100k) never fully recovered from 2008 economic recession and have not recovered to growth rates consistent with rest of market**
- **Recent studies suggest that the slow growth in the workgroup segment is due, in part, to their increased spending in the cloud**
- **The value proposition of cloud for the lower end of the market, both based on economics and the global pandemic situation, will likely propel further workgroup cloud adoption for HPC**

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Potential Drivers for Increased Cloud Usage

New Drivers of Cloud Usage

Cloud cost-effectiveness increasing for some jobs

- **Cost has always been an issue, but as the cloud becomes more friendly to a wider set of HPC workloads, it has become more cost-effective to running certain workloads in cloud platforms**
- **A part of this cost analysis draws from characteristics of running workloads not tied to monetary cost, like:**
  - Queue times on-prem can be very long
  - Cloud platforms allow users to run workloads on a variety of hardware; some technologies are more efficient for a workload than on-prem deployments
  - Cloud platforms allow for scaling beyond what may be capable on-prem

AI-Cloud Adoption

Users run many HPC-enabled AI workloads in the cloud

- **Recent data suggests that the average HPC cloud user anticipates running 1/5 of their HPC-enabled AI workloads in the cloud in the next year**
- **This increase is due to:**
  - Access to hardware & software not available on-prem
  - Access to data stored or collected in the cloud
    - This includes public data sets stored in the cloud, IoT and other sensor data collected in the cloud, or simulation-generated data stored in the cloud

Storage and Interconnects SC20 Market Update

November 17, 2020

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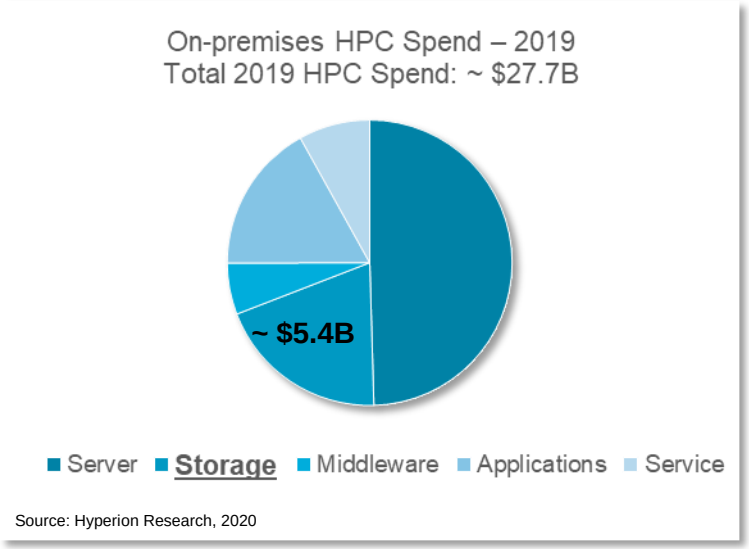
Mark Nossokoff

HPC Storage is an Attractive Market

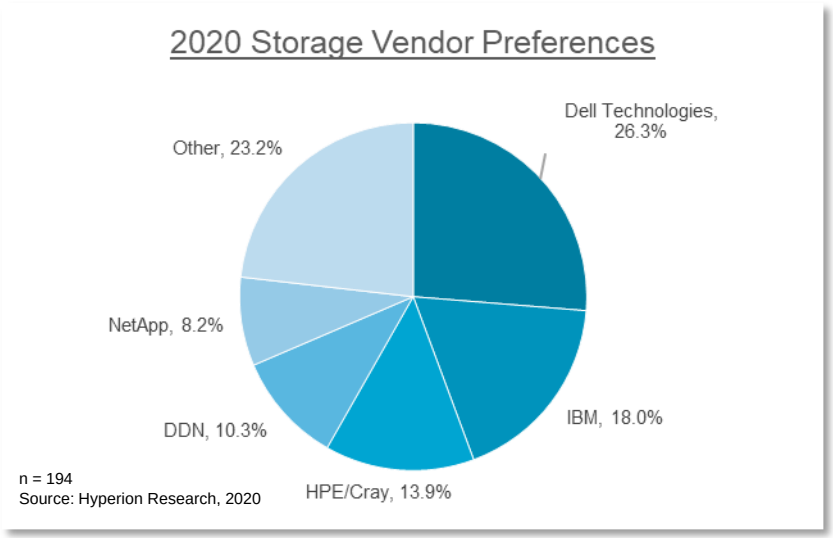


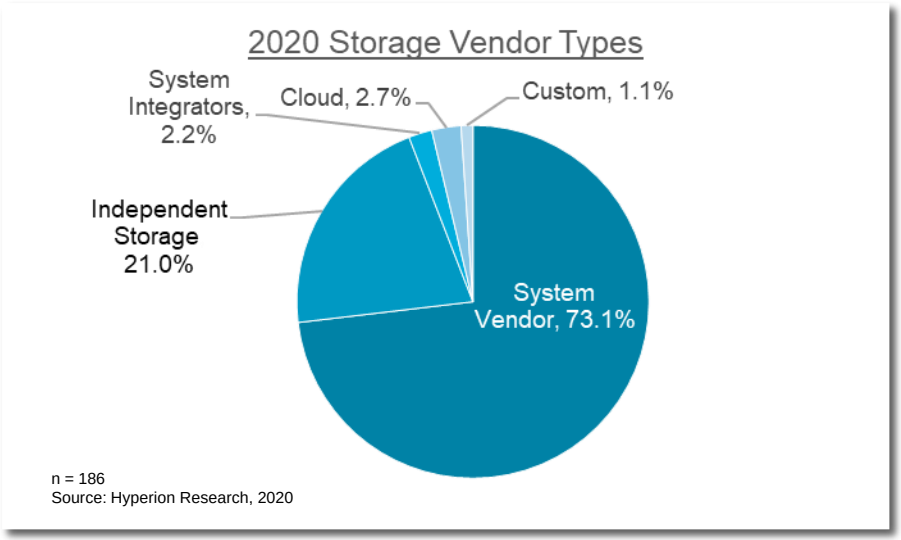
- **Storage historically the highest growth HPC element**
- **Storage represents ~ 20% of HPC spending**
- **For every $1 spent on compute, ~ $0.40 is spent on storage**

Area ($M)	2019	2020	2021	2022	2023	2024	CAGR '19-'24
Server	$13,710	$11,846	$13,295	$15,817	$17,942	$19,044	6.8%
Add-on Storage	**$5,427**	**$4,772**	**$5,410**	**$6,519**	**$7,577**	**$8,099**	**8.3%**
Middleware	$1,613	$1,402	$1576	$1,902	$2,171	$2,317	7.5%
Applications	$4,689	$4,062	$4,455	$5,248	$5,862	$6,111	5.4%
Service	$2,239	$1,899	$2,040	$2,366	$2,587	$2,643	3.4%
Total Revenue	$27,678	$23,981	$26,774	$31,862	$36,138	$38,214	6.7%

2020 HPC Storage Vendor Preferences

Dell Technologies top preferred HPC storage vendor

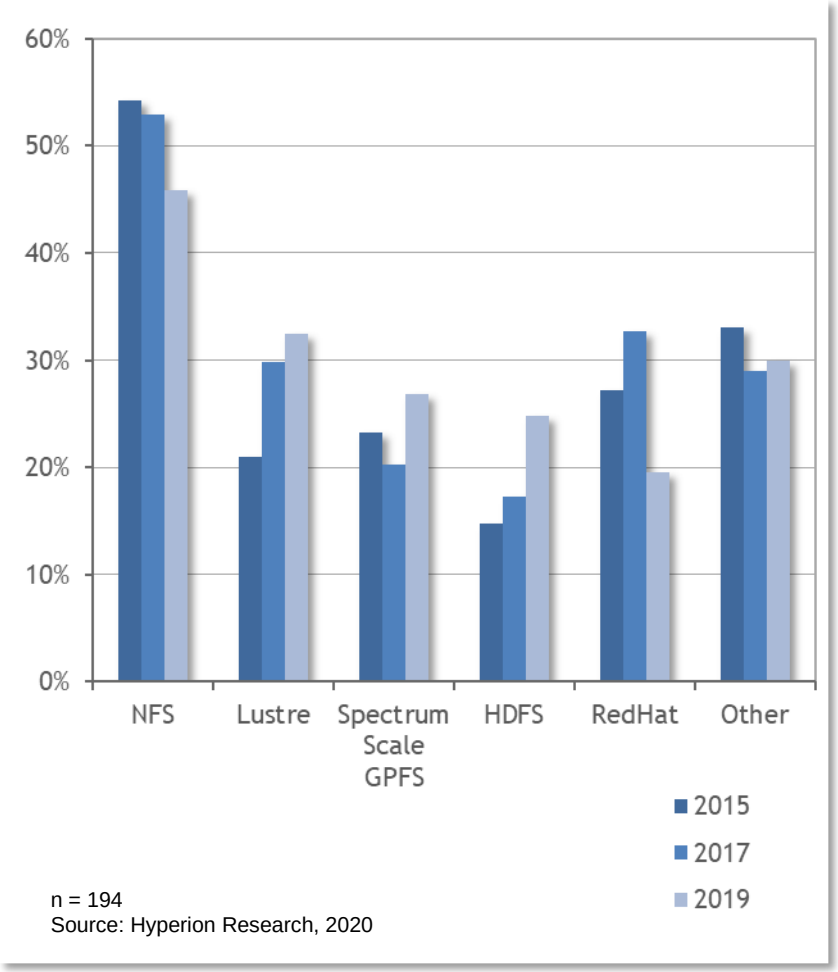




- **Dell Technologies also preferred most in Academia and Industry sectors**
- **IBM second preferred overall**
- **HPE/Cray preferred 3rd overall but tops in Government**
- **DDN 4th overall and top independent storage vendor**

File System Landscape is Changing

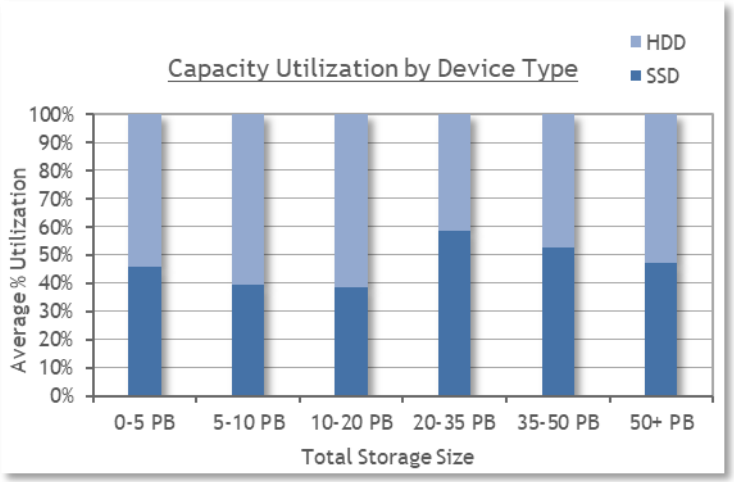
Lustre continues its adoption growth

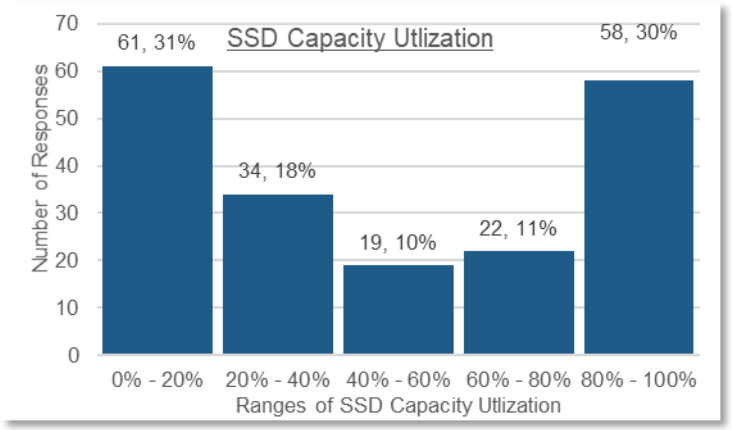


- **Academia and Government tend towards Lustre**
- **Industry tends towards NFS**
- **GFS, CEPH and PanFS in "Other"**
- **Expect shifts to continue as enterprises increasingly adopt HPC-enabled AI**

SSDs Becoming Storage Medium of Choice

Surveyed sites deployed 45% of capacity on SSDs in 2019





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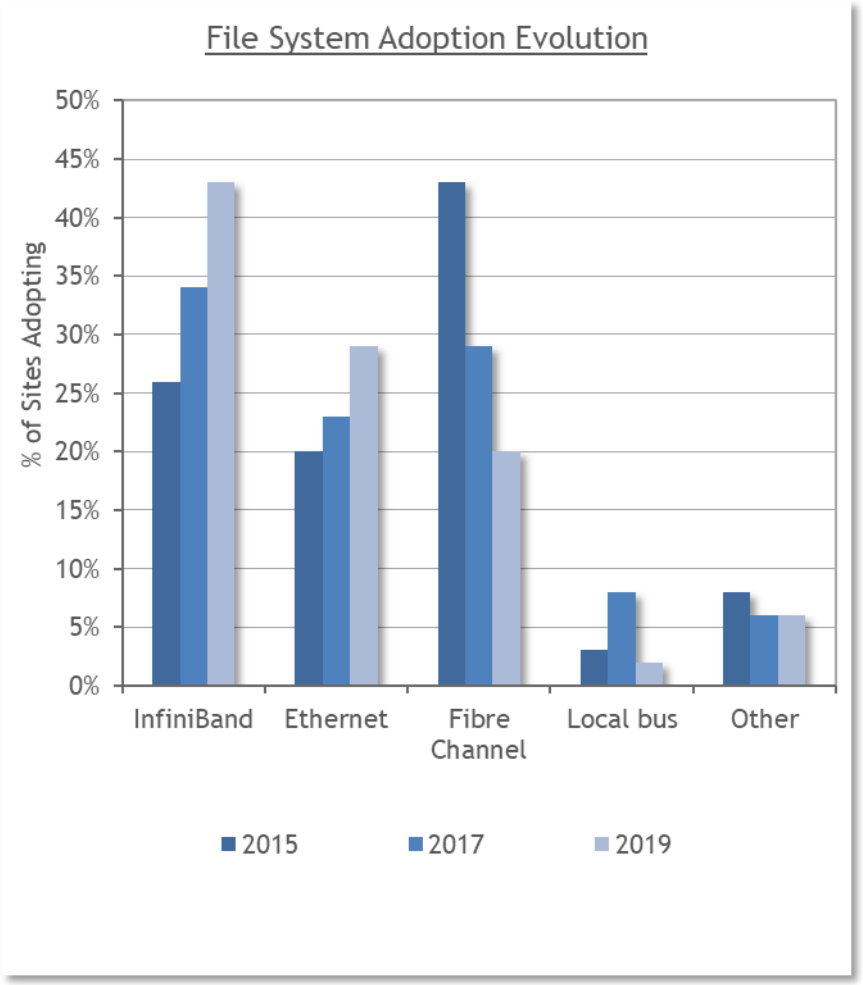
Source: Hyperion Research,2020

- **86% of sites deployed flash-based storage**
- **Wide range of media mix**
  - 15% were all flash
  - 71% were hybrid
  - 14% were all HDD
- **~ 60% of the sites have strong tendency (> 80% of respective capacity) towards either SSD or HDD**

Storage Interconnects Entering Spotlight

InfiniBand the leading storage interconnect



- **InfiniBand increasingly being adopted**
- **Ethernet also exhibiting growth**
- **Fibre Channel continues decline**
- **Interconnects becoming increasingly important to deliver the bandwidth required to keep GPU and other accelerator-based nodes fully utilized**

Future Research Directions

Driven by events already underway

- **Data and workflow management implications from continued migration of HPC workloads to the cloud**
- **Efforts to address deployment, ease of use and maintenance due to increased adoption of HPC-enabled AI by the Enterprise**
- **Application of AI techniques in storage solutions themselves to address predictive maintenance and data placement**
- **Intersection of 5G with edge computing and computational storage to minimize data movement for analysis**

Quantum Computing: Finding Its Place in the Advanced Computing Sector

November 2020

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Bob Sorensen

Promise of Quantum Computing is Substantial…

- QC systems have the potential to exceed the performance of conventional computers in areas such as:
  - Physical Simulation
    - Material Science
    - Chemistry
    - Pharmaceuticals
    - Oil and gas
  - Machine Learning
  - Optimization

- And the list grow longer every day

- **Goal is quantum supremacy…..perhaps**

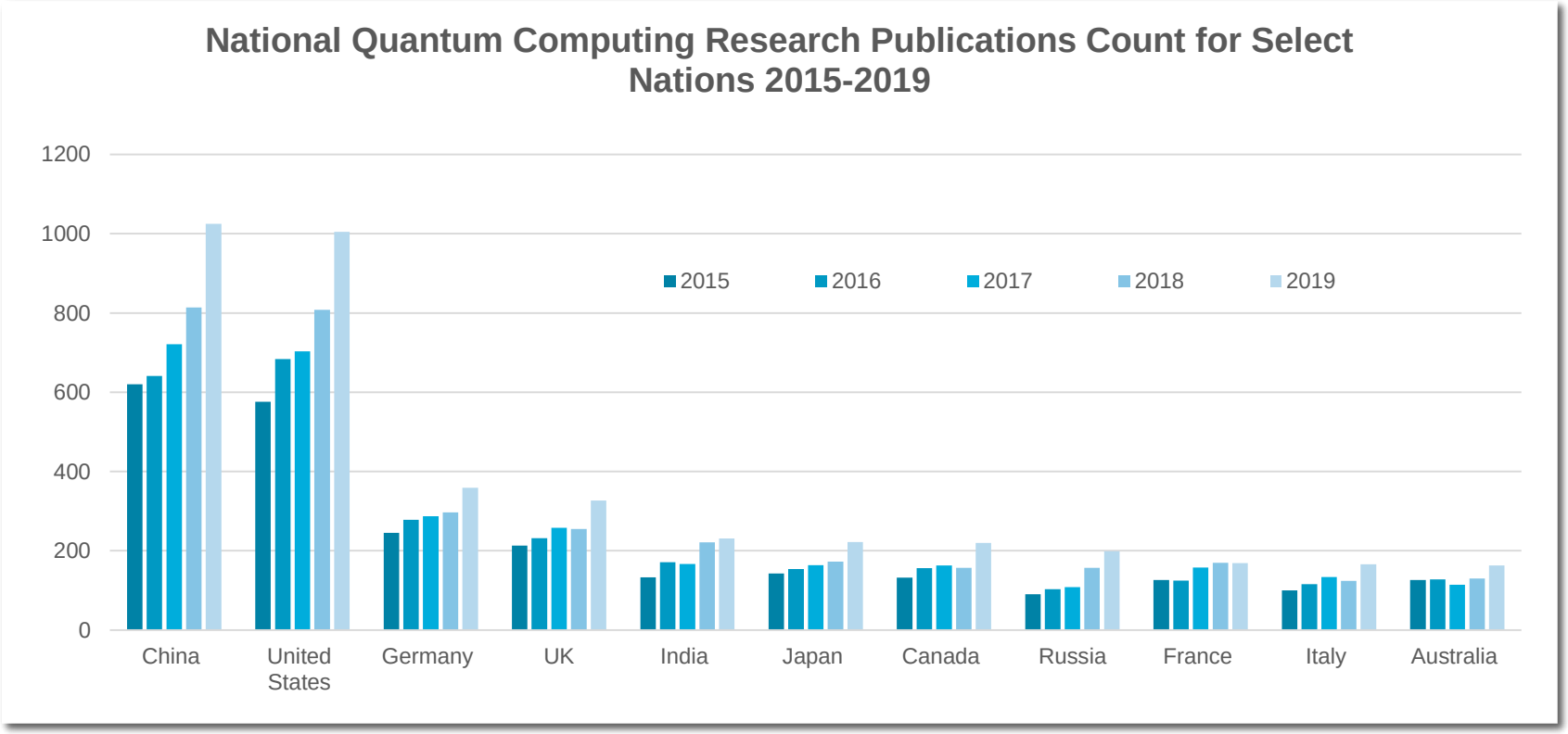
…But There are Substantial Challenges Ahead

- Formidable technical issues in QC hardware and software
- Uncertain performance gains
- Unclear time frames
- Disorganized progress in algorithm/application development
- Looming workforce issues

All these factors complicates treating QC as a stable market alongside more traditional IT sectors

- Making a business case is tough...but it needs to be done

QC Research is Global Activity



- Summary of leading R&D publications between 2015 and 2019 using
- query: "quantum comput*" OR "qubit" OR "quantum simulat*“ where * represents wildcard letters
- A total data set of 15,230 documents

Select National/Regional Government Quantum Programs

- Canada: Quantum Science Funding Framework
- China: Key National R&D project, Quantum Control and Quantum Information
- EU: The Quantum Flagship
- France: Quantum: the technological shift that France will not miss
- Germany: Government Framework Programme for Quantum Technologies
- Japan: Q-LEAP
- Russia: Digital Economy National Program
- UK: National Quantum Technologies (UKNQT) Programme
- US: National Quantum Initiative Act

QC Market Forecast Executive Summary

- The global QC market was worth about $250 million (+/- $30 million) in 2019
- Based on an anticipated CAGR of 27% between 2020 and 2024, the global QC market will grow from approximately $320 million in 2020 to $830 million in 2024
- On-prem and cloud access QC hardware will comprise about 50% of the global QC market for the next three years
- Optimization, physical simulation, and machine learning will near equally divide the algorithm space
- User access to QC will be primarily through the cloud, at three times the rate of an on-premise option

QC Market Forecast Summary

- Near-term QC Ramp Up
  - Many exploring applications/use cases and not just for traditional HPC but for enterprise IT computing environments
  - That the market will be growing – at least for the next few years - is demonstrated
- Quantum computing is not a replacement for classical computing, but a companion technology
- Development is happening in many dimensions and in parallel:
  - Hardware (qubit, QC-Lan, architecture)
  - Software (middleware, applications, use cases)
  - Algorithms
  - Hybrid classical/quantum systems
  - Quantum inspired algorithms

A Quick Tour of Exascale Architectures

November 2020

www.HyperionResearch.com
www.hpcuserforum.com

Bob Sorensen

Near-term US Exascale Plans

Three systems over 2 years at budget of ~ $1.8 billion

- **Aurora: DOE Office of Science, Argonne National Laboratory**
  - Intel Prime/Cray Sub
  - Delivery in late 2022, acceptance in 2023 (12 month-ish late)
  - Cray Shasta architecture with Intel Xeons and Intel Xe GPU
- **Frontier: DOE Office of Science: Oak Ridge National Laboratory**
  - Cray Prime
  - Delivery in late 2021 and acceptance in 2022
  - Cray Shasta with AMD EPYC CPU and future Radeon GPUs
- **El Capitan: DOE NNSA's LLNL**
  - Cray Prime
  - Delivery in late 2022, with full production targeted for late 2023
  - Cray Shasta architecture AMD EPYC processors, next generation Radeon Instinct GPUs

Focus on Aurora

Delay of approximately one year announced on July 23

- **Intel disclosed delay of 7nm Ponte Vecchio GPU, planned to be integrated with Intel Xeon CPUs in Aurora**
- **>1 EF**
- **Compute Node (est. total 2,400 total Aurora nodes)**
  - 2 Intel Xeon scalable “Sapphire Rapids” processors; 10nm+, 8 channel DDR5 memory, up to 48 cores (<200W)
  - 6 Xe arch-based GPUs; Unified Memory Architecture; 8 fabric endpoints
  - Xe arch-based “Ponte Vecchio” GPU; Tile-based chiplets, HBM stack, 7nm production node
- **CPU-GPU Interconnect: CPU-GPU: PCIe; GPU-GPU: Xe Link**
- **System Interconnect: Cray Slingshot, Dragonfly topology with adaptive routing**
- **Network Switch: 25.6 Tb/s per switch, from 64–200 Gbs ports (25 GB/s per direction)**

Focus on Frontier (CORAL-2)

First US Exascale System (Due to Aurora Delays)

- **Second-Generation AI System**
- **>1.5 EF**
- **Compute node:**
  - 1 HPC and AI Optimized AMD EPYC CPU
  - 4 Purpose Built AMD Radeon Instinct GPU
- **CPU-GPU Interconnect; AMD Infinity Fabric**
  - Coherent memory across the node
- **System Interconnect: Cray Slingshot, Multiple (Dragonfly) Slingshot NICs providing 100 GB/s network bandwidth**
- **Cray Shasta Architecture**
- **Liquid cooled with 300 kilowatts of power density per cabinet**
- **Total power = 40 MW (~125 racks)**

Focus on El Capitan (CORAL-2)

Stockpile Stewardship First and Foremost

- **Compute Node:**
  - One next generation AMD EPYC processor, codenamed Genoa featuring the Zen 4 processor core
  - Four next generation Radeon Instinct GPUs based on a new compute-optimized architecture for workloads including HPC and AI
- **CPU-GPU Interconnect: 3rd Gen AMD Infinity Architecture, including the 3rd Gen AMD Infinity Architecture, unified memory across the CPU and GPU**
- **System Interconnect: Cray Slingshot, Multiple (Dragonfly) Slingshot NICs providing 100 GB/s network bandwidth**
- **Cray Shasta Architecture**
- **Liquid cooled and have an energy budget between 30-to-40 megawatts**

Japan's Exascale System

Riken's Fugaku #1 on June 2020 Top 500 list

- **High Performance Linpack (HPL) result of 415.5 petaflops**
- **Uses Fujitsu A64 ARMv8.2-A processor**
  - 48/52 compute cores with GPU-like vector extensions
  - 4x 8 GB HBM with 1024 GB/s, on-die Tofu-D network BW (~400 Gbps)
  - High SVE FLOP/s (3.072 TFLOP/s)
- **No GPUs**
- **158,976 single socket nodes**
- **Tofu-D bandwidth 10X total global CSP traffic**
- **Peak DP > 400PFs, Peak SP> 800Pf, Peak HP > 1600 Flops**
- **Typically 37X faster that predecessor K system on target co-design applications**
- **Red Hat Enterprise Linux 8 (but Windows as well)**

China Exascale Plans

Exploring A Range of Architectures

Three prototypes under development – one or more prototypes may be selected for full-up production

- **NUDT (Tianhe)**
  - Indigenous CPU, possibly Arm-based Phytium Xiaomi or (less likely) Fujitsu A64FX
  - MT-2000+ NUDT accelerator (or follow-on)
  - 400 Gbps homegrown network
- **Sugon**
  - Heterogeneous architecture (2 CPU/2 DCU accelerators per node)
  - Hygon processor is licensed clone of AMD Gen 1 EPYC processor
  - Hygon-developed accelerator
  - Six-dimensional torus network for ~10,000 nodes
  - Board-level liquid immersion cooling
- **Sunway (prototype specifications)**
  - CPU-only SW26010 chip follow-on (260 cores @ 3Tflops per chip)

EU HPC Plans

EuroHPC program stood up in 2018

- **Chartered to develop EU-wide HPC development program**
  - 32 participating States + EU
  - Operational Duration: 11/2018-2026
- **Three Sites Recently Selected for 150-200 Pflops systems**
  - Kajaani Finland, Barcelona Spain, and Bologna Italy
  - Total Investment: 650 million Euros
    - 50% EU
    - 50% Consortium
- **Five Sites Selected for Medium Range HPCs (~4Pflops)**
  - Investment ~180 million Euros
- **Systems are owned by EuroHPC Joint Undertaking**
- **Installations to start 4Q2020**

EU HPC Plans (continued)

Exascale Plans Going Forward

- **EU Plan calls for acquisition of three exascale systems in the 2022-2023-time frame**
  - At least one to use European technology: specifically using an EPI-developed processor
  - Additional procurements in Germany in 2024, 2025
  - EU plans may include 2 ES systems in 2023-2026

- **Post Exascale System around 2027**
  - Plans call for integration and deployment of the first hybrid HPC/quantum infrastructure in Europe

UK EU Plans

UK has not joined EuroHPC

- **Not likely eligible to fully take part in EuroHPC projects or access calls when Horizon 2020 ends this year**

- **Requirements Highlighted:**
  - Support Mode/Sim and AI/DL
  - Support scientific and industrial users

- **Operational by Q42022/Q12023**

- **Cost estimated to be £700m - £1.2 bn**

- ***Stand by for more details***

HPDA/AI Market Update

November 17, 2020

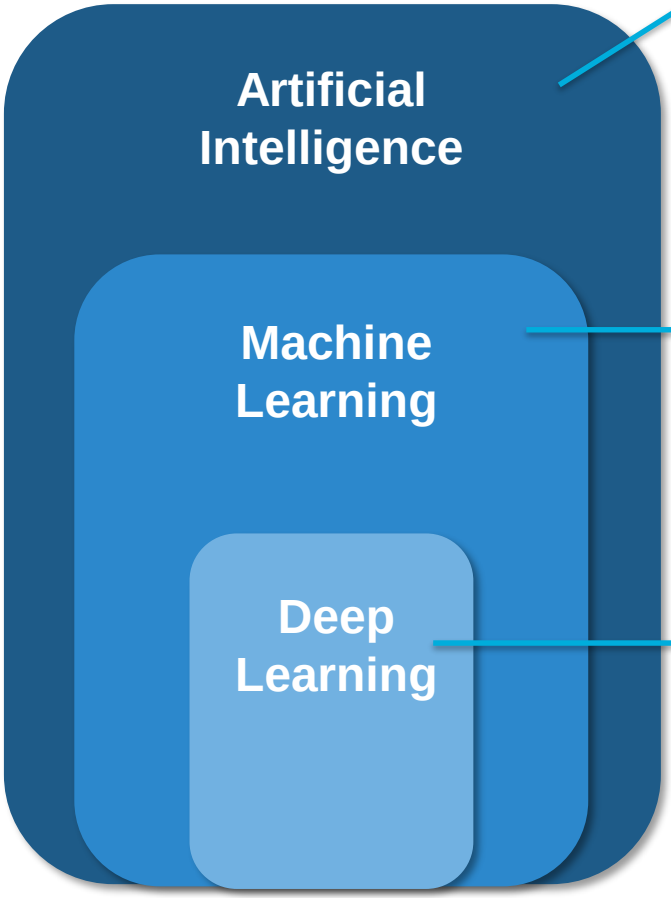
www.HyperionResearch.com
www.hpcuserforum.com

Steve Conway

AI-Related Hyperion Research Studies

- A Study of Users and Vendors of Machine Learning (U.S. Government client, in progress)
- How and Where AI Can Help Advance Science (DOE, in progress)
- Commercial and Military Applications of Edge Computing Technologies (report for U.S. Congress, 2020)
- Government Investments Recognize HPC's Ability To Boost Economic Competitiveness As Well As Science (ETP4HPC, 2019)
- AI Hardware Study, with Vendor Tracking and Analysis (U.S. Government client, 2019)
- A Primer on Artificial Intelligence and High-Performance Data Analysis (U.S. Government client, 2019)
- HPC in the Cloud (U.S. Government client, 2019)
- The Evolution of AI Hardware and Software Ecosystems (U.S. Government client, 2018)
- The Evolution of Field Competencies in Machine/Deep Learning and Resultant Industries (U.S. Government client, 2018)
- A Taxonomy of Algorithms for AI and HPDA (U.S. Government client, 2016)

Hyperion Research Definitions
AI: Machine Learning, Deep Learning



Artificial Intelligence (AI): a broad, general term for the ability of computers to do things human thinking does (but NOT to think in the same way humans think). AI includes machine learning, deep learning and other methodologies.

Machine learning (ML): a process where examples are used to train computers to recognize specified patterns, such as human blue eyes or numerical patterns indicating fraud. The computers are unable to learn beyond their training and human oversight is needed in the recognition process. The computer follows the base rules given to it.

Deep Learning (DL): an advanced form of machine learning that uses digital neural networks to enable a computer to go beyond its training and learn on its own, without additional explicit programming or human oversight. The computer develops its own rules.

Graph Analysis

An important, underappreciated AI methodology

- **Excels at identifying spatial and temporal relationships, something that learning models (machine and deep learning) are not very good at.**
- **Useful for tasks such as identifying financial fraud, predicting customer behavior and catching "bad actors."**
- **People and associated locations and objects are "tagged" with attributes and then "clustered" together according to the nature and strength of their attributes.**

High Growth Areas: HPDA-AI

HPDA is growing faster than overall HPC market; AI subset growing faster than all HPDA

Table 1

Forecast: Worldwide HPC-Based AI Revenues vs Total HPDA Revenues ($ Millions)

	2018	2019	2020	2021	2022	2023	2024	CAGR '19-'24
HPC Server Revenues	13,683	13,713	11,846	13,295	15,817	17,942	19,044	6.8%
HPDA Server Revenues	3,153	3,598	3,932	4,737	5,467	6,480	7,478	15.8%
HPC-Based AI (ML, DL & Other)	747	918	1,094	1,399	1,810	2,745	3,555	31.1%

Source: Hyperion Research, 2020

Table 2

Forecast: Worldwide ML, DL & Other AI HPC-Based Revenues ($ Millions)

	2018	2019	2020	2021	2022	2023	2024	CAGR '19-'24
ML in HPC	532	667	771	986	1,285	1,960	2,538	30.6%
DL in HPC	177	209	265	342	443	665	866	32.9%
Other AI in HPC	38	42	58	70	83	120	150	29.0%
Total	747	918	1,094	1,399	1,810	2,745	3,555	31.1%

Source: Hyperion Research, 2020

Important Commercial Use Cases

Most will take longer to mature than previously thought

Precision Medicine

Automated Driving Systems

Fraud and Anomaly Detection

Affinity Marketing

Business Intelligence

Cyber Security

IoT/Edge/Smart Cities

AI is Still Near the Start

- **Today: Special (Weak) AI**
  - Many observations but few choices
  - “One trick dogs”: 10 AI solutions in a box to solve 10 problems
  - Rudimentary training/inferencing
  - Short on real-world data
  - Examples:
    - Image & voice recognition
    - Early automated driving
    - Reading an MRI
- **Future: General (Strong) AI**
  - Many observations, many choices
  - Versatile decision-makers capable of serious experiential learning
  - More intelligent training/inferencing
  - High-volume synthetic data
  - Examples:
    - Discerning human motivation
    - Mature automated driving
    - Diagnosing/”curing” a cancer

AI Market Trends

AI will grow faster than the overall HPC market

- **The AI market is at an early stage but already highly useful (e.g., visual and voice recognition).**
- **The need for trust has elevated the issues of transparency, ethics and legal liability.**

"Unlike Tesla, Mercedes Doesn't Want Customers To Test Automated Driving Tech Before It's Ready" (motor1.com, 11/2/2020)

- **Advances in inferencing will reduce the amount of training needed for today's AI tasks, but the need for training will grow to support more challenging tasks.**
- **Learning models (ML, DL) have garnered most of the AI attention, but graph analytics will also play a crucial role with its unique ability to handle temporal and spatial relationships.**

Key Takeaways #1

- **AI is about machines guessing (inferencing) much faster than humans**
  - Human intuition is far better at this but far slower
  - For the foreseeable future, machines will mainly carry out the tedious AI work and hand off the challenging work to humans
- **AI ethics and liability activities center around the position of humans vs. machines and the HMI**
- **Current issues (transparency, biased input) could slow but not stop AI momentum**
  - Our studies show almost all HPC sites are involved in AI

Key Takeaways #2

- **HPC is crucial at the forefront of AI R&D**
  - HPC market growth + AI potential is motivating vendors
- **HPC innovations heavily influence mainstream AI:**
  - Algorithmic sophistication
  - Parallelization
  - Clustered servers (“clusters”)
  - CPU-accelerator processing
  - Ultrafast system data rates
  - Capable memory subsystems
- **AI is exiting the peak of the hype cycle**
  - Vendors are less often setting unrealistic expectations
- **HPC data center & enterprise deployments are different**
  - HPC data center: monolithic, standalone upgrade
  - Enterprise data center: integrate into existing infrastructure and workflow

Strong Hardware Activity To Support More Heterogeneous Workflows

- **Processors:**
  - Consolidation among the majors: Intel-Altera, Nvidia-Arm, AMD-Xilinx
  - 50+ chip startups: only a few will likely succeed, alone or through acquisition.
  - More processor types
- **Architectures:**
  - Moving from compute-friendly to compute- and data-friendly
  - Innovative interconnects to minimize latency at large scale
  - Accommodate heterogeneous processors
  - Interoperate with third-party clouds (hybrid, bare metal)
  - (Some) Ethernet compatibility for enterprise integration

- GPUs
- TPUs
- FPGAs
- ASICs & eASICs
- Neuromorphic Chips
- IPUs
- Inference Chips
- Training Chips
- Dataflow processors
- Vector processors
- 3D stacking
- Optical interconnects

HYPERION RESEARCH

SC20:
The HPC Innovation Excellence Award Winners

Our Award Program:
https://www.hpcuserforum.com/innovationaward/

HPC Innovation Awards

The HPC Innovation Awards are given twice a year to organizations that have made outstanding achievements using high performance computing.

The three award categories showcase ROI and success stories showing HPC's impact on increasing economic value, advancing scientific innovation and engineering progress, and on improving the quality of life worldwide.

HPC User Innovation Award
HPC Data Center Innovation Award
HPC Vendor Innovation Award

Examples Of Previous Winners

HPC Award Program Goals

- **#1 Help to expand the use of HPC by showing real ROI examples:**
  - Expand the “Missing Middle” – SMBs, SMSs, etc. by providing examples of what can be done with HPC
  - Show mainstream and leading edge HPC success stories
- **#2 Create a large database of success stories across many industries/verticals/disciplines**
  - To help justify investments and show non-users ideas for exploiting HPC
  - Creating many examples for funding bodies and politicians to use and better understand the value of HPC → to help grow public interest in expanding HPC investments
  - For OEMs to demonstrate success stories using their products

Judging Panel:
HPC User Forum Steering Committee

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Chairman, Industry Expert

Rupak Biswas
NASA Ames
Vice Chairman

Earl Joseph
Executive Director,
Hyperion Research

Vijay Agarwala
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Industry Expert

David Baldwin
Royal Dutch Shell

Doug Ball
HPC Expert

Mike Bernhardt
Exascale Computing
Project

Steve Conway
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Hyperion Research

Steve Finn
Onyx Consulting Services, LLC

Merle Giles
Moonshot Research

Keith Gray
BP

Arno Kolster
Providentia Worldwide

Doug Kothe
Oak Ridge National Laboratory

Jysoo Lee
KAUST

David Martin
Argonne National Laboratory

Jeff Broughton
NERSC/Lawrence
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Los Alamos National Labs

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National Cancer Institute

Brendan McGinty
Director, NCSA University
of Illinois

Michael Resch
HLRS, University of Stuttgart

Ryan Quick
Providentia Worldwide

Stephane Requena
GENCI

Vince Scarafino
Industry Expert

Suzy Tichenor
Oak Ridge National Laboratory

SC20 Winners: HPC Innovation Excellence Awards

***The award includes a $1,000 prize per team!*

Identifying Promising Anti-Covid Agents via HPC Cloud Computing

Jerome Baudry, et al., University of Alabama at Huntsville

- Using the Cray “Sentinel” supercomputer in Microsoft Azure, the researchers identified 125 natural substances that appear to block the action of Covid-19.
- Paper submitted for peer review: https://chemrxiv.org/articles/High_Performance_Computing_Prediction_of_Potential_Natural_Product_Inhibitors_of_SARS-CoV-2_Key_Targets/12497693

High Performance Computing Prediction of Potential Natural Product Inhibitors of SARS-CoV-2 Key Targets

Kendall Byler[%], Joseph Landman[#], Jerome Baudry[%*]

%: The University of Alabama in Huntsville, Department of Biological Sciences, Huntsville, AL, 35899
#: Hewlett Packard Enterprise, HPC MCS AI, Canton, MI, 48188

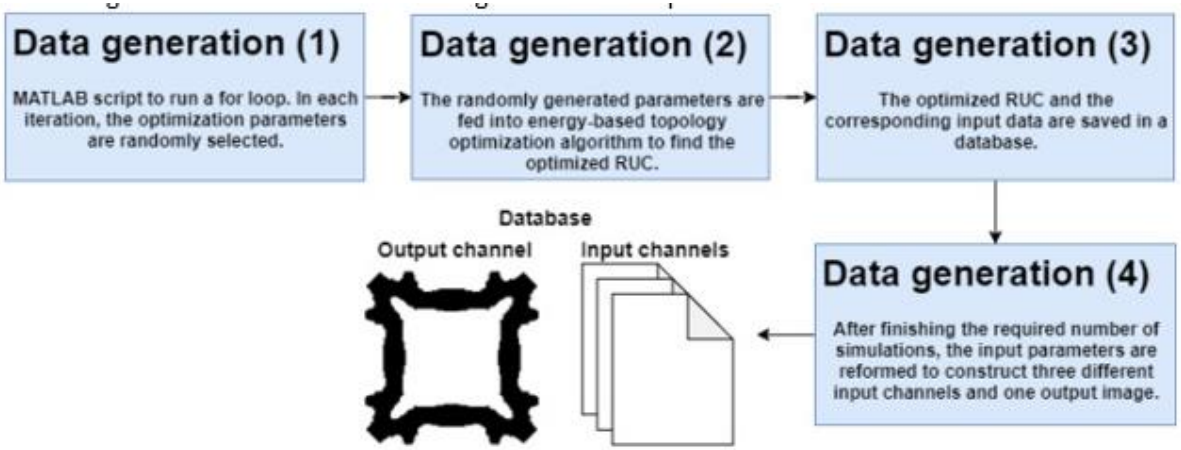
* Corresponding author: jerome.baudry@uah.edu

Abstract: An ensemble-docking of 50,000 natural products on a supercomputer has been performed against the papain-like protease, the main protease and the spike protein of the SARS-CoV-2 virus. The top compounds predicted to bind specifically to these protein targets are analyzed to identify common pharmacophore features. The functional groups more likely to lead to target engagement of these viral proteins are described and feature hydrophobic/resonant cores surrounded by hydrogen bonding capacities at specific locations. This work identifies natural products for immediate testing and suggests structural elements for anti COVID-19 drug development and screening.

Deep Learning on HPC Predicts Optimal Materials Designs

Seid Koric, et al., NCSA (University of Illinois at Urbana-Champaign)

- The NCSA Industry Application team uses HPC and GPUs to develop cutting-edge deep learning models to predict optimized structural and meta-material designs while accounting for various nonlinear optimization scenarios — demonstrating for the first time that it is possible to generate, machine train, and learn from modeling data on HPC. This project leverages NCSA's iForge cluster and Blue Waters supercomputer, and physics-informed AI to accelerate structural and meta-material design optimization.
- Paper: https://www.sciencedirect.com/science/article/pii/S026412752030633X



Improving Maize Growth Processes in the Community Land Model

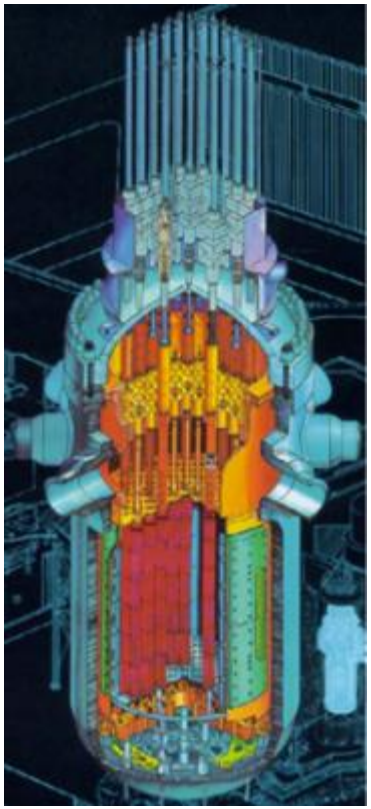
Kaiyu Guan, et al., University of Illinois at Urbana-Champaign

- The researchers used NCSA's Blue Waters supercomputer to implement and evaluate a new maize growth model, creating on the most reliable tools for long-term crop prediction in the U.S. Corn Belt.
- Article: http://www.ncsa.illinois.edu/news/story/ncsa_researchers_create_one_of_the_most_reliable_tools_for_long_term_crop_p

CASL Accurately Simulated Startup of Only New U.S. Reactor in 21 Years

Dave Kropaczek, Doug Kothe, et al., Oak Ridge National Laboratory

- CASL's Virtual Environment for Reactor Applications, or VERA, accurately simulated the 2016 startup of TVA's Watts Bar Unit 2 — the only reactor to go online in the U.S. in the 21st century.
- Article: https://www.ornl.gov/sites/default/files/2020-02/CASLweb.pdf



Deep Learning Enhancement of Large-Scale Numerical Simulations

Caspar van Leeuwen, Axel Berg, et al., SURF Open Innovation Lab and multiple Dutch universities

- The team employed deep learning to achieve orders-of-magnitude speedups on large-scale numerical simulations, with accuracy close to established Monte Carlo methods.
- Paper: https://www.surf.nl/files/2020-03/white-paper-dl4hpc-.pdf

Deep-learning enhancement of large scale numerical simulations

March 2020

Caspar van Leeuwen, Damian Podareanu, Valeriu Codreanu, Maxwell Cai, Axel Berg
SURF Open Innovation Lab, SURF

Maxwell Cai, Simon Portegies Zwart
Leiden Observatory, Leiden University

Robin Stoffer, Menno Veerman, Chiel van Heerwaarden
Meteorology and Air Quality Group, Wageningen University and Research

Sydney Otten, Sascha Caron
Institute for Mathematics, Astro- and Particle Physics IMAPP, Radboud University

Cunliang Geng, Francesco Ambrosetti, Alexandre M.J.J. Bonvin
Bijvoet Centre for Biomolecular Research, Faculty of Science - Chemistry, Utrecht University

We Invite Everyone To Apply For The Next Round Of Innovation Awards!

SC20 Update On The ROI And ROR From Investing In HPC

November 2020

www.HyperionResearch.com
www.hpcuserforum.com

Earl Joseph

DOE Grant References

Hyperion Research thanks DOE for funding this research

The authors want to thank DOE for its insights and guidance, on and for funding this research project.

This study is based upon work funded by the U.S. Department of Energy Office of Science, Office of Advanced Scientific Computing Research, and the National Nuclear Security Administration, under award number DE-SC0008540.

The grant description:

- Developing an assessment of how investments in HPC and R&D can impact a nation's competitiveness and level of innovation

Hyperion Research ROI Methodology

Two different models are used

Hyperion Research's continuing efforts in Return on Investment (ROI) research examine individual HPC projects and measure the amounts spent on the HPC resources compared with the projects' financial and innovation returns.

This research is based on the ROI economic model and innovation class index Hyperion Research first developed for DOE:

- A *macroeconomic model* that depicts the way HPC investments result in economic advancements in the form of ROI in revenue, profits (and cost savings), and jobs. It looks at HPC costs as the input and revenues, profits or cost savings, and job creation as the output.
- An *innovation class index* that provides a means of measuring and comparing innovation levels. Based on two parameters: 1) the importance of each innovation combined with 2) how many organizations can use the innovation.

The Projects In The Database

763 projects are available for the community to explore

TABLE 1

The 763 Projects in The Database (as of October 2020)

	Financial ROI Projects	Innovation ROR Projects	Total
Academic	26	375	401
Government	6	52	58
Industry	143	161	304
Total	175	588	763

Source: Hyperion Research, 2020

Note: To provide the data to the entire HPC community and ensure transparency, we publish the raw data and reports at: www.hpcuserforum.com/ROI/

Types Of Projects In The Database

Creating new approaches and designing better products were the top 2 areas

TABLE 4

Areas of the Projects

Primary Innovation/ROI Area	Count of Projects
Created New Approach	297
Better Products	193
Discovered Something New	94
Scientific Breakthrough	59
Helped Society	51
Support Research Programs	47
Cost Savings	22
Total	763

Source: Hyperion Research, 2020

The New Financial ROI Results

The ROI is now at $507 with revenue, and on average $47 for profits/cost savings

Updated results continue to indicate substantial returns for investments in HPC:

- The data now covers 763 successful HPC projects
- On average $507 dollars in revenue per dollar of HPC invested was generated (excluding outliers)
- On average $47 dollars of profit (or cost savings) per dollar of HPC invested was generated (excluding outliers)
- The average HPC investment per innovation was $2.6 million

Note that this research is looking at the economic impacts based on the HPC investment compared with the output of revenue/sales and/or profits and cost savings. It excludes the additional costs of production, sales etc. that are also required for each project.

The full data and results of this research are available at: www.hpcuserforum.com/ROI/

HYPERION RESEARCH

Updated Innovation Return on Research (ROR) Results

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

In order to properly quantify the innovation from HPC projects, Hyperion Research uses a rating system that measures both the importance and the impact of each innovation in this study.

- **The IMPORTANCE this innovation compared to all other innovations in the specific field over the last ten years:**
  5. One of the top 1 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 50 or more 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

The Innovation Class Index

Combing these two measures, Hyperion Research creates an overall INNOVATION CLASS rating for these projects:

1. Class 1 innovations – One of the top 1-3 innovations in a field over the last ten years PLUS useful to over 10 organizations
2. Class 2 innovations -- One of the top 5 innovations in a field over the last ten years PLUS useful to over 10 organizations
3. Class 3 innovations – One of the top 5 innovations in a field over the last ten years PLUS useful to over 5 organizations
4. Class 4 innovations – One of the top 10 innovations in a field over the last ten years PLUS useful to over 5 organizations
5. Class 5 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at over 10 organizations
6. Class 6 innovations – One of the top 25 innovations in a field over the last ten years PLUS useful to at least 2 organizations
7. Class 7 innovations – One of the top 50 innovations in a field over the last ten years PLUS useful to at least 2 organizations
8. Class 8 innovations – All other innovations

Innovations Rated By IMPORTANCE

The innovations are well distributed across the scale

TABLE 5

Innovations: Importance of the Innovation

	Count of Projects	Percent of all Projects
5 -- One of the top 2 to 3 innovations in the last decade	152	23.4%
4 -- One of the top 5 innovations in the last decade	159	24.5%
3 -- One of the top 10 innovations in the last decade	184	28.3%
2 -- One of the top 25 innovations in the last decade	89	13.7%
1 -- One of the top 50 innovations in the last decade	66	10.2%
Total	650	100.0%

Source: Hyperion Research, 2020

Innovations Rated By Their IMPACT To Other Organizations

The innovations are well distributed across this scale

TABLE 6

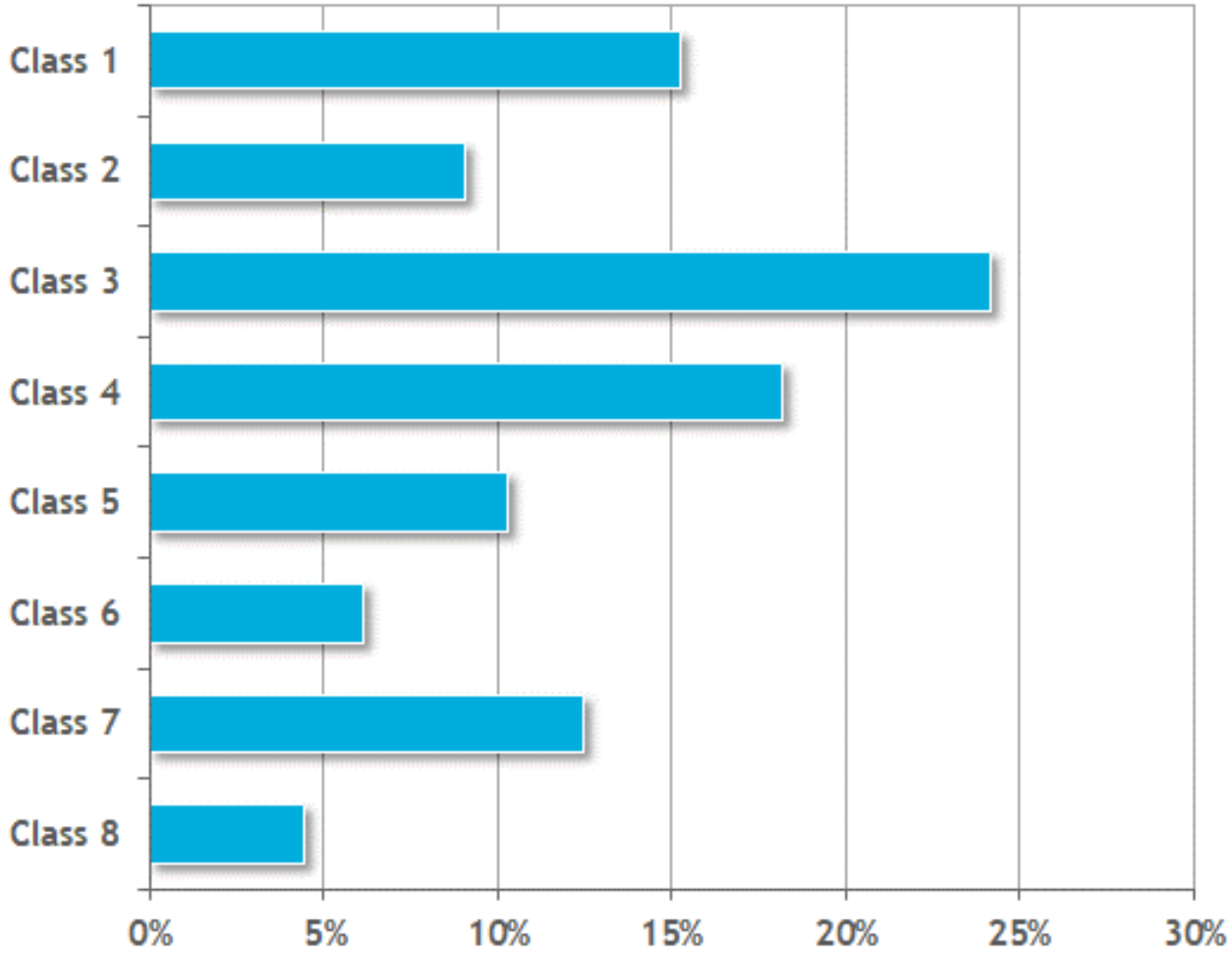
Innovations: Number of Organizations Impacted by the Innovation

	Count of Projects	Percent of all Projects
6 -- It is useful to over 50 organizations	132	20.3%
5 -- It is useful to 10 to 49 organizations	205	31.5%
4 -- It is useful to 6 to 9 organizations	98	15.1%
3 -- It is useful to 2 to 5 organizations	88	13.5%
2 -- It is only useful to 1 organization	56	8.6%
1 -- It is recognized ONLY by experts in the field	71	10.9%
Total	650	100.0%

Source: Hyperion Research, 2020

The Innovation CLASS Index Ratings

The innovations are well distributed across the index, with many that are in class 3 and 4



The Innovation CLASS Index Ratings

650 of the projects were rated using the class index

TABLE 7

Innovation Class Ratings

	Count of Projects	Percent of all Projects
Class 1	99	15.2%
Class 2	59	9.1%
Class 3	157	24.2%
Class 4	118	18.2%
Class 5	67	10.3%
Class 6	40	6.2%
Class 7	81	12.5%
Class 8	29	4.5%
Total	650	100.0%

Source: Hyperion Research, 2020

Future Outlook

Investments in HPC clearly can provide strong ROI and ROR

HPC continues to be a demonstrated enabler of innovation across a wide range of important sectors and it can drive significant returns on investments.

- This data also provides government policy makers and commercial project planners the ability to more accurately assess both the technical and financial impact of HPC funding.
- Looking ahead, advances in HPC capabilities that span traditional modeling and simulation workloads as well as new opportunities including AI (e.g., machine and deep learning), and hybrid classical/quantum computing will likely expand the breadth of HPC applicability and its related financial returns.

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In Summary

Conclusions

- **The pandemic is expected to impact 2020 by ~14%, but growth is expected in 2021**
- **For 2021 to 2024 HPC is expected to be a strong growth market & AI areas will grow even faster**
  - Exascale systems will drive growth in 2022 to 2024
  - AI, HPDA, big data are hot growth areas
  - HPC in the cloud will lift the sector writ large
- **Emerging technologies are showing up in larger numbers**
  - Processors, AI, memories, etc.
- **The cloud has become a viable option for many HPC workloads**
- **Storage will likely see major growth driven by AI, big data and the need for much larger data sets**

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QUESTIONS?

Questions or comments are welcome.

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