Understanding the Cost of Computing in the Cloud

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OBJECTIVE

A start-up company intends to use IaaS services from Amazon EC2 to run its software stack. To drill down the cost breakdown of a private cloud to analyse and compare costs against public on-demand rented resources. In this project, I have considered Amazon EC2 as the cloud provider. A comparative analysis is to be made whether computing resources should be rented from a public cloud on-demand from Amazon EC2, or it would be cheaper to set up a private cloud.

AMAZON EC2 Instance Types

Amazon EC2 provides a wide selection of instance types optimized to fit different use cases. Instance types comprise varying combinations of CPU, memory, storage, and networking capacity and give you the flexibility to choose the appropriate mix of resources for your applications. Each instance type includes one or more instance sizes, allowing you to scale your resources to the requirements of your target workload.

Generally, the storage optimized instances are designed for workloads that require high, sequential read and write access to very large data sets on local storage. They are optimized to deliver tens of thousands of low-latencies, random I/O operations per second (IOPS) to applications

CONFIGURATION 1: Hadoop/Spark Cluster with 32K-cores, 256TB memory, 50PB HDD, and 10Gb/s Ethernet Fat-Tree network (each VM should be equivalent to the d2.8xlarge instance); in addition to the compute resources, a 100PB distributed storage shared across the entire cloud should be procured, with enough capacity for 100GB/sec throughput (for pricing comparison, see S3)

In this configuration the instance type from Amazon that is compared with private resources is **d2.8xlarge**

D2 instances are well suited for the following applications:

- Massive parallel processing (MPP) data warehouse
- MapReduce and Hadoop distributed computing
- Log or data processing applications.

D2 instances provide the best disk performance when you use a Linux kernel that supports persistent grants, an extension to the Xen block ring protocol that significantly improves disk throughput and scalability. **d2.8xlarge** provide the ability to control processor C-states and P-states on Linux. C-states control the sleep levels that a core can enter when it is inactive, while P-states control the desired performance (in CPU frequency) from a core.

d2.8xlarge Configuration

Specification	Performance
vCPUs	36
Memory(GiB)	244
Network Performance	10 Gbps
Enhanced Networking	Intel 82599 VF
Physical CPU	Intel Xenon E5-2676 v3
Clock Speed	2.4 GHz
Storage	24*2000 HDD
ECU	116
Theoretical GFLOPS	691
No of Cores per processor	12
IPC	16
Pricing	$5.52

Amazon S3 Standard Pricing

Storage Pricing (varies by region)

Region: US East (Ohio)

	Pricing
S3 Standard Storage	
First 50 TB / Month	$0.023 per GB
Next 450 TB / Month	$0.022 per GB
Over 500 TB / Month	$0.021 per GB
S3 Standard-Infrequent Access (S3 Standard-IA) Storage	
All storage	$0.0125 per GB
S3 One Zone-Infrequent Access (S3 One Zone-IA) Storage	
All storage	$0.01 per GB
Amazon Glacier Storage	
All storage	$0.004 per GB

References: https://aws.amazon.com/s3/pricing

ESTIMATION OF PUBLIC CLOUD

Instance Type	vCPUs	Memory	Storage	Cost per hour	Instances Needed	Cost for 5 Years
Configuration 1(Required)	32000	256 TB	50 PB	$5.52	1000	**$241,776,000**

Storage Type	Distributed Storage	Data Transfer	Cost for Distributed Storage	Cost of Data Transfer	Cost for 5 years
Configuration 1(Calculated based on Amazon S3 pricing)	100 PB	100 GB/s	$132,000,000.00	$165,480,000	**$287,640,576**

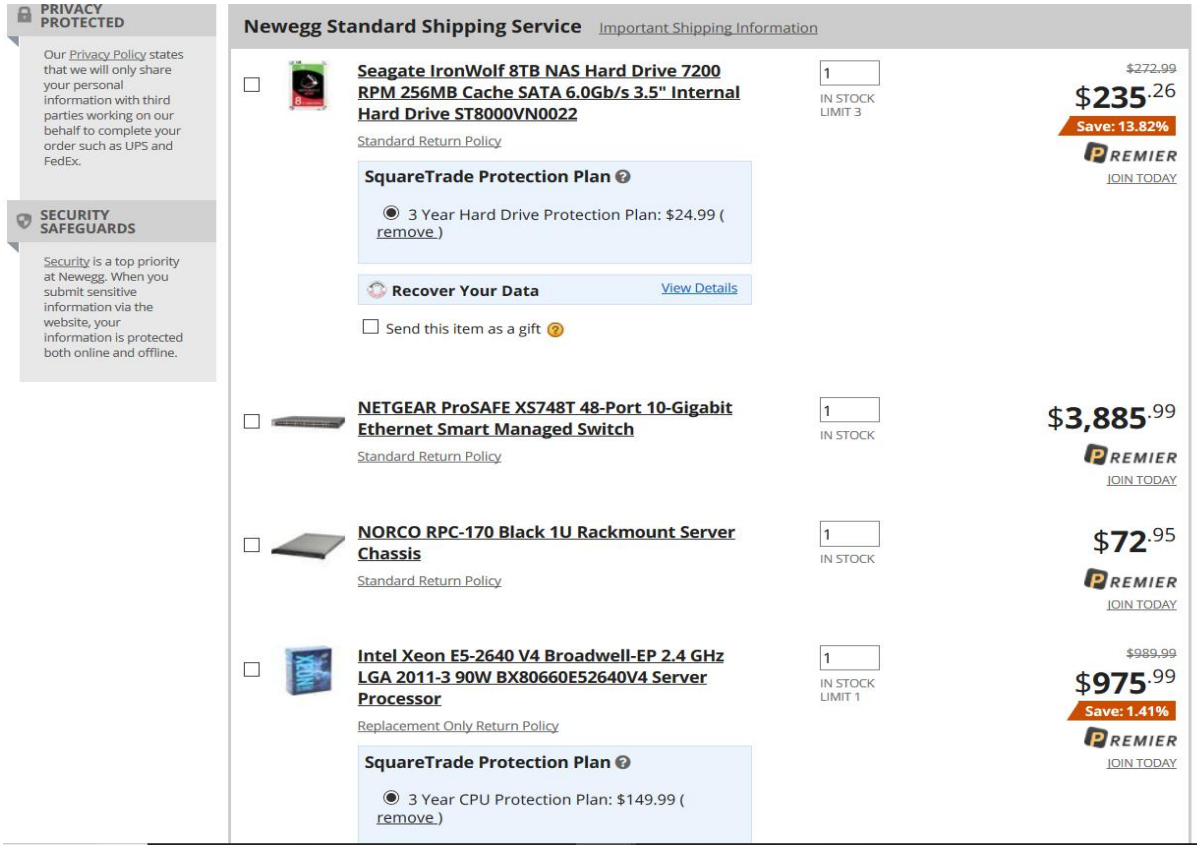
Total cost of Public cloud with the required configuration for 5 years = **$529,416,576**

Products	Sub-Components	Description	Price per Item	Quantity	Total Price($)	Reference Purchased
Compute Servers	Processor	Intel Xeon E5-2640 V4 Broadwell-EP 2.4 GHz 10 x 256KB L2 Cache 25MB L3 Cache LGA 2011-3 90W BX80660E52640V4 Server Processor	$975.99	3869	$3,776,105	https://www.newegg.com/Product/Product.aspx?Item=N82E16819117631&ignorebbr=1
	Memory	I have selected Kingston ValueRAM 64GB (4 x 16GB) DDR4 2400 RAM (Server Memory) ECC Reg DIMM (288-Pin) KVR24R17D8K4/64 each node to achieve 256 TB memory	$888.65	4153	3690563.45	https://www.newegg.com/Product/Product.aspx?Item=9SIA8H54FP0850&ignorebbr=1
	Chassis	NORCO RPC-170 Black 1U Rackmount Server Chassis 1 External 5.25" Drive Bays	$72.95	5377	392252.15	https://www.newegg.com/Product/Product.aspx?Item=N82E16811219026&ignorebbr=1
	Hard Drive	Seagate IronWolf 8TB NAS Hard Drive 7200 RPM 256MB Cache SATA 6.0Gb/s 3.5" Internal Hard Drive ST8000VN0022	$235.26	5377	1264993.02	https://www.newegg.com/Product/Product.aspx?Item=N82E16822179003&ignorebbr=1
Network Switches	48 Port Gb switch	NETGEAR ProSAFE XS748T 48-Port 10-Gigabit Ethernet Smart Managed Switch	$3,886	78	303108	https://www.newegg.com/Product/Product.aspx?Item=N82E16833122845&ignorebbr=1
Network Cables	SFP Cables	Cisco SFP-H10GB-CU3M Compatible 10G SFP+ Passive Direct Attach Copper Twinax Cable	$15	7467	112005	https://www.fs.com/products/30862.html?currency=USD&paid=google_shopping&gclid=Cj0KCQiA6enQBRDUARIsAGs1YQiJtehOaRimQtmm9fm4iiXP2asL0m2RIexfYlk4OPZuurjPbXOzOm8aAoCrEALw_wcB
Racks	Rack Mount	APC AR3300 42U NetShelter SX 600mm Wide x 1200mm Deep Enclosure.	$1,670	327	546090	https://www.newegg.com/Product/Product.aspx?Item=9SIADYY67D8361&ignorebbr=1
Storage Servers	Storage	Dell Storage MD1280	$42,779	237	10138623	http://www.dell.com/en-us/work/shop/server-poa-expansion/md1280/spd/storage-md1280
Electric Power	Cost for compute and storage nodes	(((120 W/hr * 2667) + (161w/hr *60) + (3300*70))/1000) * 5 * 365 * 24 = (321960 + 9660 + 231000 = 24558660 kw/hr Cost = 0.10(rate)	$562,620	5	2813100	https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
Cooling	Cooling required for Servers		$10,000	5	$50,000	https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
Administration	System Administration	Considering the cost of one admin for 1000 instances	$100,000/year	5377	$1,000,000	https://www.payscale.com/research/US/Job=Systems_Administrator/Salary
TOTAL	N/A	N/A	N/A	N/A	$24,086,840	

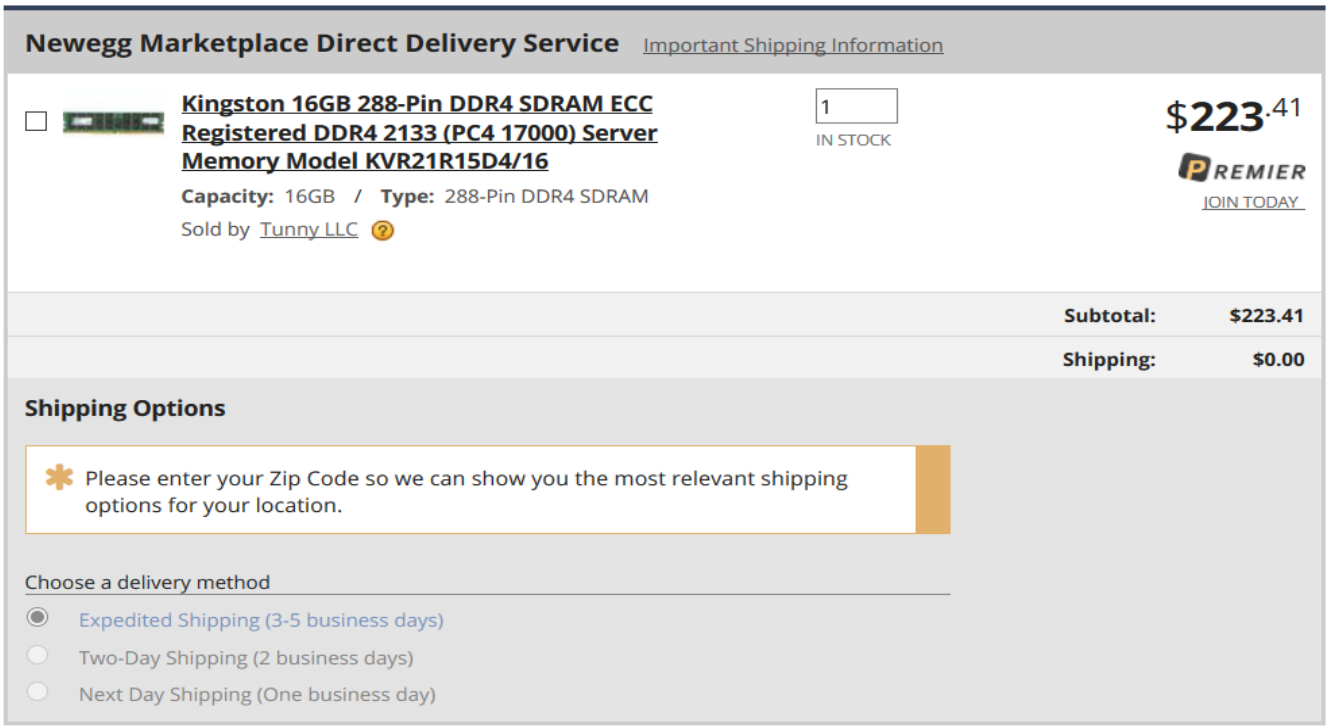
Total cost of Private Cloud with the given Specifications = **$24,086,840**

PRODUCT DETAILS

Processor, Network Switch, Chassis, Hard Drive



MEMORY



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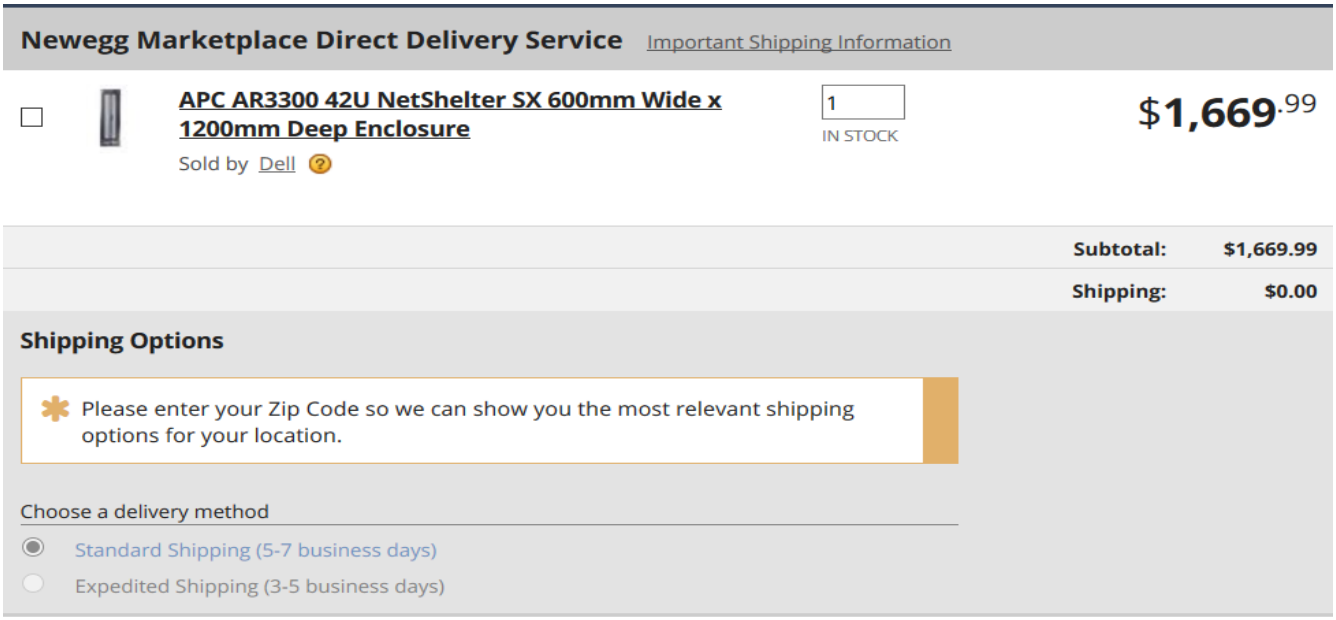

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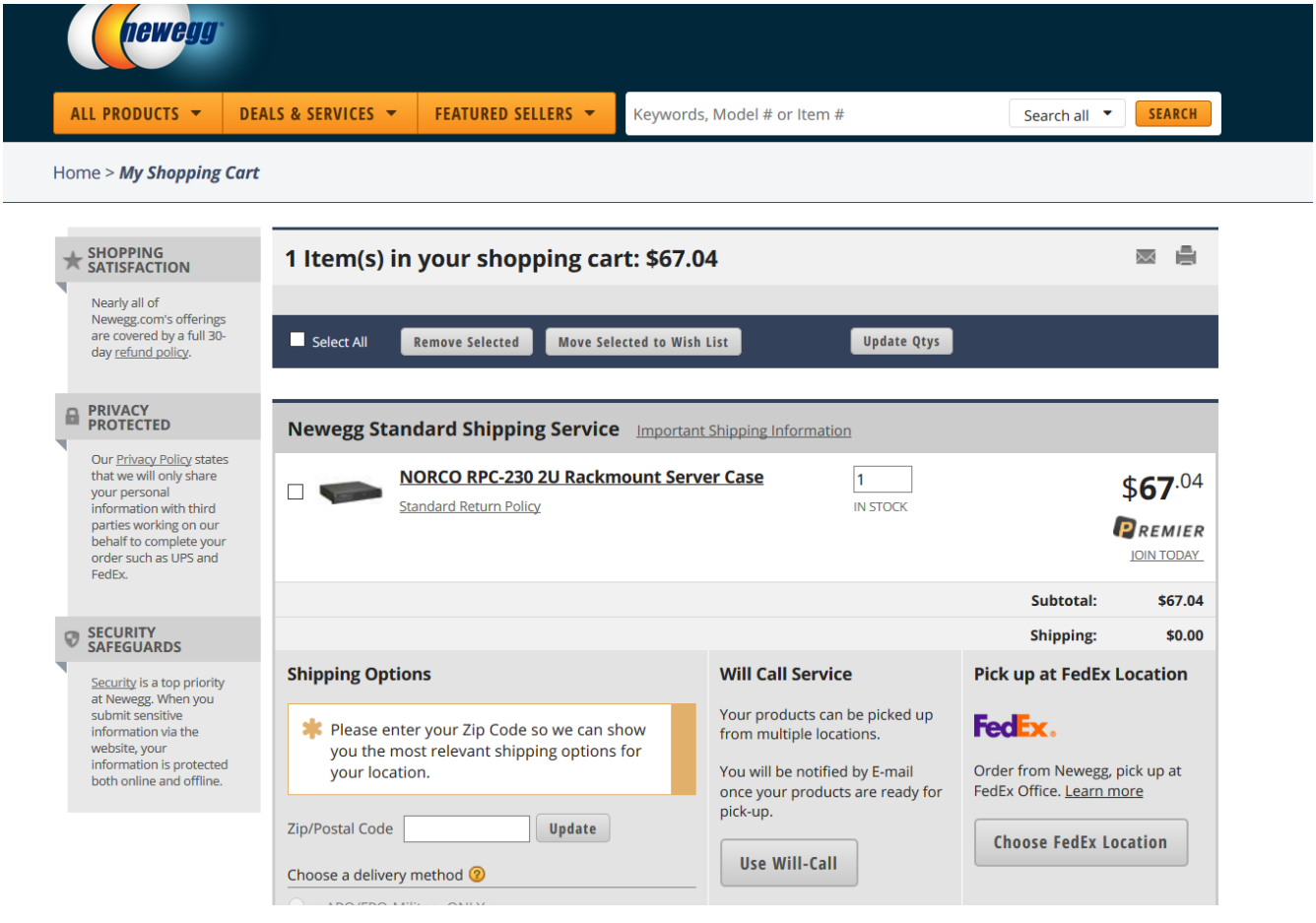
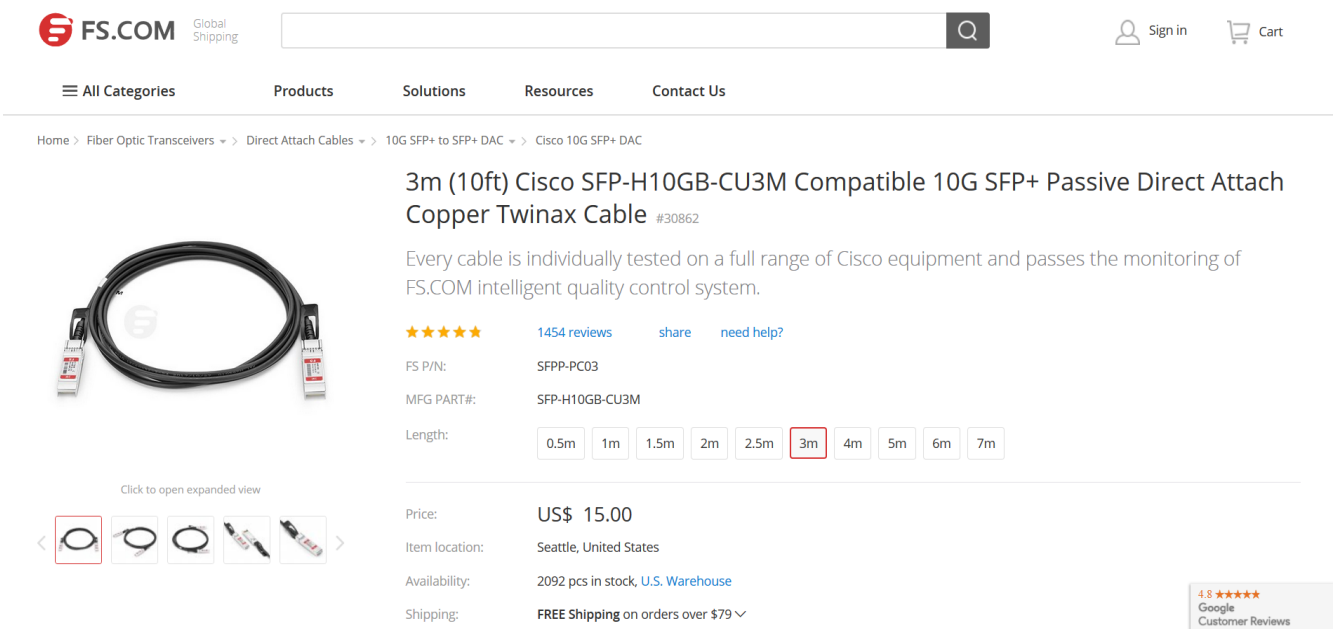
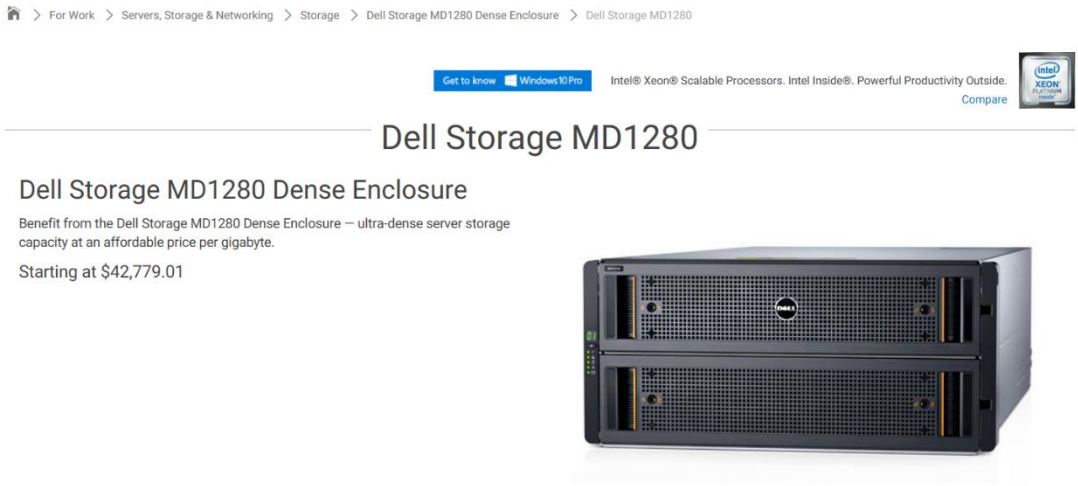


NETWORK CABLES



STORAGE SERVER



CONFIGURATION 2 Support 1 million virtual machines (VM) where each VM requires 2-core, 15GB RAM, 32GB SSD storage, and 1Gb/s Fat-Tree network (each VM should be equivalent to the r3.large instances); in addition to the compute resources, a 10PB distributed storage shared across the entire cloud should be procured, with enough capacity for 10GB/sec throughput (for pricing comparison, see S3)

r3.large configuration

Specifications	Performance
VCPUs	2
Memory(GiB)	15
SSD Storage(GB)	1x32
Processor	Intel Xeon Ivy Bridge
Memory Bandwidth	63000 MB/s
On Demand price($/hr)	0.175

R3 instances provide:

- The latest Intel Xeon Ivy Bridge Processors
- Support for Enhanced Networking that provides lower latency, low jitter, and very high packet per second performance
- Faster random I/O Performance - up to 150,000 4kb random reads per second
- Support for EBS optimization (r3.xlarge, r3.2xlarge, and r3.4xlarge only)

R3 instances are recommended for In-memory analytics, high performance databases including relational databases and NoSQL databases such as MongoDB, and MemcacheD / Redis applications. R3 instances support Hardware Virtualization (HVM) Amazon Machine Images (AMIs) only.

References:https://aws.amazon.com/about-aws/whats-new/2014/04/10/r3-announcing-the-next-generation-of-amazon-ec2-memory-optimized-instances/

COST OF PUBLIC CLOUD

Configuration 2 - Public Cloud

S. No	Instance Type	vCPUs	Memory	Storage	Cost per hour	Number of Instances Required	Cost for 5 Years
	Configuration2 (required 1M VMs)	1M	15 GB per each Virtual Machine	32 GB per each VM	$0.17	1M	$7,446,000,000.00
S. No	**Storage Type**	**Distributed Storage**	**Data transfer**	**Cost for Distributed Storage**	**Cost for data transfer**		**Cost for 5 Years**
	Configuration2 (required)	10 PB	1GB/s	$13,212,057.60	$1,555,200.00		$14,767,257.00
				(.021*12*5*1024*1024*10)	(.01*60*60*12*24*5*30)	Total Cost	$7,460,767,257.00

The total cost for r3 instance is **$7,460,767,257.00**

COST OF PRIVATE CLOUD

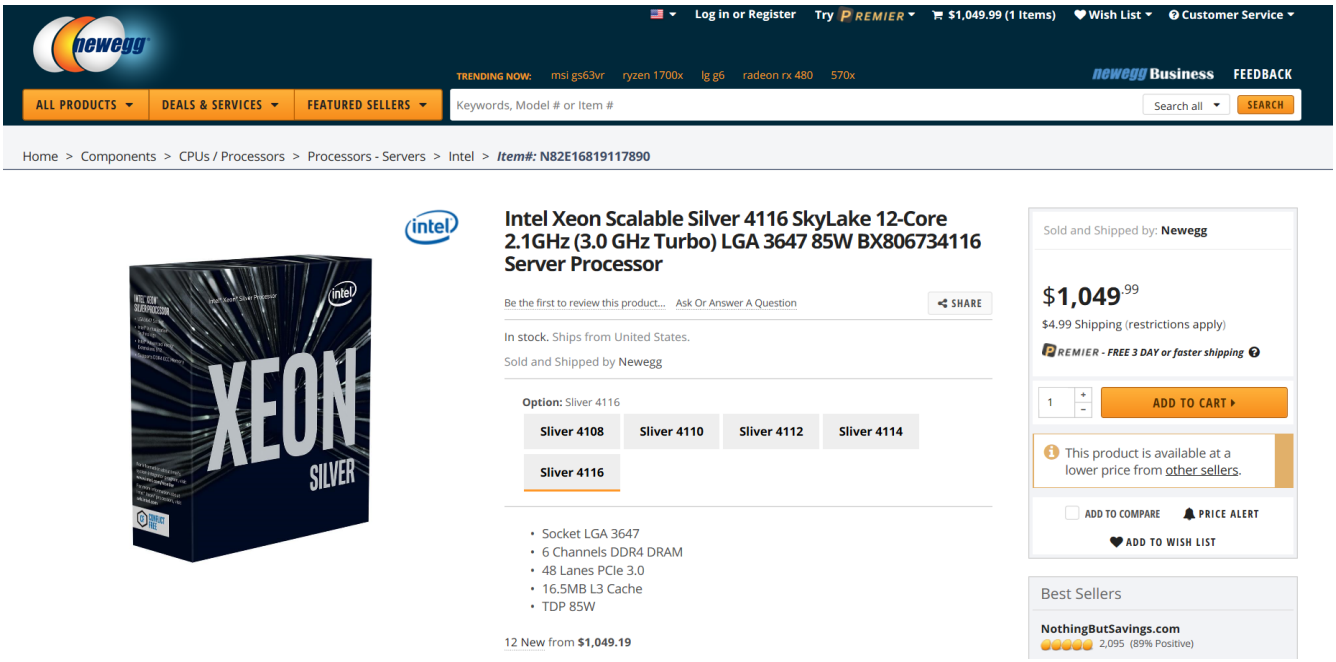
S.No	Products	Sub Products	Description	Price Per Item ($)	Quantity	Total Price ($)	Web Links
1	Compute Servers	Cores (processors)	I have considered a server with CPUs each with 12 core.Intel Xeon Scalable Silver 4116 SkyLake 12-Core 2.1GHz (3.0 GHz Turbo) LGA 3647 85W BX806734116 Server Processor	$1,050.00	45000	$47,250,000.00	https://secure.newegg.com/Shopping/ShoppingCart.aspx
		Memory	I have considered a RAMs of 16 GB (15 GB RAM)	$229.00	45000	$10,305,000.00	http://www.acmemicro.com/Product/11790/16GB-PC3-14900-DIMM-DDR3-1866-Registered-ECC-Dual-Rank-1-5V-Brand-Name-Original?Crits_CheckValue=Memory+Capacity%7C+up+to+16+GB&pager_index=
		Hard drive	I have considered one 32 GB SSD for each server. Intel 32GB MEMPEK1W032GAXT Optane Memory Series NVMe PCIe M.2 2280 1350MB/sec Read 20nm 3D Xpoint, Retail	$79.00	45000	$3,555,000.00	http://www.acmemicro.com/Product/15735/Intel-32GB-MEMPEK1W032GAXT-Optane-Memory-Series-NVMe-PCIe-M-2-2280-1350MB-sec-Read-20nm-3D-Xpoint-Retail?Crits_CheckValue=Product+Type%7CSSD&Crits_CheckValue=Hard+Drive+Capacity%7C+up+to+64+GB&pager_index=
		Chassis	LIAN LI PC-V320X Black Aluminum Mid Chassis Computer Case	$179.99	45000	$8,100,000.00	https://www.newegg.com/Product/Product.aspx?Item=N82E16811112570&ignorebbr=1&nm_mc=KNC-GoogleAdwords-PC&cm_mmc=KNC-GoogleAdwords-PC-_-pla-_-Cases+%28Computer+Cases+-+ATX+Form%29-_-
2	Network Switches	48 Port Network Switch	NETGEAR ProSAFE XS748T 48-Port 10-Gigabit Ethernet Smart Managed Switch	$3,886.61	1684	$6,544,024.00	https://www.amazon.com/NETGEAR-ProSAFE-48-Port-Gigabit-Managed/dp/B00I5W5M12
3	Network Cables	SFP cables	Juniper Networks SRX-SFP-10GE-DAC-3M Compatible 10G SFP+ Passive Direct Attach Copper Twinax Cable	$15.00	45637	$684,555.00	https://www.fs.com/products/36630.html
4	Racks	Rack Mount (Istar USA w4210 42U 1000 mm depth Rackmount Server Cabinet)	Assuming that we can place 10 nodes per Rack of Istar	$1,245.99	62500	$77,874,375.00	https://www.newegg.com/Product/Product.aspx?Item=N82E16816215077
5	Storage Servers	Dell Storage MD1280	High capacity 8TB hard drives. To achieve 1PB distributed storage I have decided to go with 225 numbers to achieve 10PB	$42,779.00	175	$7,486,325.00	http://www.pogolinux.com/quotes/editsys?sys_id=1067693
6	Electric Power	Electric Power cost for Compute Nodes	As per the current Industrial charges, the power cost for kwh per node is 6.47 The total power consumed by each compute node is considered to be 800 W	$2,267.00	45000	$102,015,000.00	https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
7	Cooling	Cooling and Power required for storage	Total BTU/hr generated is 535780136518.77 units.	$2,544.82	45000	$114,480,000.00	https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
8	Administration	System Administartion	We have considered one admin for each 1000 servers	$100,000.00	5	$500,000.00	
Total Cost of private clou		Not Applicable	Not Applicable	Not Applicable	Not Applicable	**$456,194,279.89**	

The total cost of private cloud for the given configuration is **$456,194,279.89**

PRODUCT DETAILS

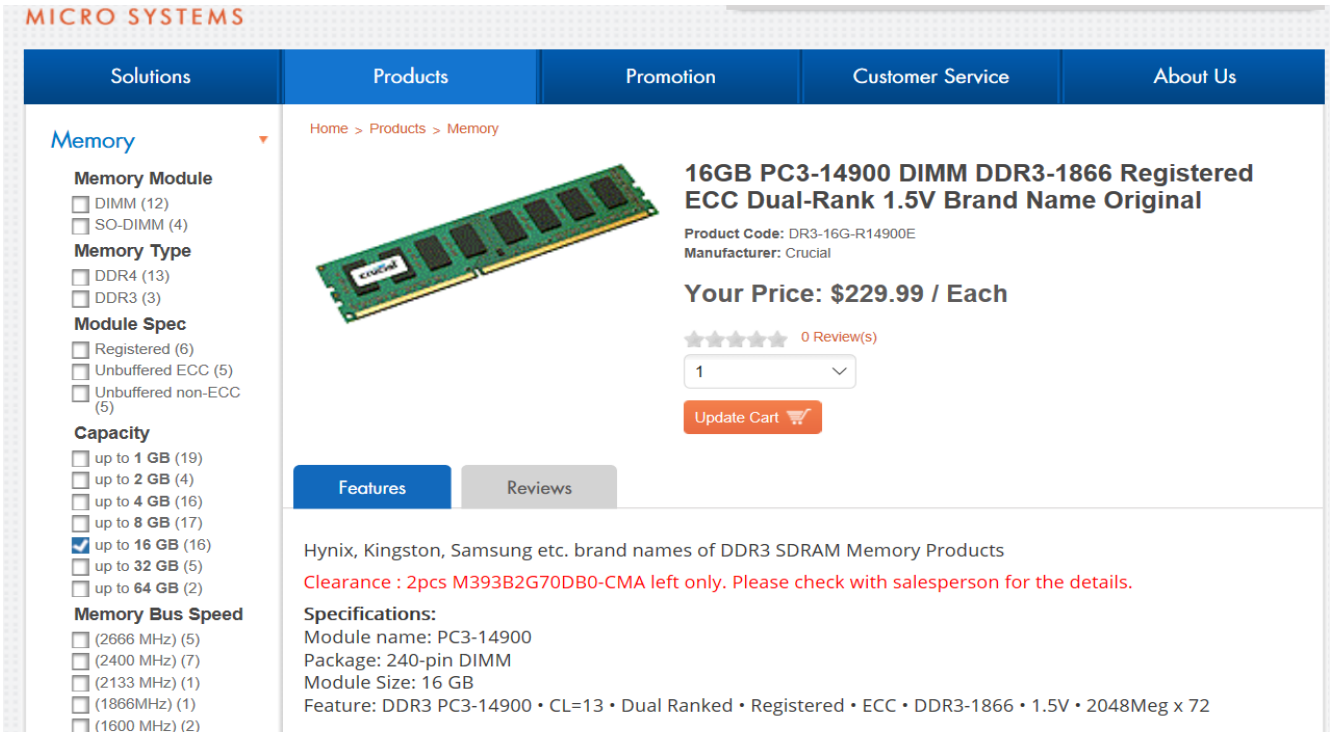
PROCESSOR

https://secure.newegg.com/Shopping/ShoppingCart.aspx



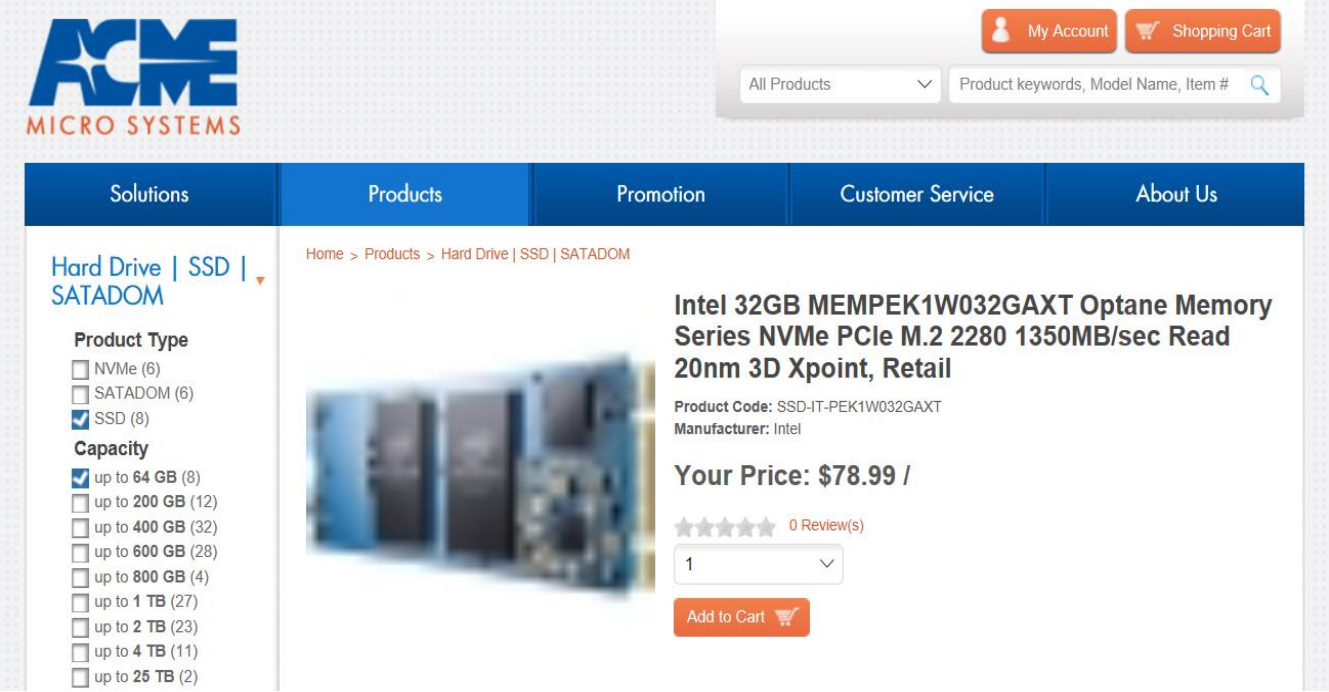
MEMORY

http://www.acmemicro.com/Product/11790/16GB-PC3-14900-DIMM-DDR3-1866-Registered-ECC-Dual-Rank-1-5V-Brand-Name-Original



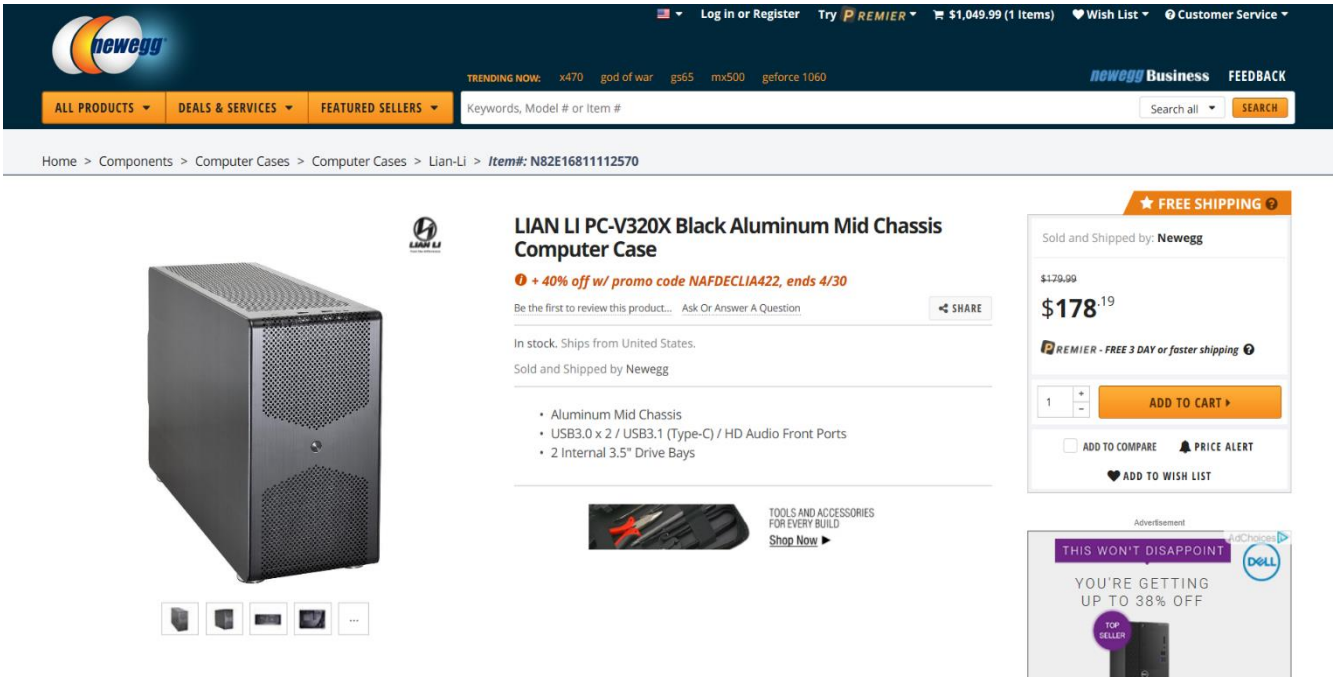
HARD DRIVE

http://www.acmemicro.com/Product/15735/Intel-32GB-MEMPEK1W032GAXT-Optane-Memory-Series-NVMe-PCIe-M-2-2280-1350MB-sec-Read-20nm-3D-Xpoint-Retail



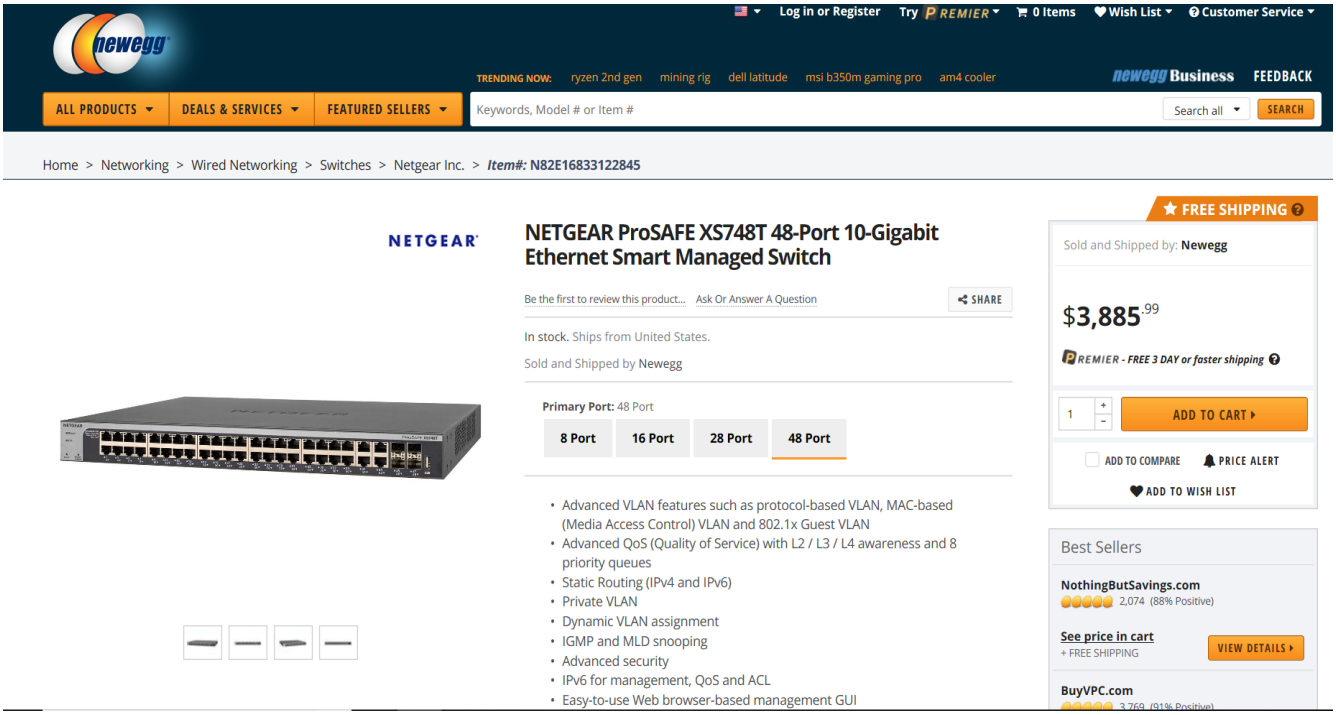
CHASSIS

https://www.newegg.com/Product/Product.aspx



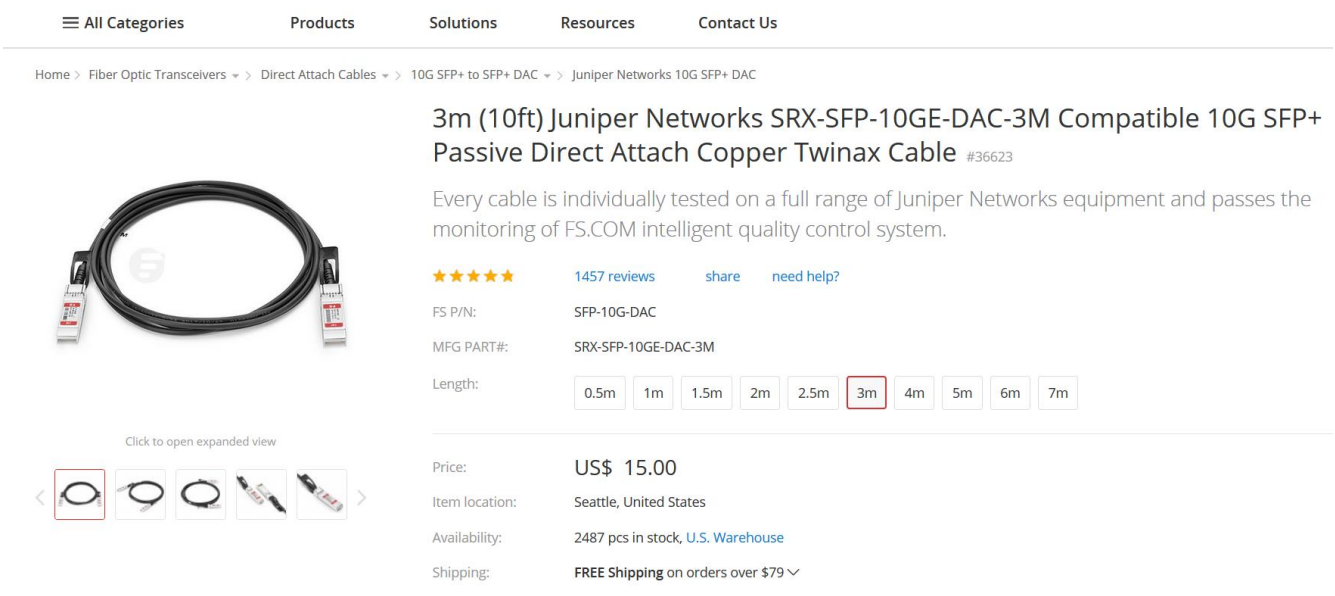
NETWORK SWITCH

Reference : https://www.newegg.com/Product/Product.aspx?Item=N82E16833122845&ignorebbr=1



NETWORK CABLES

Reference: https://www.fs.com/products/36630.html



STORAGE SERVER

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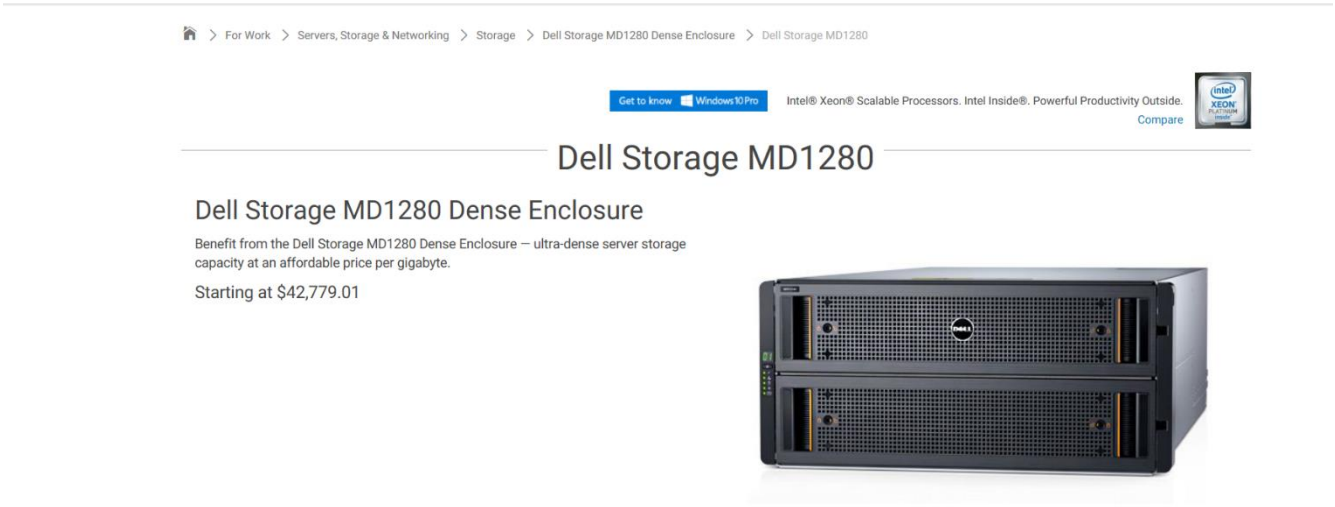

RACKS

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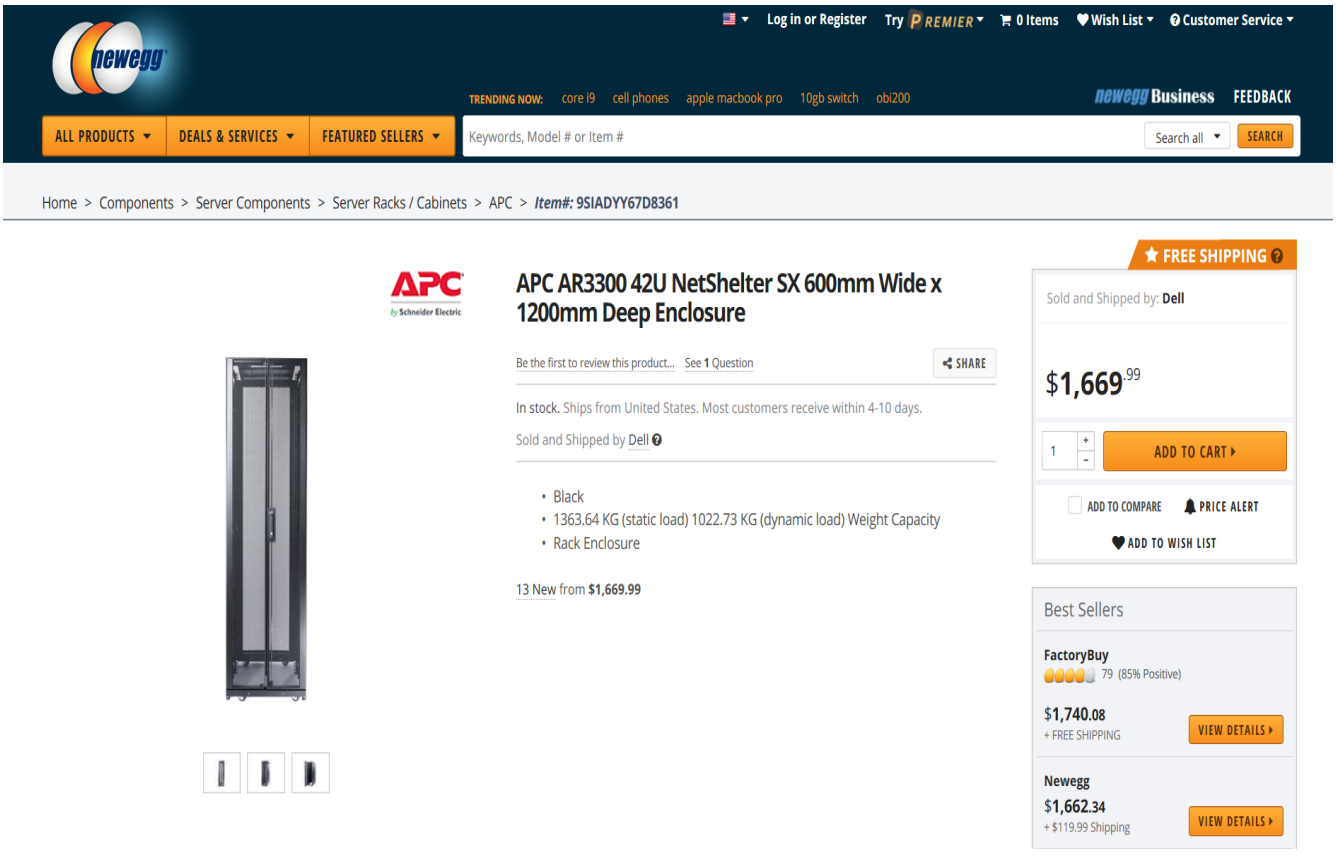


CONFIGURATION 3

Support deep learning with 1 exaflop of mixed precision performance (hint: each VM should be equivalent to p3.16xlarge instances; you will want to use the NVIDIA V100 GPUs (8 GPUs per node), and allocate 8-cores per GPU (64-cores per node) with 8GB of memory per core (512GB per node); the network to use is at least 10Gb/s per GPU (100Gb/s should work), and should be organized in a Fat-Tree network; in addition to the compute resources, a 1PB distributed storage shared across the entire cloud should be procured, with enough capacity for 10GB/sec throughput (for pricing comparison, see S3)

p3.16xlarge Hardware Configuration

SPECIFICATION	PERFORMANCE
vCPUs	64
Memory(GB)	488
Processor	Intel Xeon E5(Broadwell) and 488 GB DRAM
Network Bandwidth	25 Gbps
EBS Bandwidth	14 Gbps
GPU Memory	128
GPUs Tesla v100	8
On Demand Price	$24.48

P3 instances are well-suited for distributed deep learning frameworks, such as MXNet, that scale out with near perfect efficiency. P3 instances are fundamentally disrupting how organizations typically consume computing hardware for artificial intelligence/machine learning/high-performance computing services.

References: https://aws.amazon.com/ec2/instance-types/p3/

			PUBLIC CLOUD					
S. No	Instance Type	GPUs	Memory	VCPUs	Main Memory	Cost per Hour	Number of Instances	Cost for 5 Years
1	Configuration3 (1 Exa flop Precision)	1000	128 GiB per each node	64 cores per node	512 GB per node	$24.48	1,000.00	$1,072,224,000.00
S. No	Storage Type	Distributed Storage	Data transfer	Cost for Distributed Storage	Cost for data transfer			Cost for 5 Years
1	AWS S3	Over 500 TB/month	> 5 PB per month	$0.021 per GB	Assuming $0.01 per GB			
	Configuration3 (required)	1 PB	10Gb/s	$1,321,205.76	$15,768,000.00			$17,089,205.00
							Total Cost	$1,089,313,205.00

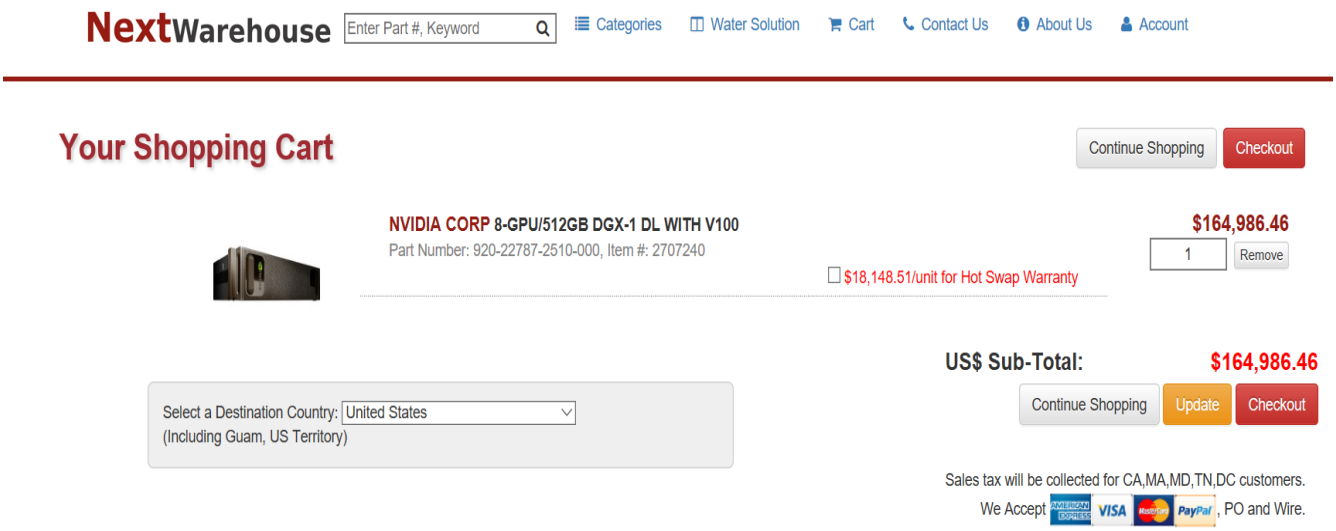
COST EVALUATION OF PRIVATE CLOUD

				PRIVATE CLOUD			
S.No	Products	Sub Products	Description	Price Per Item ($)	Quantity	Total Price ($)	Web Links
1	Compute Servers	Cores (processors)	I have decided to go with NVIDIA v100 8GPUs each of 8 core per GPU to achieve 1 exaflop of mixed precision	$164,986.00	1000	$164,986,000.00	http://www.nextwarehouse.com/cart.cfm?action=ADD&itm_id=2707240&qty=1
		Memory	I have selected Kingston ValueRAM 64GB (4 x 16GB) DDR4 2400 RAM (Server Memory) ECC Reg DIMM (288-Pin) KVR24R17D8K4/64 each node to achieve 256 TB memory	$888.65	1000	$888,000.00	http://www.acmemicro.com/Products/Memory?Crits_CheckValue=Memory+Capacity%7C+up+to+64+GB&pager_index=
2	Network Switches	48-Port Switch	NETGEAR ProSAFE XS748T 48-Port 10-Gigabit Ethernet Smart Managed Switch	$3,885	26	$101,010	https://www.newegg.com/Product/Product.aspx?Item=N82E16833122845&ignorebbr=1
3	Network Cables	SFP Cables	Juniper Networks SRX-SFP-10GE-DAC-3M Compatible 10G SFP+ Passive Direct Attach Copper Twinax Cable	$15	1050	$15,750	https://www.fs.com/products/36630.html
4	Racks	Rack Mount	APC AR3300 42U NetShelter SX 600mm Wide x 1200mm Deep Enclosure. I have assumed to place 4 nodes per Rack summing up 1000 together	$1,670	250	$417,500	https://www.newegg.com/Product/Product.aspx?Item=9SIADYY67D8361&ignorebbr=1
5	Storage Servers	Dell Storage MD1280	84 hard drives in a 5U standard rack mount chassis with a High capacity 8TB hard drives. To achieve 1PB distributed storage I have decided to go with 2 numbers	$42,779	3	$128,337	http://www.dell.com/en-us/work/shop/server-jbod-expansion/md1280/spd/storage-md1280/pv_md1280_1084
6	Electric Power	Power of compute nodes	As per the current Illinois Industrial wages, the cost of one kilowatt per hour is 7.59 cents	$11,387	1000	$11,387,000	https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
7	Cooling	ooling for servers and nod	There are 1000 nodes considered for this configuration		1000	$1,200,000	
8	Administration	System Administration	Considering one admin for 1000 servers	$100,000/year	5 years	$500,000	https://www.payscale.com/research/US/Job=Systems_Administrator/Salary
	TOTAL COST	N/A	N/A	N/A	N/A	**$179,123,597.00**	

PRODUCT DETAILS

PROCESSOR

Reference: http://www.nextwarehouse.com/cart.cfm?action=ADD&itm_id=2707240&qty=1



MEMORY

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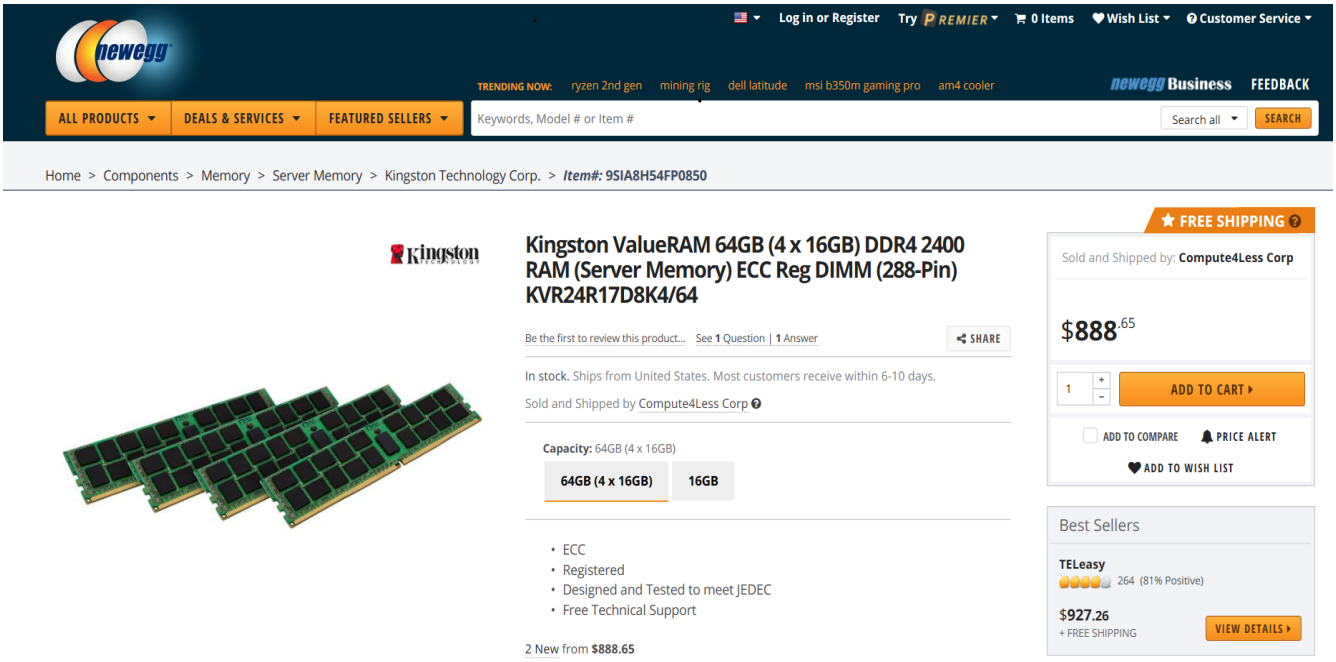
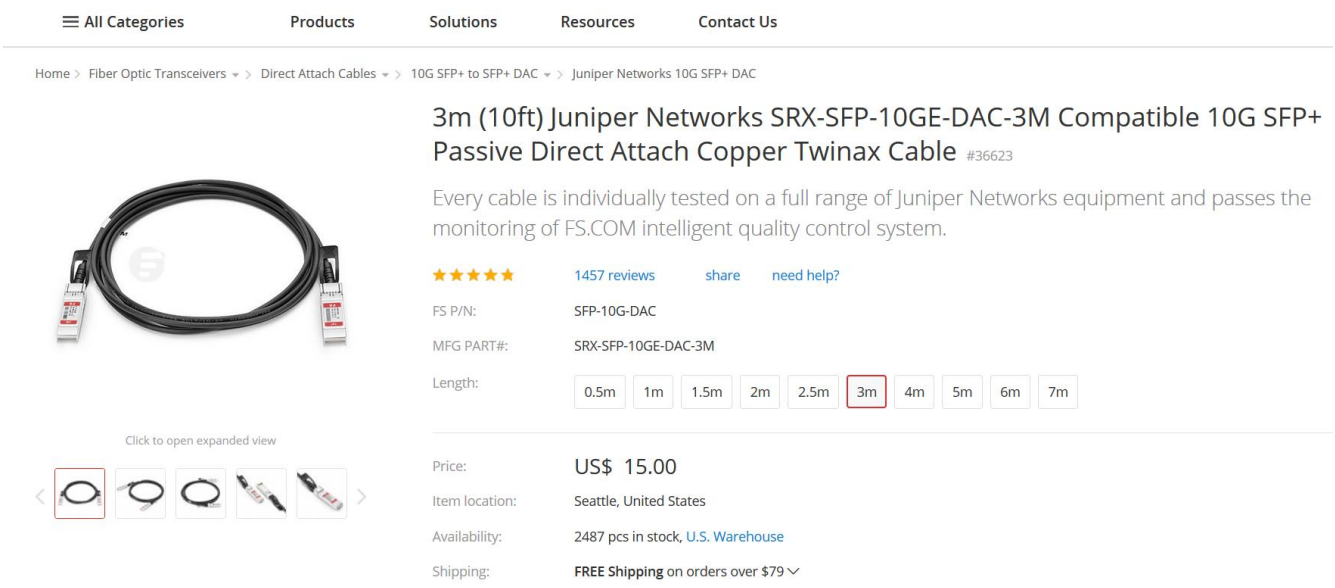


NETWORK SWITCH

Reference : https://www.newegg.com/Product/Product.aspx?Item=N82E16833122845&ignorebbr=1

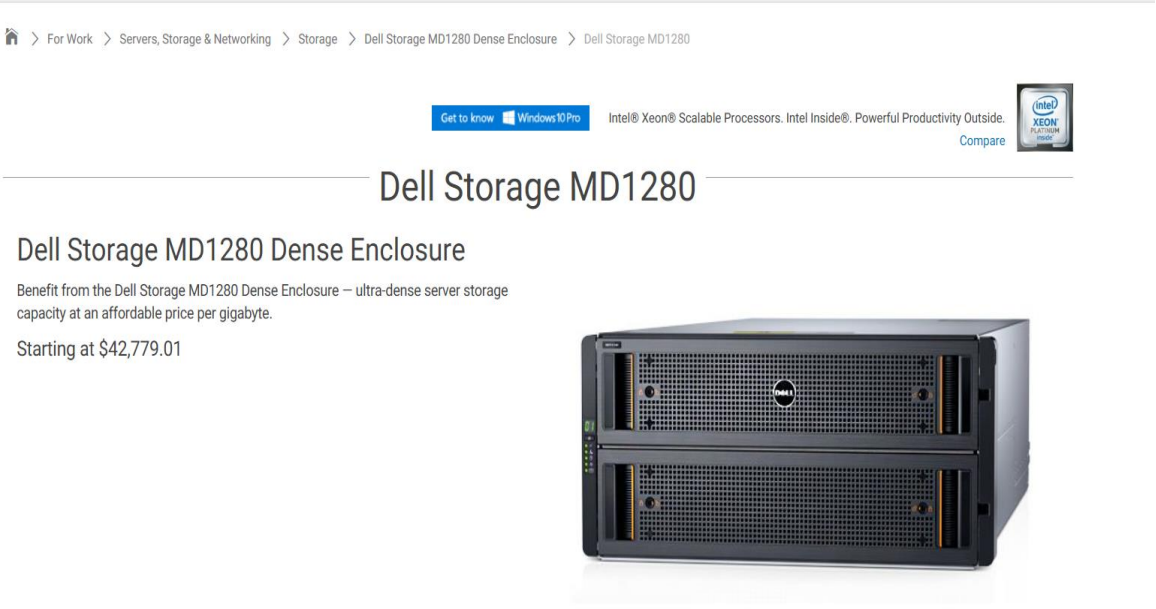
NETWORK CABLES

Reference: https://www.fs.com/products/36630.html



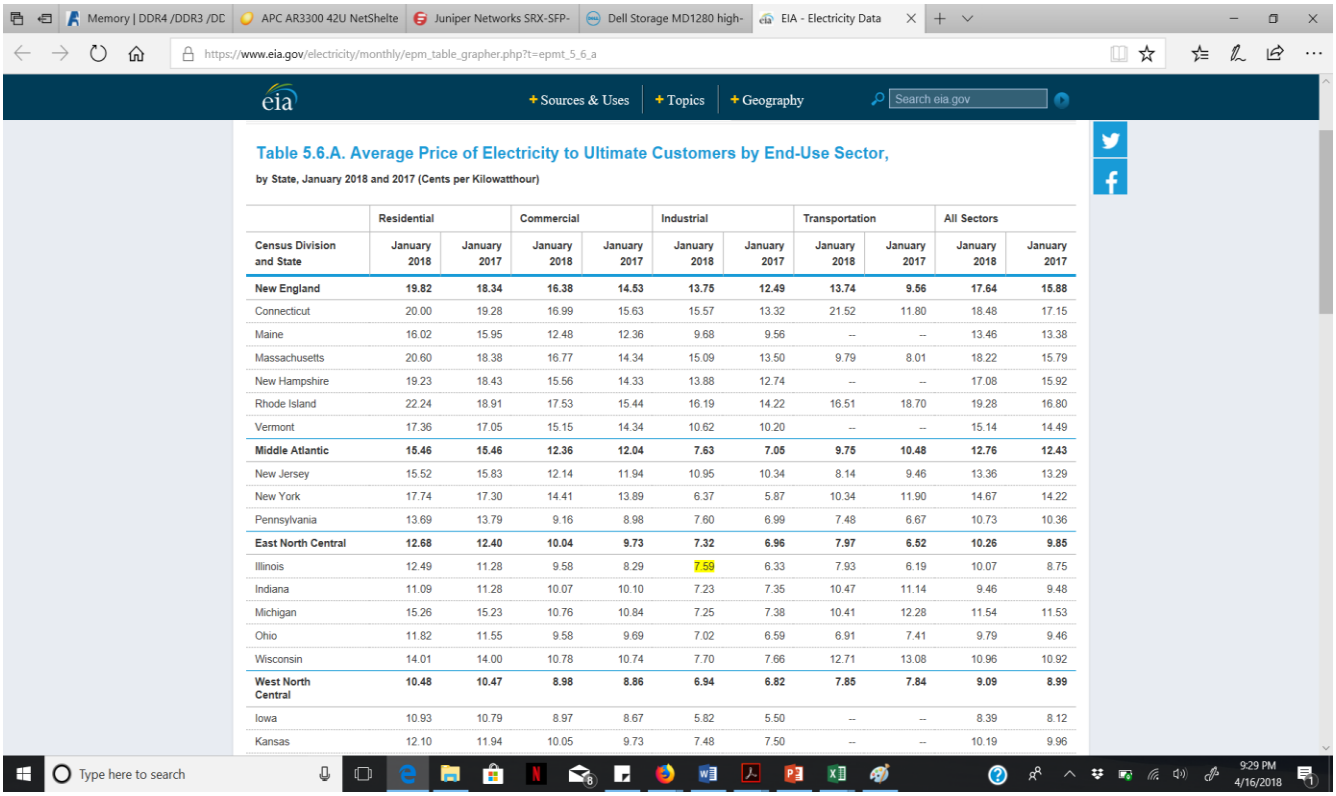
STORAGE SERVER

http://www.dell.com/en-us/work/shop/server-jbod-expansion/md1280/spd/storage-md1280/pv_md1280_1084



ELECTRICITY PRICING

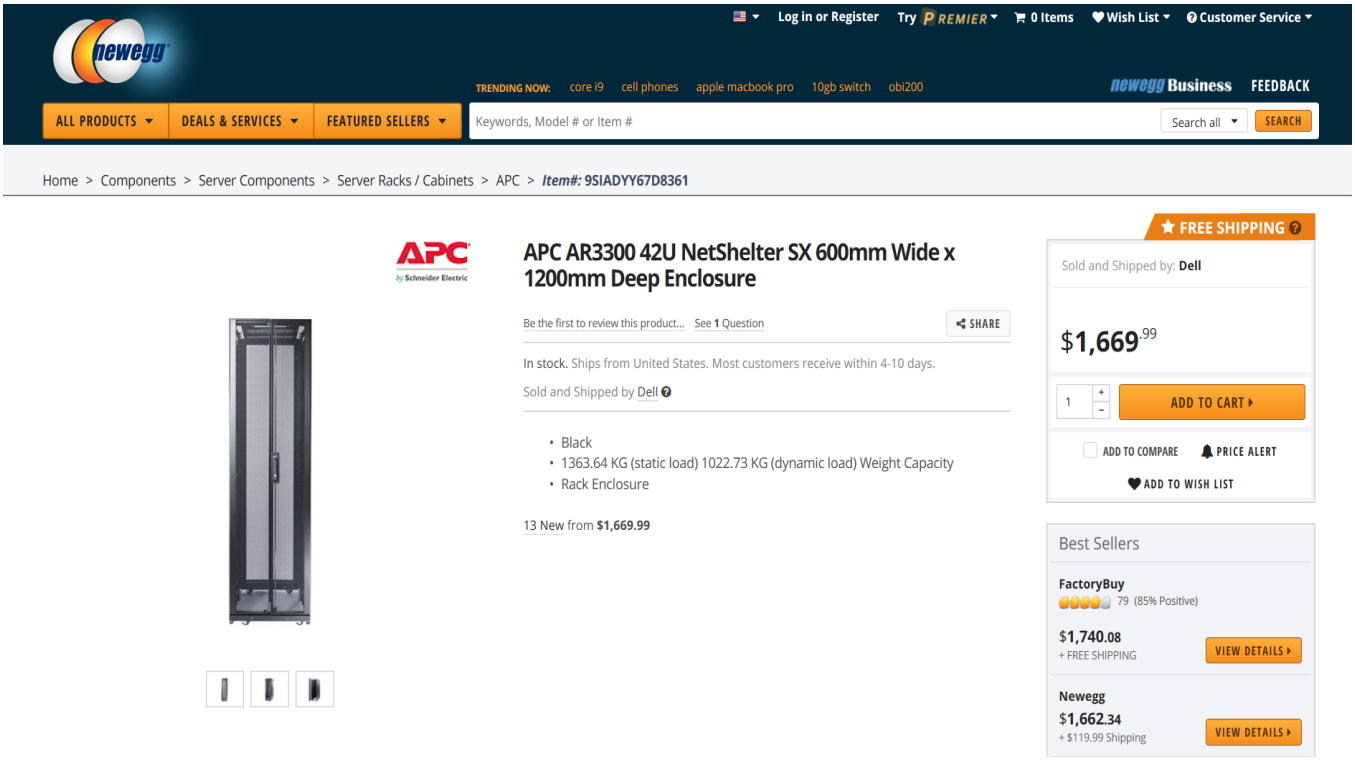
Reference: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a



	Residential		Commercial		Industrial		Transportation		All Sectors	
Census Division and State	January 2018	January 2017	January 2018	January 2017	January 2018	January 2017	January 2018	January 2017	January 2018	January 2017
New England	**19.82**	**18.34**	**16.38**	**14.53**	**13.75**	**12.49**	**13.74**	**9.56**	**17.64**	**15.88**
Connecticut	20.00	19.28	16.99	15.63	15.57	13.32	21.52	11.80	18.48	17.15
Maine	16.02	15.95	12.48	12.36	9.68	9.56	--	--	13.46	13.38
Massachusetts	20.60	18.38	16.77	14.34	15.09	13.50	9.79	8.01	18.22	15.79
New Hampshire	19.23	18.43	15.56	14.33	13.88	12.74	--	--	17.08	15.92
Rhode Island	22.24	18.91	17.53	15.44	16.19	14.22	16.51	18.70	19.28	16.80
Vermont	17.36	17.05	15.15	14.34	10.62	10.20	--	--	15.14	14.49
Middle Atlantic	**15.46**	**15.46**	**12.36**	**12.04**	**7.63**	**7.05**	**9.75**	**10.48**	**12.76**	**12.43**
New Jersey	15.52	15.83	12.14	11.94	10.95	10.34	8.14	9.46	13.36	13.29
New York	17.74	17.30	14.41	13.89	6.37	5.87	10.34	11.90	14.67	14.22
Pennsylvania	13.69	13.79	9.16	8.98	7.60	6.99	7.48	6.67	10.73	10.36
East North Central	**12.68**	**12.40**	**10.04**	**9.73**	**7.32**	**6.96**	**7.97**	**6.52**	**10.26**	**9.85**
Illinois	12.49	11.28	9.58	8.29	7.59	6.33	7.93	6.19	10.07	8.75
Indiana	11.09	11.28	10.07	10.10	7.23	7.35	10.47	11.14	9.46	9.48
Michigan	15.26	15.23	10.76	10.84	7.25	7.38	10.41	12.28	11.54	11.53
Ohio	11.82	11.55	9.58	9.69	7.02	6.59	6.91	7.41	9.79	9.46
Wisconsin	14.01	14.00	10.78	10.74	7.70	7.66	12.71	13.08	10.96	10.92
West North Central	**10.48**	**10.47**	**8.98**	**8.86**	**6.94**	**6.82**	**7.85**	**7.84**	**9.09**	**8.99**
Iowa	10.93	10.79	8.97	8.67	5.82	5.50	--	--	8.39	8.12
Kansas	12.10	11.94	10.05	9.73	7.48	7.50	--	--	10.19	9.96

RACK

Reference: https://www.newegg.com/Product/Product.aspx?Item=9SIADYY67D8361&ignorebbr=1



SUMMARY TABLE

	Configuration 1	Configuration 2	Configuration 3
Public Cloud (including EC2 and S3) Cost over 5 years, 24/7 operation, with 100% usage	**$529,416,576**	**$7,460,767,257**	**$1,089,313,205.00**
Private Cloud cost over 5 years, 24/7 operation, with 100% usage	**$29,613,840**	**$456,194,279.89**	**$179,123,597.00**
What utilization must be achieved with the private cloud to make the private cloud option more attractive than the public cloud?	The cost of private cloud setup is almost one third of the total cost of public setup in this configuration. So **private cloud seems to be more attractive and economical** unless the utilization reduces to 50% If this happens then the public cloud will be preferred over private.	The total public cloud is extremely expensive in this configuration when compared to the total cost for setting up the private cloud where the cost of public is almost 7 times more than the private cloud setup. So, it is **preferable to go with private setup** in this configuration.	The difference between the public cloud setup and the private cloud setup is almost 10 times higher, so any kind of utilization won't affect much and the **private cloud will always be advised to purchase and economical** than the public cloud setup.

CONCLUSION

We can clearly estimate based on the above analysis that the total cost of private cloud is cheaper than the total cost of public cloud. So, it is better to purchase a private cloud. However, it depends on the amount of utilization for each configuration for a span of 5 years. Public cloud seems to be attractive and affordable with lesser utilizations over a long time.