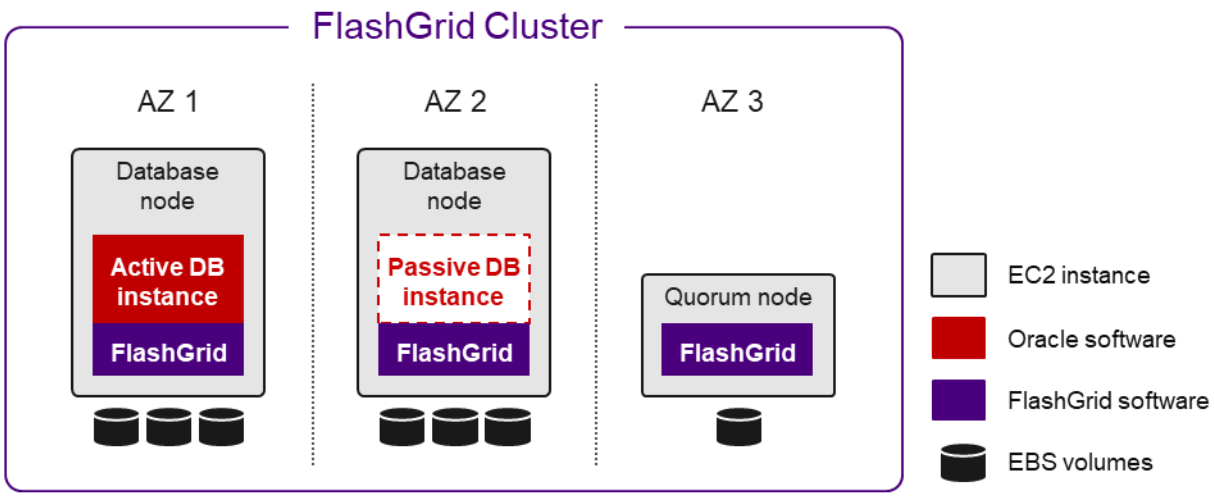
Architecture Overview

FlashGrid Cluster for Oracle Failover HA enables achieving uptime SLA of 99.95% for Oracle Databases running on Amazon EC2 through enhanced reliability of the database servers, fast failure isolation, and rapid failover between availability zones. FlashGrid Cluster is delivered as a fully integrated Infrastructure-as-Code template that can be customized and deployed to your AWS account in a few clicks. It is fully customer-managed and does not restrict any Oracle Database functionality.

Key components of FlashGrid Cluster for Oracle Database Failover HA on AWS include:

- Amazon EC2 instances
- Amazon EBS storage
- FlashGrid Storage Fabric™ software
- FlashGrid Cloud Area Network™ software
- FlashGrid Reliability Services
- Oracle Grid Infrastructure software (includes Oracle Clusterware and Oracle ASM)
- Oracle Database (Enterprise Edition or Standard Edition)



FlashGrid Cluster for Oracle Failover HA on AWS

FlashGrid Cluster architecture highlights:

- Active-Passive database HA
- 1+1 or 2+1 redundancy
- Zero RPO
- Spreading database nodes across availability zones (multi-AZ) protects against data center outages and local disasters.
- FlashGrid Cloud Area Network™ software enables high-speed overlay networks with advanced capabilities for HA.
- FlashGrid Storage Fabric™ software shares EBS volumes between nodes and availability zones.
- FlashGrid Read-Local™ Technology minimizes storage network overhead by serving reads from locally attached EBS volumes.
- Oracle ASM and Clusterware provide data protection and availability.
- Data is mirrored across separate nodes and availability zones.

Multi-AZ for Maximum Uptime and Fault Tolerance

Amazon Web Services consists of multiple independent *regions*. Each region is partitioned into several availability zones. Each availability zone consists of one or more discrete data centers housed in separate facilities, each with redundant power, networking, and connectivity. Availability zones are physically separate, such that even extremely uncommon disasters such as fires or flooding would only affect a single availability zone.

Although availability zones within a region are geographically isolated from each other, they have direct low-latency network connectivity between them. The network latency between availability zones is generally lower than 1ms. This makes it possible to use synchronous mirroring of data between AZs and achieving zero RPO in case of a failover.

Spreading cluster nodes across multiple availability zones helps to minimize downtime even when an entire data center experiences an outage or a local disaster. FlashGrid recommends using multi-AZ cluster configurations unless there is a specific need to use a single availability zone.

Possible Cluster Configurations

In most cases a multi-AZ cluster with two database nodes (1+1 redundancy) is recommended for Failover HA (see the diagram above). 2-way data mirroring is used with Normal Redundancy ASM disk groups. An additional EC2 instance (*quorum* node) is required to host quorum disks. Such a cluster can tolerate the loss of any one node without incurring database downtime.

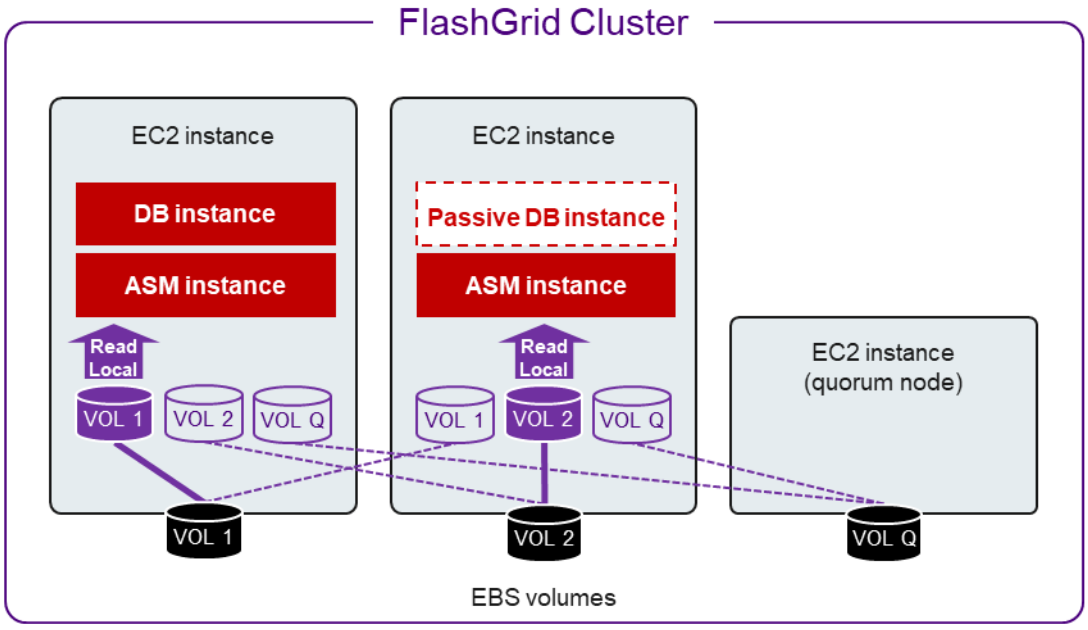
FlashGrid Cluster can also be deployed in other configurations for specific use-cases:

- Three database nodes (2+1 redundancy) may be used for consolidating multiple databases and reducing overprovisioning of the compute resources.
- Separate storage nodes may be configured for extra capacity and storage throughput for running extra-large (200+ TB) databases.
- Single AZ configurations may be used to meet specific requirements (for example, for test clusters to avoid inter-AZ traffic fees).

Multiple databases can share one FlashGrid Cluster as separate databases or as pluggable databases in a multitenant container database. For larger databases and for high-performance databases, dedicated clusters are typically recommended for minimizing interference.

Shared Storage Architecture

FlashGrid Storage Fabric software turns EBS volumes attached to individual EC2 instances into shared disks accessible from all nodes in the cluster. The sharing is done at the block level with concurrent access from all nodes.



FlashGrid Storage Fabric with FlashGrid Read-Local Technology

FlashGrid Read-Local Technology

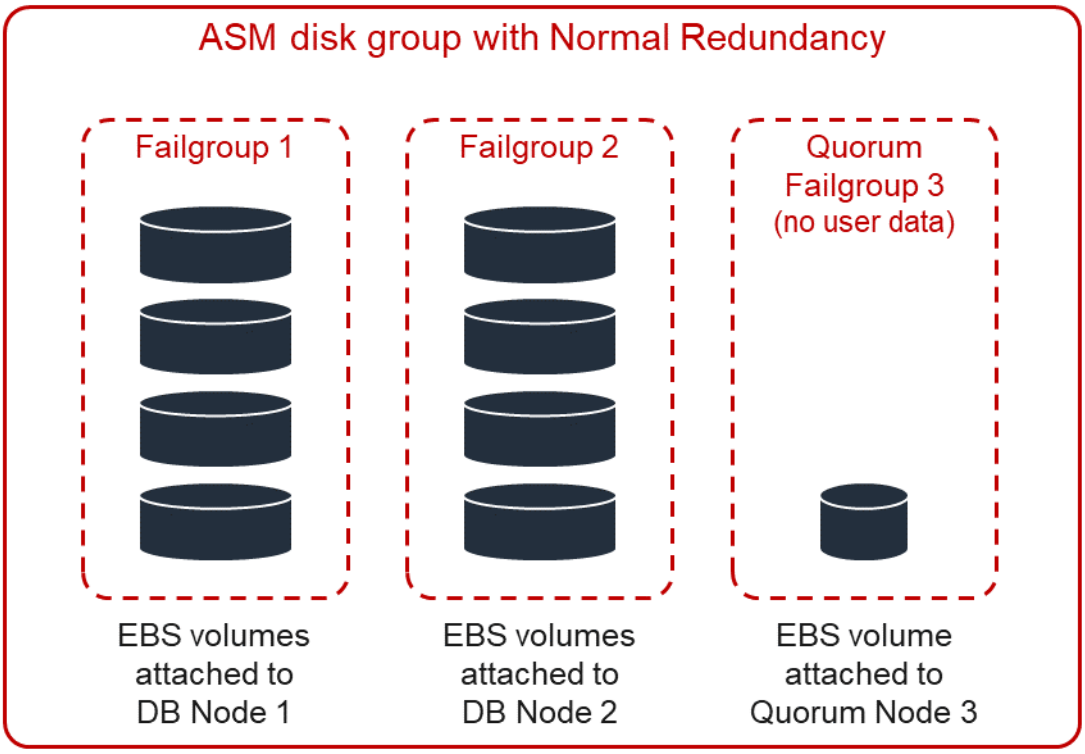
In a cluster with two or three database nodes, each database node has a full copy of user data stored on EBS volumes attached to that database node. The FlashGrid Read-Local™ Technology allows serving all read I/O from the locally attached EBS volumes. Read requests avoid the extra network hop, thus reducing read latency and the amount of network traffic. As a result, more network bandwidth is available for the write I/O traffic.

ASM disk group structure and data mirroring

FlashGrid Storage Fabric leverages proven Oracle ASM capabilities for disk group management, data mirroring, and high availability.

In a cluster with two database nodes all disk groups are configured with *Normal Redundancy*. In the *Normal Redundancy* mode each block of data has two mirrored copies. Each ASM disk group is divided into failure groups – one *regular* failure group per database node plus one *quorum* failure group. Each disk is configured to be a part of a failure group that corresponds to the node where the corresponding EBS volume is attached.

ASM stores mirrored copies of each block in different failure groups. Thus, the cluster can continue running and access data when any one of the disks fails or any one of the nodes goes down. Since the data mirroring is done synchronously, there is no data loss in the event of an abrupt failure.



A Normal Redundancy disk group in a 2-node RAC cluster on AWS

High Availability and Uptime Considerations

FlashGrid Storage Fabric and FlashGrid Cloud Area Network™ have a fully distributed architecture with no single point of failure. Additionally, the FlashGrid Cluster architecture leverages HA capabilities built in Oracle Clusterware and ASM.

Node availability

Because EC2 instances can move between physical hosts, a failure of a physical host causes only a short outage for the affected node. The node instance will automatically restart on another physical host. This significantly reduces the risk of double failures.

A single-AZ configuration provides protection against loss of a database node. It is an efficient way to accommodate planned maintenance (e.g. database or OS patching) without causing database downtime. However, the potential failure of a resource shared by multiple instances in the same availability zone, such as network, power, or cooling, may cause database downtime.

Placing instances in different availability zones minimizes the risk of simultaneous node failures.

Data availability with EBS storage

An Amazon EBS volume provides persistent storage that survives a failure of the EC2 instance that the volume is attached to. After the failed instance restarts on a new physical node, all its volumes are re-attached with no data loss.

Amazon EBS volumes have built-in redundancy that protects data from failures in the underlying physical media. In the FlashGrid Cluster architecture, Oracle ASM performs data mirroring on top of the built-in protection of Amazon EBS. Together, Amazon EBS and ASM's mirroring provide durable storage with two layers of data protection, which exceed the typical levels of data protection in on-premises deployments.

Zero RPO

Data is mirrored across 2+ nodes in a synchronous manner. In case a node fails, no committed data is lost.

Fast failure detection and failover time

In the event of a failure of an active database node or database instance, the database instance can be immediately started (failed over) on the second node.

The time to restore the database service after an unexpected failure consists of the *time to detect the failure* plus the *time to restart the database instance on the second node*.

The time to detect the failure is between 30 to 60 seconds. FlashGrid Cluster uses several techniques to reduce the detection time in various scenarios including EC2, EBS, network, out-of-memory, or a different type of OS-level failure. The fast failure detection is an important benefit of the FlashGrid Cluster architecture. Other implementations of Oracle Database on AWS may suffer from long outages because of their limited abilities to detect certain failure types.

The time to start the database instance on the second node depends on the size of redo log that must be re-applied and the number of uncommitted transactions that must be undone. Essentially, this time depends on the transaction rate at the time of the failure and the sizing of the EC2 instance and the EBS volumes. The recovery time can be reduced by using higher performance EC2 instances and EBS volumes.

With proper sizing of resources, FlashGrid Cluster enables Recovery Time Objective (RTO) as low as 120 seconds for essentially all types of failures, including the more complicated scenarios, such as system disk EBS volume failure, running out-of-memory, etc.

Uptime SLA

AWS states an uptime SLA of 99.99% for two EC2 instances running in different availability zones. By using the multi-AZ architecture, FlashGrid Cluster enables achieving the 99.95% or greater uptime SLA at the database service level.

The 99.95% uptime SLA assumes downtime of no more than 4 hours per year. In the FlashGrid Cluster for Failover HA architecture, database instance startup time during a failover is the biggest potential contributor to the database downtime. Therefore, measuring the startup time during crash-recovery under typical and peak application loads and proper sizing of EC2 and EBS resources is important for minimizing the downtime and meeting the uptime SLA.

FlashGrid Health Checker tool helps to minimize preventable failures by checking for possible mistakes in the database and cluster configuration.

Note: For an uptime SLA greater than 99.99% and for zero-downtime maintenance FlashGrid recommends using FlashGrid Cluster for Oracle RAC on AWS with 3+ RAC database nodes and active-active HA.

FlashGrid Reliability Services

Ensuring reliable operation of each database node is an integral part of maintaining highly available operation and achieving the target uptime SLA. Also, unexpected failures must be quickly contained to minimize disruption.

FlashGrid Reliability Services provide a layer of failure protection and prevention at the database node level:

- OS configuration optimized for HA clustering
- Disk heartbeat services for fast EBS failure detection
- Out-of-memory prevention services

- Monitoring of network connectivity, EBS responsiveness, memory utilization, CPU utilization, etc.
- Alerting on failure events
- “Call home” alerts sent directly to FlashGrid support
- Collecting diagnostics information and logs for troubleshooting
- Health Checker tool for analyzing cluster and database configuration for identifying possible misconfiguration and preventing failures.

Performance Considerations

Multiple availability zones

Using multiple availability zones (AZs) provides substantial availability advantages. However, it does increase network latency because of the distance between the AZs. The network latency between AZs is less than 1ms in most cases and will not have critical impact on performance of many workloads. For example, in the US-West-2 region for 8KB transfers we measured 0.3ms, 0.6 ms, and 1.0 ms between different pairs of availability zones compared to 0.1 ms within a single availability zone.

Read-heavy workloads will experience zero or little impact because all read traffic is served locally and does not use the network between AZs.

Note that differences in latency between different pairs of AZs provides an opportunity for optimization by choosing which AZs to place database nodes in. In a 2-node cluster it is optimal to place database nodes in the two AZs with the lowest latency between them. See our knowledge base article for more details.

Storage performance

In most cases, the use of General Purpose SSD (gp3) volumes is recommended. The performance of each gp3 volume can be configured from 3,000 to 16,000 IOPS and 125 to 1,000 MBPS. By using multiple volumes per disk group attached to each database node, the database storage throughput can reach the maximum of 400,000 IOPS and 12,500 MBPS (with r6in.32xlarge or r6in.metal instances).

Performance vs. on-premises solutions

EBS GP3 storage is SSD based and provides an order of magnitude of improvement in IOPS and latency over traditional spinning HDD based storage arrays. With up to 400,000 IOPS and 12,500 MBPS per node, the performance is even higher than a typical dedicated all-flash storage array. It is important to note that the storage performance is not shared between multiple clusters. Every cluster has its own dedicated set of EBS volumes, which ensures stable and predictable performance with no interference from noisy neighbors.

An extra-large database architecture, that uses R6in or M6in instances and separate storage nodes, provides up to 30,000 MBPS of storage throughput. Thus, enabling the deployment of extra-large (200+ TB) databases and migrations from large Exadata systems.

Reference performance results

When moving database workloads to the cloud, the main areas of concern regarding performance tend to be around storage I/O because the CPU and memory can be sized like any on-premises system. Hence, for performance measurements we use Calibrate_IO and SLOB tools that exercise storage i/o.

Calibrate_IO

The CALIBRATE_IO procedure provides a convenient way to measure storage performance, including maximum bandwidth, random IOPS, and latency. The CALIBRATE_IO procedure generates I/O through the database stack on actual database files. It is also useful for comparing the performance between two storage systems because CALIBRATE_IO’s results are not influenced by non-storage factors such as memory size or number of CPU cores.

The test is read-only and safe to run on an existing database. However, do not run it on a production system because it will cause severe performance degradation of the applications using the database.

Test script:

```
SET SERVEROUTPUT ON;
DECLARE
  lat NUMBER;
  iops INTEGER;
  mbps INTEGER;
BEGIN DBMS_RESOURCE_MANAGER.CALIBRATE_IO (24, 10, iops, mbps, lat);
DBMS_OUTPUT.PUT_LINE ('Max_IOPS = ' || iops);
DBMS_OUTPUT.PUT_LINE ('Latency = ' || lat);
DBMS_OUTPUT.PUT_LINE ('Max_MB/s = ' || mbps);
end;
/
```

Calibrate_IO results measured by FlashGrid:

Max IOPS	Max MBPS	Latency, ms
383,711	11901	0.066

Note that Calibrate_IO's results are not influenced by whether the database nodes are in the same availability zone or not.

SLOB

SLOB is a popular tool for generating I/O intensive Oracle workloads. SLOB generates database SELECTs and UPDATEs with minimal computational overhead. It complements Calibrate_IO by generating a mixed (read+write) I/O load. Database AWR reports generated during a SLOB test provide various performance metrics but we will focus on I/O performance.

SLOB results measured by FlashGrid:

Physical Write Database Requests	Physical Read Database Requests	Physical Read+Write Database Requests
38,477 IOPS	344,660 IOPS	383,138 IOPS

Test configuration details

- Two database nodes: r6in.metal
- EBS storage: (24) gp3 volumes per node, 16000 IOPS, 1000 MBPS each
- SGA size: 3 GB (We chose a smaller SGA to minimize caching effects and maximize physical I/O)
- 8KB database block size
- SLOB configuration: 240 schemas, 240MB each, UPDATE_PCT= 10 (10% updates, 90% selects)

Full Control of the Database and OS

FlashGrid Cluster is fully customer managed. This allows more interoperability, control, and flexibility than DBaaS offerings. Customer assigned administrators have full (root) access to the EC2 instances and the operating system. Additional third-party tools, connectors, monitoring or security software can be installed on the cluster nodes for compliance with corporate or regulatory standards.

Short Learning Curve for Oracle DBAs

Management of the Oracle databases running on FlashGrid Cluster is done using standard Oracle tools and services that include Oracle Clusterware, ASM, RMAN, Data Guard, GoldenGate, etc. All database features are available. The patching process is same as in a typical on-premises environment. FlashGrid Cluster adds tools and services for managing the cluster configuration and maintaining its reliable operation. But there is no need to learn any new proprietary procedures for performing standard DBA functions.

Tiered Storage Options

FlashGrid Cluster by default uses the EBS GP3 volume for data disks. The EBS GP3 volumes deliver high IOPS and high MBPS throughput at an affordable price. However, databases that have tens or hundreds of terabytes of "slow" data may benefit from the lower cost EBS SC1 volumes used as bulk second-tier storage. For example, a separate disk group on EBS SC1 volumes can be used for storing Large Object (LOB) tablespaces.

The price of the EBS SC1 volumes is $0.015/GB-month (may vary by region) compared to $0.08/GB-month for EBS GP3, that is 5.3x lower. For a database with 100 TB of "slow" data (and 2-way mirroring) the cost savings can be $156,000 per year.

The EBS SC1 volumes can be added to a cluster after deployment or can be added to the cluster configuration file with help from FlashGrid support. If planning to use the EBS SC1 volumes, please review the configuration with FlashGrid support to ensure reliable operation. Note that the EBS SC1 volumes are not suitable as the main storage.

Optimizing Oracle Database licenses

For customers on a per-CPU Oracle licensing model, optimizing the number of Oracle licenses may be an important part of managing costs. With FlashGrid Cluster, the following options are available to optimize Oracle Database licensing:

- **The X2iezn instance type** has smaller number of CPU cores at higher frequency (up to 4.5 GHz) paired with a large memory size and high network bandwidth. Separate storage nodes can also be used for extra storage throughput.
- **Bare-metal instances** allow the use of server hardware without the virtualization layer.
- **Dedicated hosts** allow management of licenses at the physical host level instead of the VM level. Multiple VM instances (belonging to different clusters) can share the same physical host and associated licenses.
- **Consolidating** multiple smaller databases on a single cluster (and scheduling CPU intensive jobs at different times) has the potential for reducing the total number of CPU cores.
- **Optimizing** system and software configuration often allows reducing CPU consumption, thus reducing the required number of CPU cores.

Disaster Recovery Strategy

An optimal Disaster Recovery (DR) strategy for Oracle databases will depend on the higher-level DR strategy for the entire application stack.

In a Multi-AZ configuration, FlashGrid Cluster provides protection against a catastrophic failure of an entire data center. However, it cannot protect against a region-wide outage or against an operator error causing destruction

of the cluster resources. The most critical databases may benefit from having one or more replicas as part of the DR strategy. The most common replication tool is (Active) Data Guard but there are other tools that can be used.

The replica(s) may be placed in a different region and/or in the same region:

- **Remote standby** in a different region protects against a region-wide outage or disaster. Asynchronous replication should be used.
- **Local standby** in the same region protects against a logical destruction of a database cluster caused by an operator error, software bugs, or malware. Synchronous replication should be used for zero RPO.
- A combination of both remote and local standby may be used for most critical systems.

A standalone (no clustering) database server may be used as a standby replica. However, using an identical clustered setup for the standby provides the following benefits:

- Consistent performance in case of a DR scenario.
- Ability to routinely switch between the two replicas.
- Ability to apply software updates and configuration changes on the standby first.

Security

System and data access

FlashGrid Cluster is deployed on EC2 instances in the customer's AWS account and managed by the customer. The deployment model is similar to running your own EC2 instances and installing FlashGrid software on them. FlashGrid staff has no access to the systems or data.

OS hardening

OS hardening can be applied to the database nodes (as well as to quorum/storage nodes) for security compliance. Customers may choose to use their own hardening scripts or FlashGrid's scripts that are available for CIS Server Level 1 aligned hardening.

Data Encryption

All data on EBS storage can be encrypted. By default, encryption is enabled and uses AWS managed keys. Optionally, customer managed symmetric KMS encryption key can be used.

Oracle Transparent Data Encryption (TDE) can be used as a second layer of data encryption if the corresponding Oracle license is available.

TCPS

Customers requiring encrypted connectivity between database clients and database servers can configure TCPS for client connectivity.

Compatibility

Software versions

The following versions of software are supported with FlashGrid Cluster:

- Oracle Database: ver. 19c, 18c, 12.2, 12.1, or 11.2
- Oracle Grid Infrastructure: ver. 19c
- Operating System: Oracle Linux 7/8, Red Hat Enterprise Linux 7/8

EC2 instance types

The following EC2 instance types are typically recommended for database nodes:

- R6i: high memory to CPU ratio
- M6i: higher CPU to memory ratio
- R6in, M6in: high speed storage and network, best for storage-intensive databases
- X2idn, X2iedn, X2iezn: highest memory to CPU ratio, high speed network

Database nodes must have at least four physical CPU cores (8 vCPUs with hyperthreading) to ensure reliable operation.

Quorum nodes require fewer resources than database nodes, a single CPU core is sufficient. The c6i.large instance type is recommended for quorum servers. Note that there is no Oracle Database software installed on the quorum servers, hence the quorum servers do not increase the number of licensed CPUs.

Database features

FlashGrid Cluster does not restrict the use of any database features. DBAs can enable or disable database features based on their requirements and available licenses.

Database tools

Various database tools from Oracle or third parties can be used with Oracle RAC databases running on FlashGrid Cluster. This includes RMAN and RMAN-based backup tools, Data Guard, GoldenGate, Cloud Control (Enterprise Manager), Shareplex, DBvisit, and AWS DMS.

Shared file systems

The following shared file access options can be used with FlashGrid Cluster:

- ACFS or DBFS for shared file access between the database nodes.
- Amazon EFS or NFS can be mounted on database nodes for sharing files with other systems, e.g. application servers.
- File based access to S3.

Automated Infrastructure-as-Code deployment

The FlashGrid Launcher tool automates the process of deploying a cluster. It provides a flexible web-interface for defining cluster configuration and generating an Amazon CloudFormation template for it. The following tasks are performed automatically using the CloudFormation template:

- Creating cloud infrastructure: VMs, storage, and optionally network
- Installing and configuring FlashGrid Cloud Area Network
- Installing and configuring FlashGrid Storage Fabric
- Installing, configuring, and patching Oracle Grid Infrastructure
- Installing and patching Oracle Database software
- Creating ASM disk groups

The entire deployment process takes approximately 90 minutes. After the process is complete the cluster is ready for creating databases. Human errors that could lead to costly reliability problems and compromised availability are avoided using automatically generated and standardized Infrastructure-as-Code templates.

Terraform

Customers who prefer to use Terraform instead of CloudFormation can use the FlashGrid Launcher REST API to generate a Terraform template.

Generating templates via REST API

The entire deployment process can be fully automated without needing to manually use the FlashGrid Launcher's web GUI, by using its REST API instead to generate CloudFormation or Terraform templates.