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SPC Benchmarks: *An Aid to Evaluate Storage Products*

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Agenda

- Storage performance, price-performance and power/energy consumption
- Storage Performance Council (SPC) Overview
- Evaluation using SPC Benchmark 1™ (SPC-1™)
  - Storage Vendor Perspective
  - End-User/Customer Perspective

Storage Performance
Price-Performance
Power/Energy Consumption

Keys to a Successful Storage Product

- **Performance, price-performance and power/energy consumption are three key factors:**
  - **Successful development of a storage product *(vendor perspective)*.**
  - **Successful purchase or upgrade *(end-user/customer perspective)*.**

Performance – Vendor Perspective

- **A “measure of success” during product development.**
  (Are performance targets maintained during the development cycle?)

- **A factor in internal product positioning.**
  (Where should the product be positioned and marketed within a product family?)

- **A key differentiator in competitive positioning.**
  (How should the product be positioned and marketed against competitors?)

Performance – End-User Perspective

- **Can the product deliver the I/O performance required for successful application performance.**
  - **Volume/Quantity *(throughput)***
    I/O rate needed to support the required online transaction rate.
    Data throughput needed to support batch processing requirements.
  - **Response/Residence Time**
    I/O response time required for acceptable OLTP performance.
    Data rate required for batch processing timing requirements.

Price-Performance

- **Vendor Perspective:**

  A key differentiator in competitive positioning.

  (How should the product be positioned and marketed against competitors?)

- **End-User/Customer Perspective:**

  What is the realistic cost, including support and maintenance, for a product that meets the performance and, optionally power/energy consumption requirements.

Power/Energy Consumption

- A relatively new factor that is gaining importance for consideration along with performance and price-performance.
- End users/customers are developing energy 'budgets' during data center planning to consider:
  - Increasing cost of finite energy sources: coal, petroleum products, etc.
  - Ecological impact of increasing energy use.

Storage Performance Council (SPC)

The SPC provides the means to accurately assess and compare storage performance, price-performance and power/energy consumption for both storage vendors and end-users/customers.

Storage Performance Council (SPC) Overview

Storage Performance Council (SPC)

- **The SPC is a non-profit corporation founded in 1998 to accomplish the following:**
  - Define, standardize and promote the first industry-standard storage performance benchmarks
  - Disseminate objective, verifiable storage performance data to developers and end-users/customers of computer systems

SPC Objectives

- Provide an incentive for storage performance improvements in the computer systems industry
- Enable end-users/customers to accurately compare storage products in a multi-vendor marketplace
- Establish a level “playing field” for storage vendors
- Publicize storage performance results
- Ensure accuracy and authenticity of those results

SPC Membership

EMC Corporation

SPC Membership

KAIST

ORACLE

SK hynix memory solutions

TOSHIBA
Leading Innovation

LSI

PENNSTATE

SOLIDFIRE

UC SANTA CRUZ

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SAMSUNG

STEC
The SSD Company™

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NetApp
Go further, faster

Seagate

Symantec Corporation

Western Digital

NIMBUS DATA

sgi

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON DC

xio

SPC Membership Consolidation

EMC Corporation ⇦ XtremIO

SPC Benchmarks

- **SPC Benchmark 1™ (SPC-1™)**
- **SPC Benchmark 2™ (SPC-2™)**
- SPC-1 and SPC-2 are the two “core” benchmarks of the SPC.
- From those “core” benchmarks, the SPC developed:
  - Component-level benchmarks
  - Energy extensions to measure power consumption

SPC Benchmark 1 (SPC-1)

- SPC-1 consists of a single workload that demonstrates storage performance type of business critical applications.
- Those applications are characterized by predominately random I/O operations, requiring both queries as well as update operations.
- Examples of those types of applications include OLTP, database operations and mail server implementations.

SPC Benchmark 2 (SPC-2)

- SPC-2 consists of three distinct workloads to demonstrate the storage subsystem performance of business critical applications, which require large-scale, sequential movement of data.
- Those applications are characterized predominately large I/Os organized into one or more concurrent sequential patterns.

SPC Benchmark 2 (SPC-2)

- SPC-2 Workloads:
  - **Large File Processing** *(LFP)*: Simple sequential processing of one or more large files *(scientific computing, large-scale financial processing, etc.)*.
  - **Large Database Query** *(LDQ)*: Scans or joins of large relational tables *(data mining, business intelligence, etc.)*
  - **Video on Demand** *(VOD)*: Delivery of individualized video entertainment to a community of subscribers from a digital film library.

SPC Component Benchmarks

- There is a distinct need to provide objective and verifiable performance measurement and comparisons of individual storage components such as storage devices *(HDDs/SSDs)*, HBAs/controllers, small storage subsystems, storage software, etc.
- SPC-1 and SPC-2 provide that type of performance measurement and comparison, but are used for large, complex storage configurations.

SPC Component Benchmarks

- **SPC Benchmark 1C™ (SPC-1C™)**
  - SPC-1C is based on the SPC-1 benchmark specification and will utilize the single SPC-1 workload.
- **SPC Benchmark 2C™ (SPC-2C™)**
  - SPC-2C is based on the SPC-2 benchmark specification and will utilize the three SPC-2 workloads

SPC Component Benchmarks

- SPC-1C and SPC-2C provide performance measurement and comparison for storage components such as:
  - Storage devices *(HDDs, SSDs and hybrid devices)*
  - HBAs/controllers
  - Small storage subsystems *(single enclosure)*
  - Processors used in the above components
  - Storage software such as Logical Volume Managers

SPC Energy Extensions

- **SPC Benchmark 1/Energy™ (SPC-1/E™)**
- **SPC Benchmark 2/Energy™ (SPC-2/E™)**
- **SPC Benchmark 1C/Energy™ (SPC-1C/E™)**
- **SPC Benchmark 2C/Energy™ (SPC-2C/E™)**
- Each SPC benchmark includes an optional energy extension, which includes energy use measurement and reporting.

Evaluation using SPC Benchmark 1™ (SPC-1™) Storage Vendor Perspective

SPC-1 Performance

- Every SPC member company that has used SPC-1 has “discovered” opportunities to improve product performance.
- SPC-1 measurements have become a “measure of success” during product development.

SPC-1 Performance

- **Many member companies have incorporated SPC-1 measurements into the product development cycle.**
  - Provides a basis for performance targets.
  - Used in regular regression testing to assess performance improvement or degradation.
- **Audited SPC-1 Result upon product release to provide external “proof point” for competitive positioning.**

SPC-1 – Storage Vendor Perspective

Additional SPC-1 technical details and storage vendor perspectives provided in the *"Storage Performance, Price-Performance and Power: The Three Key to Success"* presentation that is part of the Performance track.

Evaluation using SPC Benchmark 1™ (SPC-1™) End-User/Customer Perspective

SPC-1 – End User/Customers

- SPC-1 Results provide accurate, reliable performance, price-performance and energy/power consumption data for product comparisons in purchase evaluations.
- That same data can also be used to prepare detailed capacity plans, including an energy budget for the storage portion of a data center.

SPC-1 – End User/Customers

- **Each SPC-1 Result includes a required Executive Summary and Full Disclosure Report (FDR) which contain:**
  - **SPC-1 Reported Data *(performance, price-performance, etc.).***
  - **Detailed benchmark configuration documentation.**
  - **Optionally, power (SPC-1/E) reported data.**

SPC-1 Reported Data

SPC-1 Reported Data	
Tested Storage Product (TSP) Name: Huawei OceanStor Dorado2100 G2	
Metric	**Reported Result**
SPC-1 IOPS™	400,587.11
SPC-1 Price-Performance™	$0.57/SPC-1 IOPS™
Total ASU Capacity	3,801.046 GB
Data Protection Level	Protected 2 *(Mirroring)*
Total Price	$227,062.00
Currency Used	U.S. Dollars
Target Country for availability, sales and support	USA

- **SPC-1 IOPS™:** The maximum I/O Request Throughput at the 100% load point.
- **SPC-1 Price-Performance™:** The ratio of **Total Price** to **SPC-1 IOPS**.
- **Total ASU Capacity:** The total Application Storage Unit (ASU) capacity represents the total storage capacity available to be read and written by an end-user application, in this case, the SPC-1 Workload Generator.

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- **Data Protection Level: Protected 2** ensures that the single point of failure of any **component** in the configuration will not result in permanent loss of access or integrity to the SPC-1 Data Repository.
  Protected 1 ensures that the single point of failure of any **storage device** in the configuration will not result in permanent loss of access or integrity to the SPC-1 Data Repository.

SPC-1 Reported Data

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Currency Used	U.S. Dollars
Target Country for availability, sales and support	USA

- **Total Price:** The cost of the Priced Storage Configuration plus three year of hardware maintenance and software support.
- **Currency Used:** The formal name of the currency used in calculating the **Total Price** and **SPC-1 Price-Performance**. That currency can be the local currency of the **Target Country** or the currency of a different country (non-local currency).

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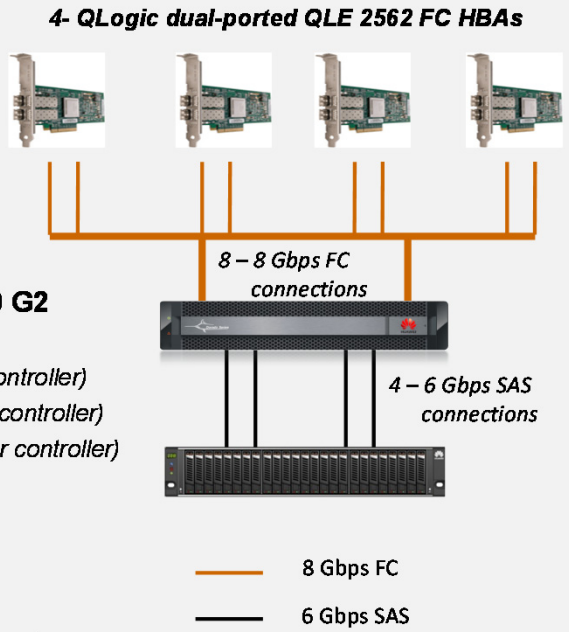
- **Target Country:** The country in which the Priced Storage Configuration is available for sale in which the required hardware maintenance and software support is provided either directly from the Test Sponsor or indirectly via a third-party supplier.
- The Executive Summary and Full Disclosure Report (FDR) for each SPC Result *(all benchmarks)* is available on the SPC website at: *http://www.storageperformance.org/results*.

SPC-1 Configuration

- **The Executive Summary and Full Disclosure Report (FDR) document the SPC-1 configuration in detail from HBAs to the storage devices.**
- **In addition all steps to prepare the configuration for benchmark execution are documented in detail, include any system parameters changed from default values.**

SPC-1 Configuration



Huawei OceanStor Dorado2100 G2

dual controllers - Active-Active

48 GB memory/cache (24 GB per controller)

8 – 8 Gbps FC connections (4 per controller)

4 – 6 Gbps SAS connections (2 per controller)

25 – 200 GB SSD disk drives

1 – Disk Enclosure

25 – 200 GB SSD disk drives

50 – 200 GB SSD disk drives

25 – disk drives in the controller enclosure

25 – disk drives in the disk enclosure

Priced Storage Configuration:
4 – Qlogic dual-port QLE2562 FC HBAs
Huawei OceanStor Dorado2100 G2 **dual-controllers – Active Active** 48 GB memory/cache *(24 GB per controller)* 8 – 8 Gbps FC front-end ports *(4 per controller)* *(8 – 8 Gbps connections used)* 4 – 24 Gbps SAS backend ports *(2 per controller)* *(4 – 6 Gbps connections used)* 25 – 200 GB SSD disk drives
1 – Disk Enclosure 25 – 200 GB SSD disk drives
50 – 200 GB SSD disk drives *25 – SSD disk drives in the controller enclosure* *25 – SSD disk drives in the disk enclosure*

SPC-1 Performance

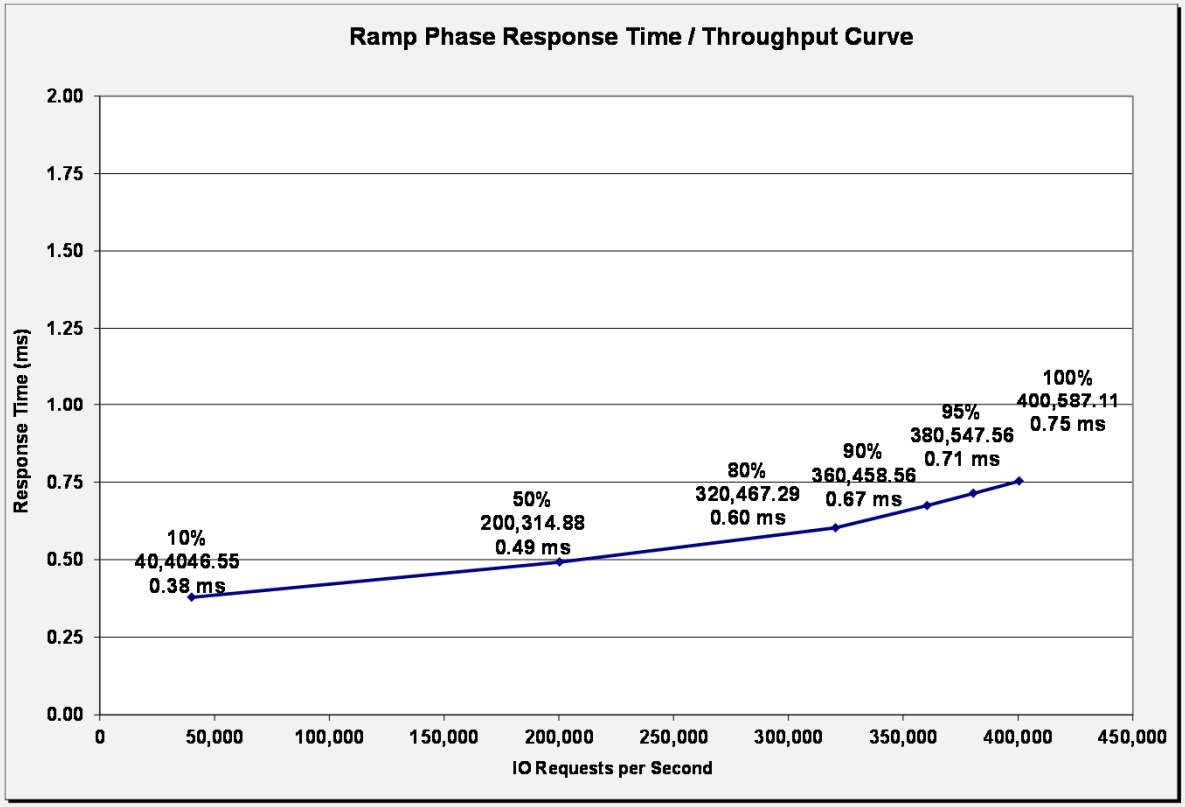
- **Detailed performance data available:**
  - Throughput in IOPS
  - Average response time in milliseconds (ms)
  - Data rate in MB per second
- **Performance data reported for various levels:**
  - All ASUs (overall performance)
  - By individual ASU
  - By reads and writes

SPC-1 Performance

Response Time / Throughput Curve

100%, 95%, 90%, 80%, 50% and 10% of the maximum specified BSU level

8,012 BSUs, 400,600 SPC-1 IOPS maximum



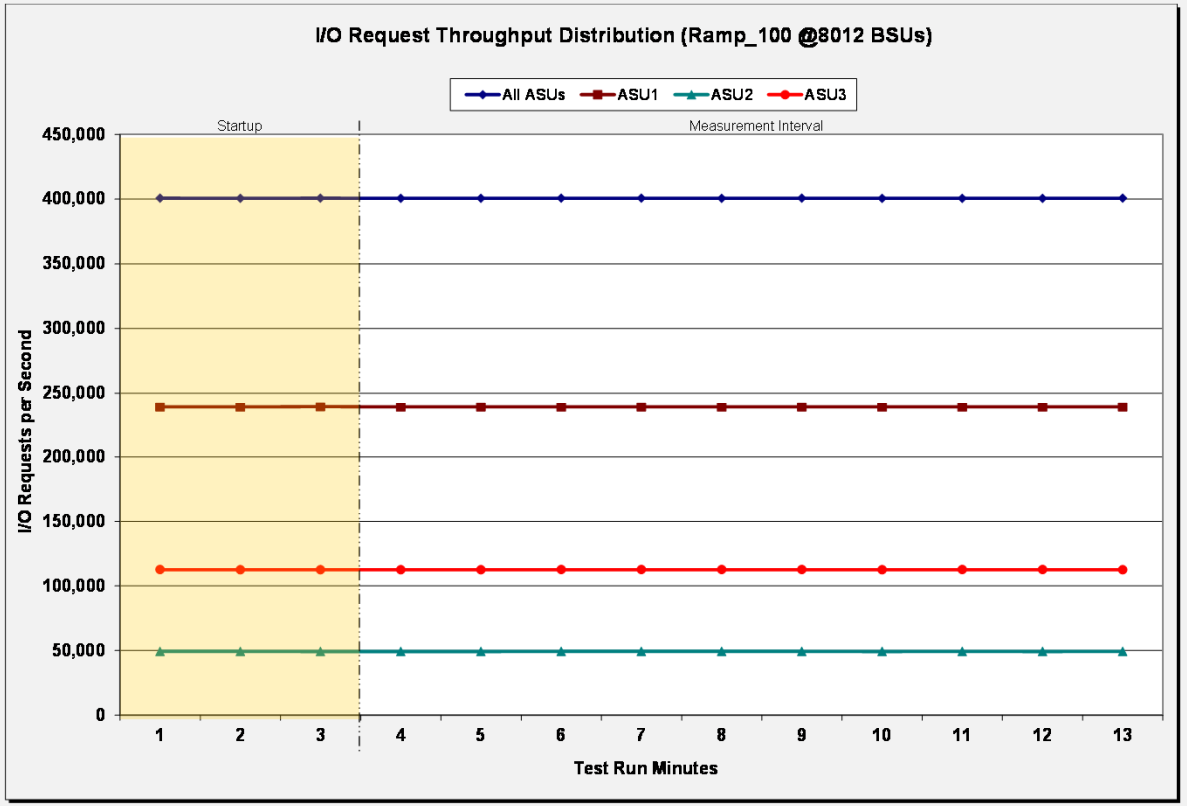
SPC-1 Performance – SPC-1 IOPS

8,012 BSUs specified

400,587.11
SPC-1 IOPS

The reported SPC-1 performance metric

	I/Os per Second					
	All ASUs	ASU1	ASU2	ASU3	Reads	Writes
0	400,705.27	238,809.93	49,271.97	112,623.37	158,023.13	242,682.13
1	400,530.70	238,697.07	49,278.05	112,555.58	157,968.37	242,562.33
2	400,702.60	238,929.47	49,236.58	112,536.55	156,119.22	242,583.38
3	400,536.13	238,727.08	49,253.33	112,555.72	157,946.30	242,589.83
4	400,540.38	238,752.93	49,264.92	112,522.53	158,013.92	242,526.47
5	400,647.87	238,708.37	49,297.17	112,642.33	158,005.67	242,642.20
6	400,631.25	238,756.32	49,275.32	112,599.62	158,042.55	242,588.70
7	400,580.83	238,679.93	49,310.08	112,590.82	157,916.62	242,664.22
8	400,660.08	238,772.10	49,299.98	112,588.00	158,049.42	242,610.67
9	400,552.60	238,709.65	49,260.57	112,582.38	158,019.80	242,532.80
10	400,563.37	238,669.17	49,292.32	112,601.88	157,926.35	242,637.02
11	400,549.28	238,705.77	49,252.85	112,590.67	157,924.05	242,625.23
12	400,609.28	238,765.10	49,308.98	112,535.20	158,051.60	242,557.68
Average	**400,587.11**	**238,724.64**	**49,281.55**	**112,580.92**	**157,989.63**	**242,597.48**



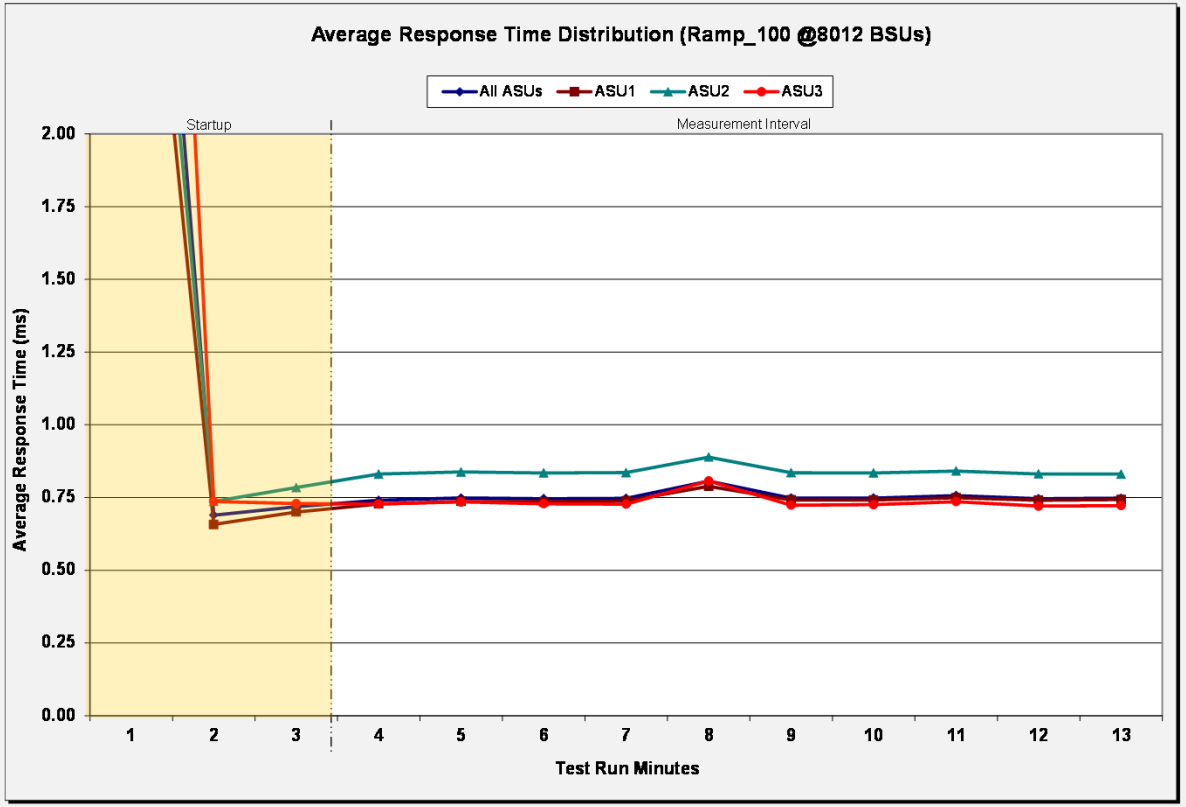
SPC-1 Performance – Response Time

8,012 BSUs specified

0.75 ms

The reported SPC-1 average response time

	Average Response Time (ms)					
	All ASUs	ASU1	ASU2	ASU3	Reads	Writes
0	4.29	3.47	3.81	6.24	1.06	6.39
1	0.69	0.66	0.74	0.74	0.65	0.71
2	0.72	0.70	0.78	0.73	0.74	0.71
3	0.74	0.73	0.83	0.73	0.80	0.70
4	0.75	0.74	0.84	0.73	0.81	0.71
5	0.75	0.74	0.83	0.73	0.81	0.70
6	0.75	0.74	0.84	0.73	0.81	0.70
7	0.81	0.79	0.89	0.81	0.84	0.78
8	0.75	0.74	0.84	0.72	0.82	0.70
9	0.75	0.74	0.83	0.73	0.82	0.70
10	0.76	0.75	0.84	0.74	0.82	0.71
11	0.75	0.74	0.83	0.72	0.82	0.70
12	0.75	0.74	0.83	0.72	0.82	0.70
Average	**0.75**	**0.74**	**0.84**	**0.74**	**0.82**	**0.71**



SPC-1 Performance – Sustainability

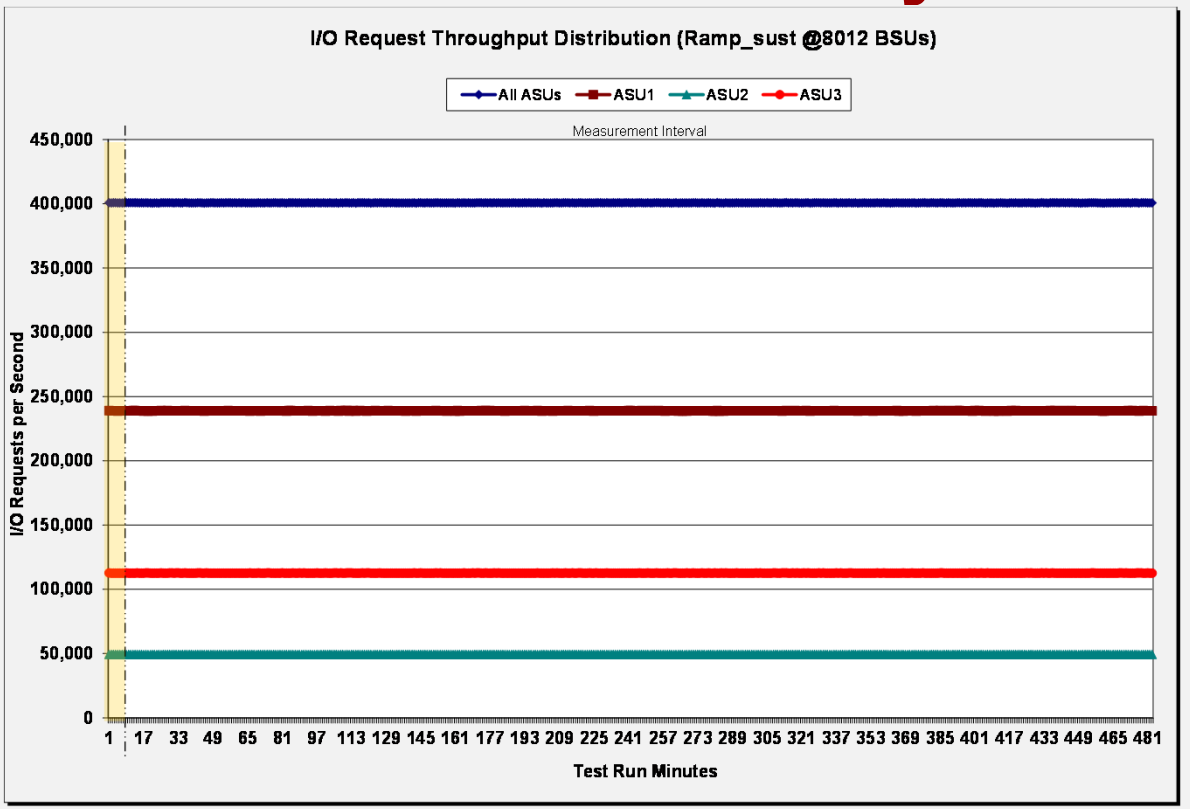
Sustainability Test Run throughput performance:

8,012 BSUs specified

400,609.19
SPC-1 IOPS reported

Maintained over an 8 hour Measurement Interval.

Compared to reported SPC-1 performance metric of **400,587.11**.



SPC-1 Performance – Sustainability

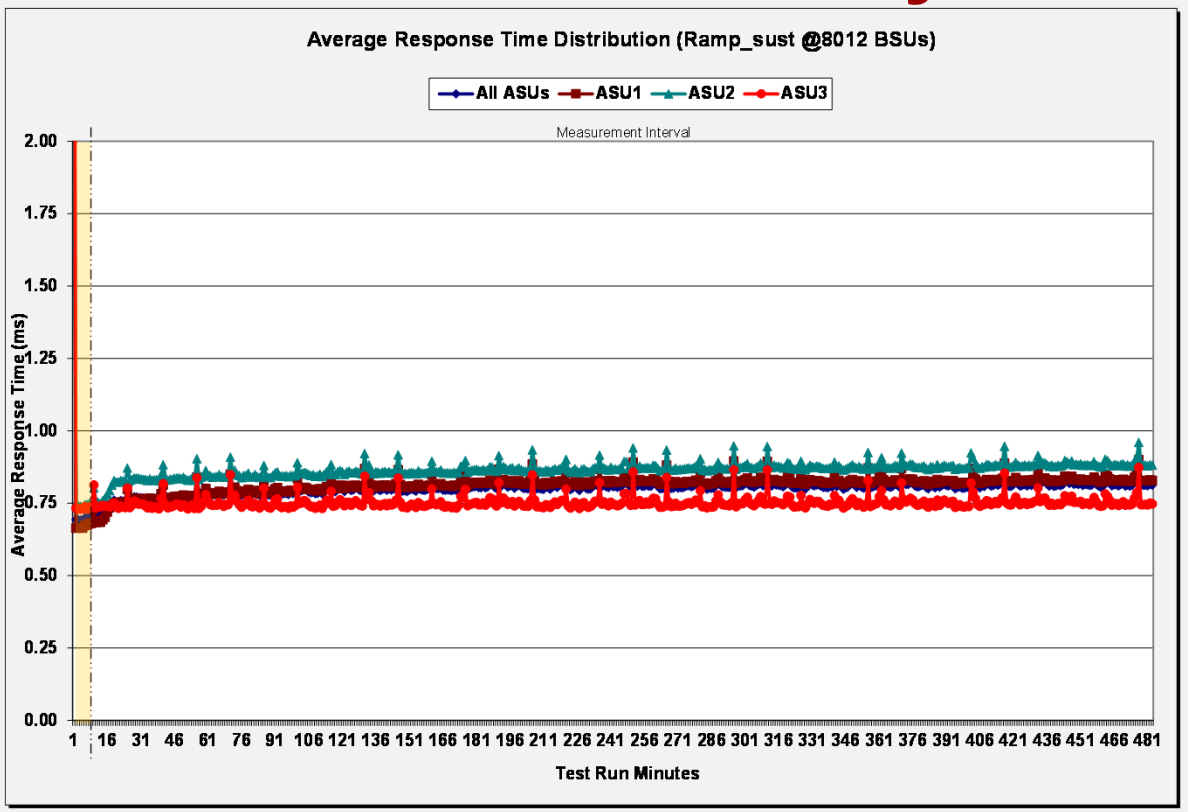
Sustainability Test Run response time performance:

8,012 BSUs specified

0.80 ms average response response time reported

Maintained over an 8 hour Measurement Interval.

Compared to a reported SPC-1 response time metric of **0.75 ms**.



SPC-1 Price-Performance

- **The SPC-1 pricing is for a customer orderable configuration that corresponds to the benchmark configuration *(Priced Storage Configuration)*.**
- **Any discounts includes must be generally available. Special customer discounts are not permitted.**
- **Includes hardware maintenance and software support for three years.**

SPC-1 Price-Performance

- **Hardware maintenance and software support pricing must include:**
  - Acknowledgement of new and existing problems within 4 hours.
  - On-site presence of a qualified maintenance engineer or provision of a customer replaceable part within 4 hours of the above acknowledgement for any hardware failure that would result in a inoperative configuration that can be remedied by the repair or replacement of the part.

SPC-1/E Energy/Power Consumption

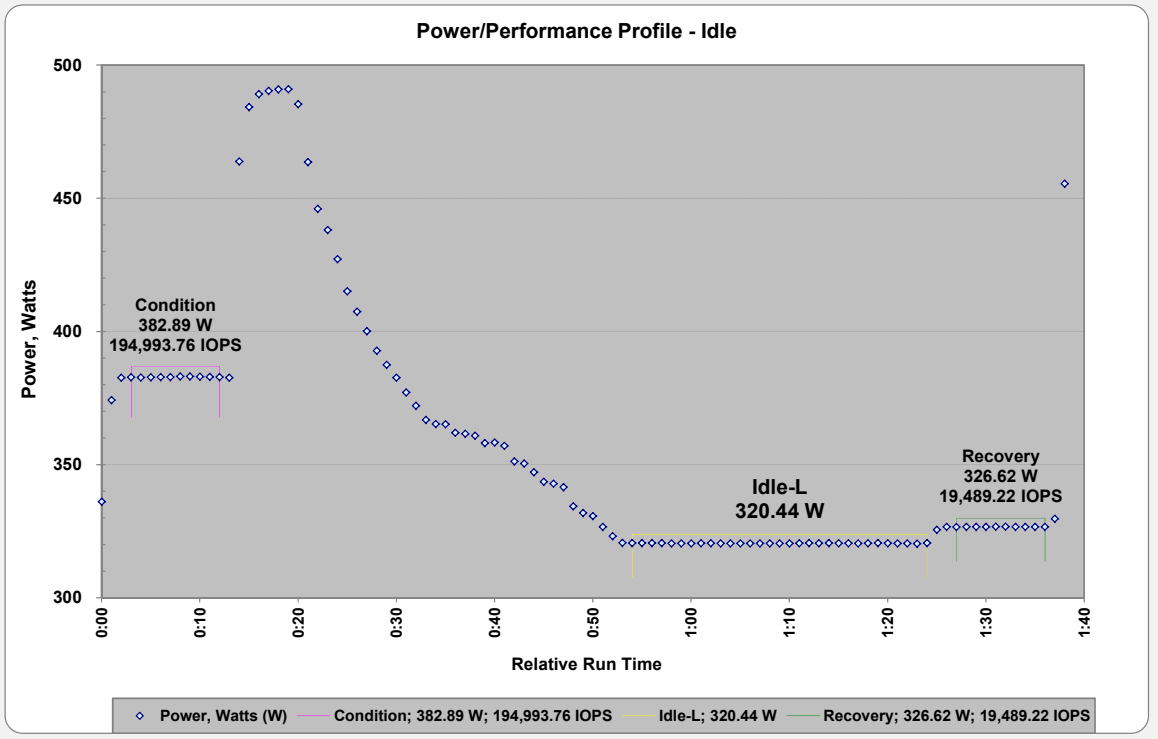
- SPC-1/E includes energy/power consumption measurements with each SPC-1 Test Run.
- Energy/power consumption measurements are synchronized with the performance measurements to provide a comprehensive, unified view of the storage product.
- SPC-1/E includes an Idle Test to provide a complete range of reporting.

SPC-1/E Energy/Power Consumption

- **SPC-1/E energy/power consumption data:**
  - Can be used to evaluate storage products based on energy/power consumption requirements in addition to performance and price-performance.
  - Can be used to prepare a detailed energy capacity plan for the storage portion of a data center.

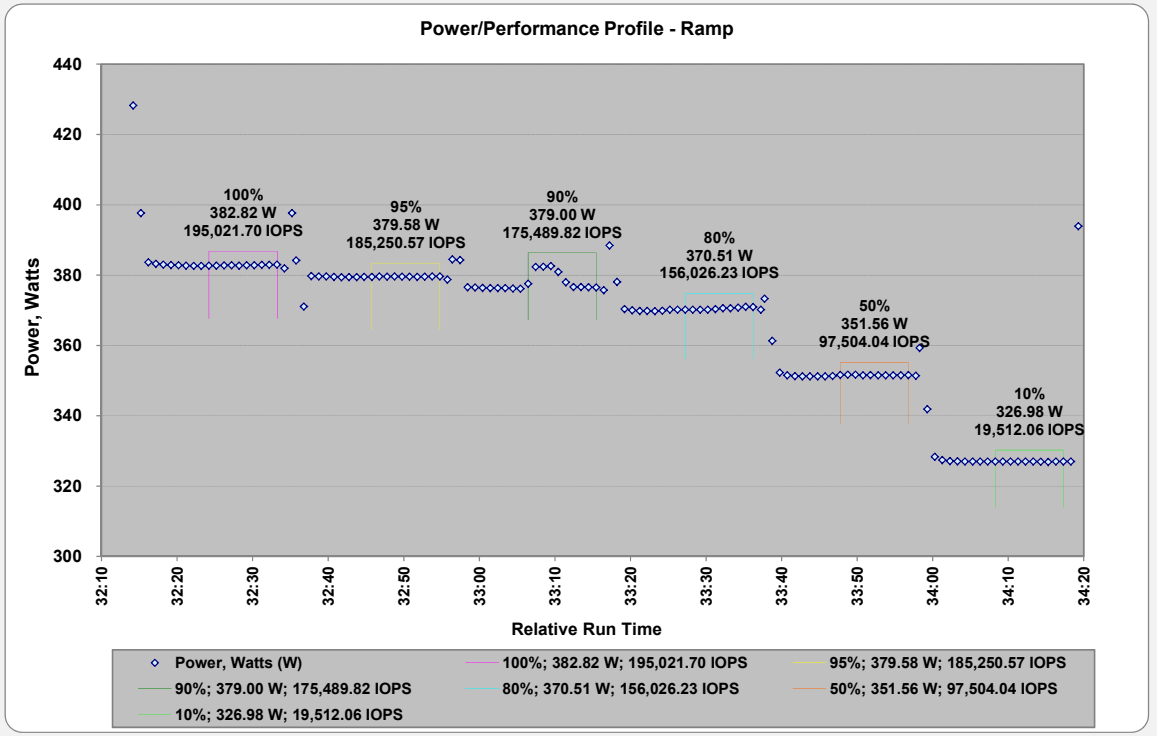
SPC-1/E – Idle Test

Execution Component	Load Level	SPC-1 IOPS™	Power (W)
Idle – Conditioning (***Condition***)	100%	194,993.76	382.89
Idle (***Idle-L***)	0%	0.00	320.44
Idle - Recovery (***Recovery***)	10%	19,489.22	326.62



SPC-1/E – Various Performance Loads

Execution Component	Load Level	SPC-1 IOPS™	Power (W)
IOPS ***(100%)***	100%	195,021.70	382.82
Ramp95 ***(95%)***	95%	185,250.57	379.58
Ramp90 ***(90%)***	90%	175,489.82	379.00
Ramp80 ***(80%)***	80%	156,026.23	370.51
Ramp50 ***(50%)***	50%	97,504.04	351.56
Ramp10 ***(10%)***	10%	19,512.06	216.98



SPC-1/E Energy/Power Profile

Power Environment							
Average RMS Voltage:	199.71				Average Power Factor:		0.968
				Usage Profile			
	Hours of Use per Day			Nominal	Nominal	Nominal	Nominal
	Heavy	Moderate	Idle	Power, W	Traffic, IOPS	IOPS/W	Heat, BTU/hr
Low Daily Usage:	0	8	16	330.81	32,501.35	98.25	1,128.76
Medium Daily Usage:	4	14	6	346.94	82,881.73	238.90	1,183.78
High Daily Usage:	18	6	0	365.77	141,395.68	386.57	1,248.05
			Composite Metrics:	347.84	85,592.92	246.07	
Annual Energy Use, kWh:	3,047.07						
Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:		$ 365.65	

The above SPC-1/E table describes conditions in environments that respectively impose light ***("low")***, moderate ***("medium")*** and extensive ***("high")*** demands on the storage configuration and the resultant power usage profile for each environment.

SPC-1/E Energy/Power Profile

Power Environment							
Average RMS Voltage:	199.71			Average Power Factor:	0.968		
				Usage Profile			
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Annual Energy Use, kWh:	3,047.07						
Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:	$ 365.65		

80%, 50% and Idle data from slide 48.

- **Heavy** SPC-1 Workload: **370.51W** at 80% of maximum reported performance (***157,026.23 SPC-1 IOPS***).
- **Moderate** SPC-1 Workload: **351.56W** at 50% of maximum reported performance (***97,504.04 SPC-1 IOPS***).
- **Idle** SPC-1 Workload: **320.44W** at 0% of maximum reported performance (***0.00 SPC-1 IOPS***).

SPC-1/E Energy/Power Profile

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Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:		$ 365.65	

- **Low Daily Usage**: Zero hours of **Heavy** SPC-1 Workload, 8 hours of **Moderate** SPC-1 Workload and **16 HOURS** of **IDLE** SPC-1 Workload.
- **Medium Daily Usage**: 4 hours of **Heavy** SPC-1 Workload, **14 HOURS** of **MODERATE** SPC-1 Workload and 6 hours of **Idle** SPC-1 Workload.
- **High Daily Usage**: **18 HOURS** of **HEAVY** SPC-1 Workload, 6 hours of **Moderate** SPC-1 Workload and zero hours of **Idle** SPC-1 Workload.

SPC-1/E Energy/Power Profile

Power Environment								
Average RMS Voltage:	199.71					Average Power Factor:	0.968	
				Usage Profile				
	Hours of Use per Day			Nominal	Nominal	Nominal	Nominal	
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Annual Energy Use, kWh:	3,047.07							
Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:		$ 365.65		

- **Nominal Power, W:** The average power consumption over the course of a day *(24 hours)*, taking into account hourly load variations.
- **Nominal Traffic, IOPS:** The average level I/O requests (SPC-1 IOPs) over the course of a day *(24 hours)*, taking into account hourly load variations.
- **Nominal IOPS/W:** The overall efficiency with which I/O requests can be supported, reflected by the ratio of **Nominal Traffic** versus the **Nominal Power**.

SPC-1/E Energy/Power Profile

Power Environment							
Average RMS Voltage:	199.71			Average Power Factor:			0.968
				Usage Profile			
	Hours of Use per Day			Nominal	Nominal	Nominal	Nominal
	Heavy	Moderate	Idle	Power, W	Traffic, IOPS	IOPS/W	Heat, BTU/hr
Low Daily Usage:	0	8	16	330.81	32,501.35	98.25	1,128.76
Medium Daily Usage:	4	14	6	346.94	82,881.73	238.90	1,183.78
High Daily Usage:	18	6	0	365.77	141,395.68	386.57	1,248.05
			Composite Metrics:	347.84	85,592.92	246.07	
Annual Energy Use, kWh:	3,047.07						
Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:		$ 365.65	

- **LOW DAILY USAGE**: An average of **32,501.35 SPC-1 IOPS** with an average power consumption of **330.81 watts** resulting in **98.25 SPC-1 IOPS per watt**.
- **MEDIUM DAILY USAGE**: An average of **82,881.73 SPC-1 IOPS** with an average power consumption of **346.94 watts** resulting in **238.90 SPC-1 IOPS per watt**.
- **HIGH DAILY USAGE**: An average of **82,881.73 SPC-1 IOPS** with an average power consumption of **346.94 watts** resulting in **238.90 SPC-1 IOPS per watt**.

SPC-1/E Energy/Power Profile

Power Environment							
Average RMS Voltage:	199.71				Average Power Factor:		0.968
				Usage Profile			
	Hours of Use per Day			Nominal	Nominal	Nominal	Nominal
	Heavy	Moderate	Idle	Power, W	Traffic, IOPS	IOPS/W	Heat, BTU/hr
Low Daily Usage:	0	8	**16**	**330.81**	**32,501.35**	**98.25**	**1,128.76**
Medium Daily Usage:	4	**14**	6	**346.94**	**82,881.73**	**238.90**	**1,183.78**
High Daily Usage:	**18**	6	0	**365.77**	**141,395.68**	**386.57**	**1,248.05**
			Composite Metrics:	**347.84**	**85,592.92**	**246.07**	
Annual Energy Use, kWh:	3,047.07						
Energy Cost, $/kWh:	$ 0.12			Annual Energy Cost, $:		$ 365.65	

- A 155.01% increase in throughput *(32.501.35 to 82,881.73 SPC-1 IOPS)* with a resulting 143.16% increase in SPC-1 IOPS per watt *(98.25 to 238.90)* only required 4.87% more power *(330.81 to 346.94 watts)*.
- A subsequent 70.60% increase in throughput *(82,881.73 to 141,395.68 SPC-1 IOPS)* with a resulting 61.81% increase in SPC-1 IOPS per watt *(238.90 to 386.57)* only required 5.43% more power *(346.94 to 365.77 watts)*.

SPC-1/E Energy/Power Profile

Power Environment

Average RMS Voltage: 199.71 **Average Power Factor:** 0.968

	Hours of Use per Day			Usage Profile			
	Heavy	Moderate	Idle	Nominal Power, W	Nominal Traffic, IOPS	Nominal IOPS/W	Nominal Heat, BTU/hr
Low Daily Usage:	0	8	16	330.81	32,501.35	98.25	1,128.76
Medium Daily Usage:	4	14	6	346.94	82,881.73	238.90	1,183.78
High Daily Usage:	18	6	0	365.77	141,395.68	386.57	1,248.05
Composite Metrics:				347.84	85,592.92	246.07	

Annual Energy Use, kWh:	3,047.07		
Energy Cost, $/kWh:	$ 0.12	Annual Energy Cost, $:	$ 365.65

- **COMPOSITE METRICS:** The aggregated **NOMINAL POWER**, **NOMINAL TRAFFIC** and **NOMINAL IOPS/W** for all three environments: **LOW**, **MEDIUM** and **HIGH DAILY USAGE**.
- **ANNUAL ENERGY USE, KWH:** An estimate of the average energy use across the three environments over the course of year and computed as (**NOMINAL POWER** * 24 * 0.365)
- **ENERGY COST, $/KWH:** A standardized energy cost per kilowatt hour.
- **ANNUAL ENERGY COST:** An estimate of the annual energy cost across the three environments over the course of a year and computed as (**ANNUAL ENERGY USE** * **ENERGY COST**).

Huawei SPC progress and plans

Thank you

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