

Integrating Active Directory Certificate Services with Azure Cloud HSM

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Summary

To use ADCS backed by a certificate stored in Azure Cloud HSM, the Azure Cloud HSM Client SDK must be installed and configured as a Key Storage Provider. ADCS must be configured to use the Azure Cloud HSM Client Key Storage Provider to store the CA private key.

For general information about Active Directory Certificate Services (ADCS) refer to:

<https://learn.microsoft.com/en-us/windows-server/identity/ad-cs/>

Prerequisites

System Requirements

- Windows Server (2016, 2019, 2022)
- [Azure Cloud HSM Client SDK](#)
- Azure Cloud HSM resource has been deployed, initialized, and configured.

ADCS Install Prerequisites

- Copy of partition owner certificate “PO.crt” on ADCS server.
- Known address of your HSM “hsm1.chsm-<resourcename>-<uniquestring>.privatelink.cloudhsm.azure.net”.
- Knowledge of Crypto User credentials

Important Note: The Windows Server for ADCS should be deployed in the same region as your existing Cloud HSM and existing private VNET and subnet you created earlier. Customers using any version of Windows Server should install the most recent version of the Visual C++ Redistributable.

Option 1: ADCS Installation on existing Azure Cloud HSM Admin VM

Customers that deploy ADCS following option 1 will install and configure ADCS on their existing Admin VM which already has the partition owner certificate PO.crt and Azure Cloud HSM SDK tools and utilities which they used to initialize and configure their Azure Cloud HSM. This may be the easier path for customers as all Azure Cloud HSM SDK tools and certs are already present on your Admin VM and it reduces your need for additional Azure resources and configuration steps.

➔ Go to [Windows Server Prerequisites](#) for the next steps.

Option 2: ADCS Installation of a new Windows Server VM

Customers that deploy ADCS following option 2 chose to install and configure ADCS on a separate, new Windows Server VM. You will need to complete the prerequisite steps below on your new Windows Server before proceeding with ADCS installation and configuration. You will also need to copy from your Admin VM your PO.crt file to the /Cert directory where you extracted the Cloud HSM SDK on your ADCS server.

Option 2: Azure Cloud HSM SDK Prerequisites

STEP 1: Download and Install Azure Cloud HSM SDK on to your ADCS Server

Customers can download the Azure Cloud HSM SDK and Client Tools from GitHub:
@ [microsoft/MicrosoftAzureCloudHSM: Azure Cloud HSM SDK](#)

- To install the Azure Cloud HSM SDK for Windows, download and run the Azure Cloud HSM SDK MSI (Windows Installer Package). This installer will automatically configure all necessary environment variables and dependencies and set up the Cloud HSM Client to run as a service. In the example below, running the Cloud HSM MSI deploys the SDK to C:\Program Files\Microsoft Azure Cloud HSM Client SDK. This is the directory for all Azure Cloud HSM management and client utilities including CNG and KSP providers which can be found under \libs\cng and \libs\ksp.

```

PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs> dir .\cng\

Directory: C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs\cng

Mode                LastWriteTime         Length Name
----                -
-a----            6/18/2024   2:39 PM         155568 azcloudhsm_cng_config.exe
-a----            6/18/2024   2:40 PM        3334176 azcloudhsm_cng_provider.dll

PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs> dir .\ksp\

Directory: C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs\ksp

Mode                LastWriteTime         Length Name
----                -
-a----            6/18/2024   2:40 PM        3279904 azcloudhsm_ksp.dll
-a----            6/18/2024   2:39 PM        154032 azcloudhsm_ksp_client.exe
-a----            6/18/2024   2:41 PM        298528 azcloudhsm_ksp_import_key.exe

```

STEP 2: Configure the Azure Cloud HSM Client Tools

You will need to update the “hostname” property in the \bin\azcloudhsm_resource.cfg file. The azcloudhsm_resource.cfg is used to initialize the Azure Cloud HSM cluster. It must point to the private link FQDN for “hsm1” before the cluster is fully initialized as only hsm1 is currently running.

To find the FQDN that includes private link go to your resource group, and select Private Endpoint then select DNS Configuration. You will see configuration name and the FQDN that includes *.privatelink.cloudhsm.azure.net for each HSM instance. Use “hsm1” FQDN as the hostname for the \bin\azcloudhsm_resource.cfg file.

```

azcloudhsm_mgmt_util.cfg - Notepad
File Edit Format View Help
{
  "servers": [
    {
      "hostname" : "hsm1.contoso-aycya2e2fsb9fxhu.privatelink.cloudhsm.azure.net",
      "port" : 2225,
      "certificate": "..\\cert\\cert-c",
      "pkey": "..\\cert\\pkey-c",
      "CAfile": "",
      "CApath": "..\\cert\\ssl",
      "ssl_ciphers": "default",
      "server_ssl" : "yes",
      "enable" : "yes",
      "owner_cert_path": "..\\cert\\PO.crt",
      "nonce_size" : 128
    }
  ]
}

```

Important Note: Customers that want to run the Azure Cloud HSM SDK on Windows will need to install OpenSSL on their server. We recommend installing the Chocolatey Package Manager on your Windows Server to ease with the installation of OpenSSL. Once installed you may need to close your console window and open a new console window for next steps.

Windows Installation for Chocolatey

1. Open PowerShell prompt as 'Administrator'
2. Run the following command to Set Execution Policy and Download Chocolatey:

```

Set-ExecutionPolicy Bypass -Scope Process -Force; [System.Net.ServicePointManager]::SecurityProtocol =
[System.Net.ServicePointManager]::SecurityProtocol -bor 3072; iex ((New-Object
System.Net.WebClient).DownloadString('https://community.chocolatey.org/install.ps1'))

```

3. Run the following command for OpenSSL Installation:

```

choco install openssl --version 1.1.1.1900 -y

```

STEP 3: Validate PO.crt exists on your ADCS Server

If the PO.crt file is missing, you will need to copy the PO.crt file from your Admin VM you initialized your Azure Cloud HSM to your ADCS server under the /cert directory. If you fail to copy, or if PO.crt file is missing or incorrect when you attempt to run azcloudhsm_mgmt_util or azcloudhsm_client you will receive an error.

```
PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK\cert> dir

Directory: C:\Program Files\Microsoft Azure Cloud HSM Client SDK\cert

Mode                LastWriteTime         Length Name
----                -
d-----          7/30/2024   8:04 PM             ssl
-a-----          6/18/2024   2:07 PM          1364 cert-c
-a-----          7/30/2024   8:07 PM          1058 P1.csr
-a-----          6/18/2024   2:07 PM          1732 pkey-c
-a-----          7/30/2024   8:08 PM          1266 PO.crt
-a-----          7/30/2024   8:08 PM          1732 PO.key
-a-----          7/30/2024   8:08 PM          1220 POAC.crt
-a-----          6/18/2024   2:07 PM           174 README.txt
```

STEP 4: Validate access to your Azure Cloud HSM

1. Start the azcloudhsm_mgmt_util by executing:

```
.\azcloudhsm_mgmt_util.exe .\azcloudhsm_resource.cfg
```

2. Logon as CU using the username and password when you created a 'user' with the crypto user role.

```
loginHSM CU cu1 user1234
```


```
cloudmgmt>loginHSM CU cu1 user1234
loginHSM success on server 0(10.0.2.4)
loginHSM success on server 1(10.0.2.5)
loginHSM success on server 2(10.0.2.6)
cloudmgmt>
```

Windows Server Configuration

The Windows Server prerequisites are applicable and required for both option 1 and option 2 choices prescribed above.

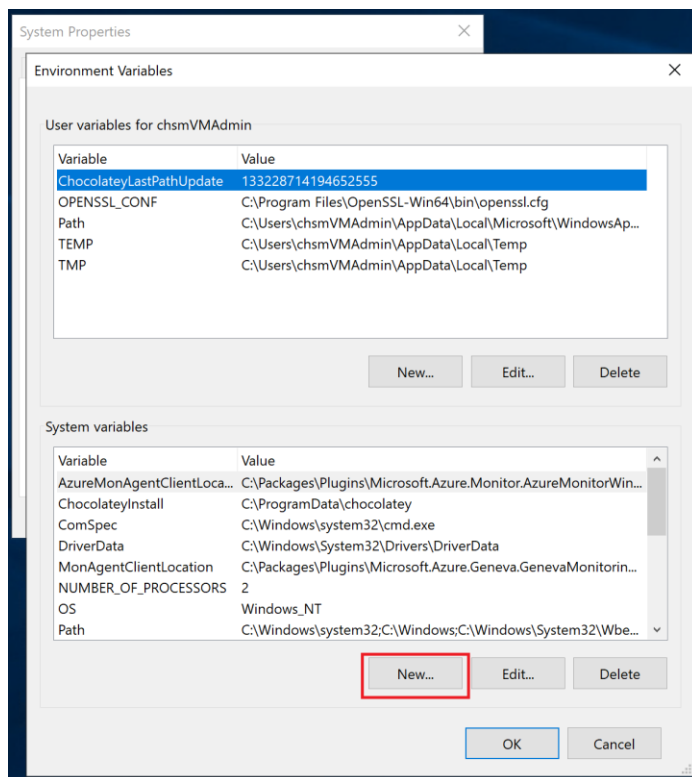
1. Ensure you have copied over your PO.crt (partition owner cert) file to the ..\cert directory which from this example resides under C:\Program Files\Microsoft Azure Cloud HSM Client SDK\cert
2. If you installed the Azure Cloud HSM SDK using MSI, the client is already configured to run as a service. If the client is not running, you can open Services.msc, right-click on the Microsoft Azure Cloud HSM Client Service, and select "Start."

Important Note: The Azure Cloud HSM client must always be running for ADCS and CNG/KSP providers to be operational.

Name	Description	Status	Startup Type	Log On As
 Microsoft Azure Cloud HSM Client Service	Azure Cloud HSM Client Service connects applications with Cloud HSM	Running	Automatic	Local System

3. Add the following system environment variables to your Windows Server.

Variable Name	Variable Value	Example
azcloudhsm_username	<crypto user username>	cu1
azcloudhsm_password	<crypto user username>:<crypto user password>	cu1:user1234

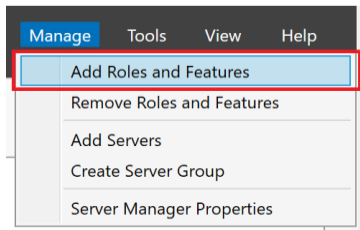


Install Active Directory Certificate Services

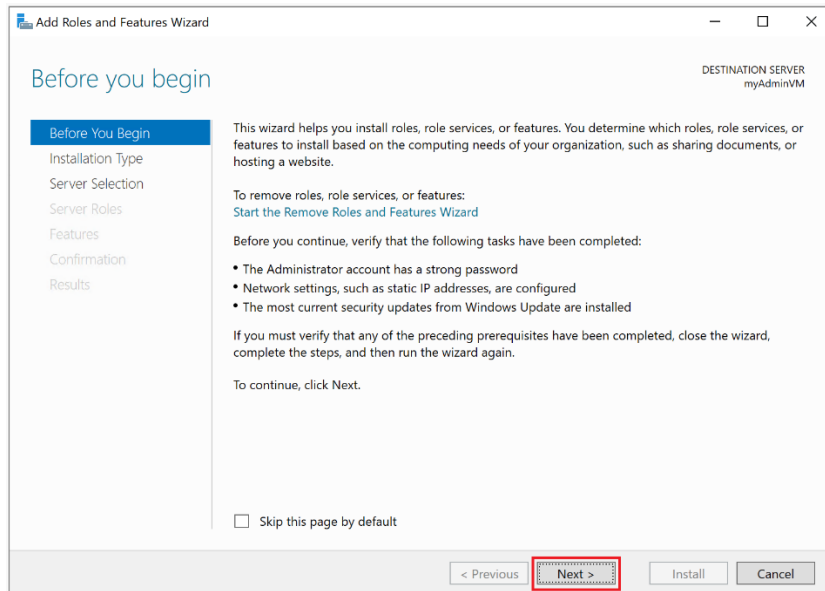
1. Open Server Manager

- Click the **Start > Server Manager** to open the Server Manager Dashboard.

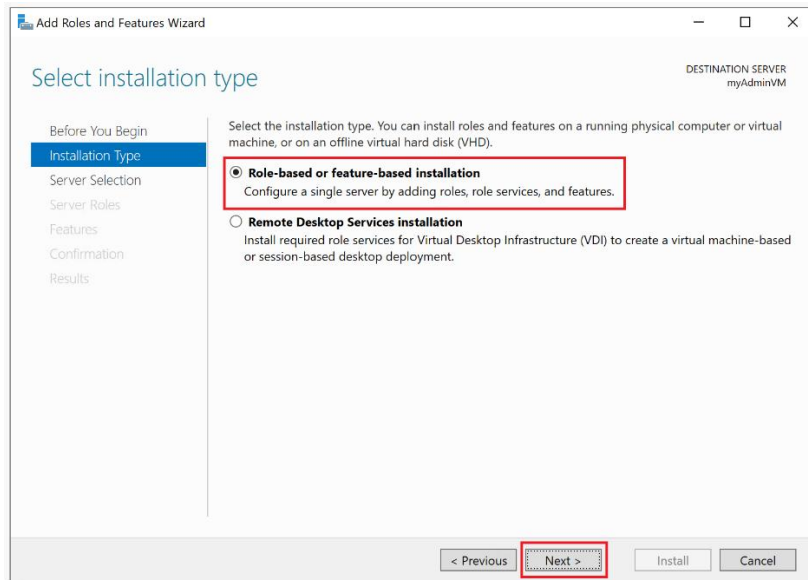
2. Click **Manage** in the upper-right corner, then select **Add Roles and Features** from the context menu.



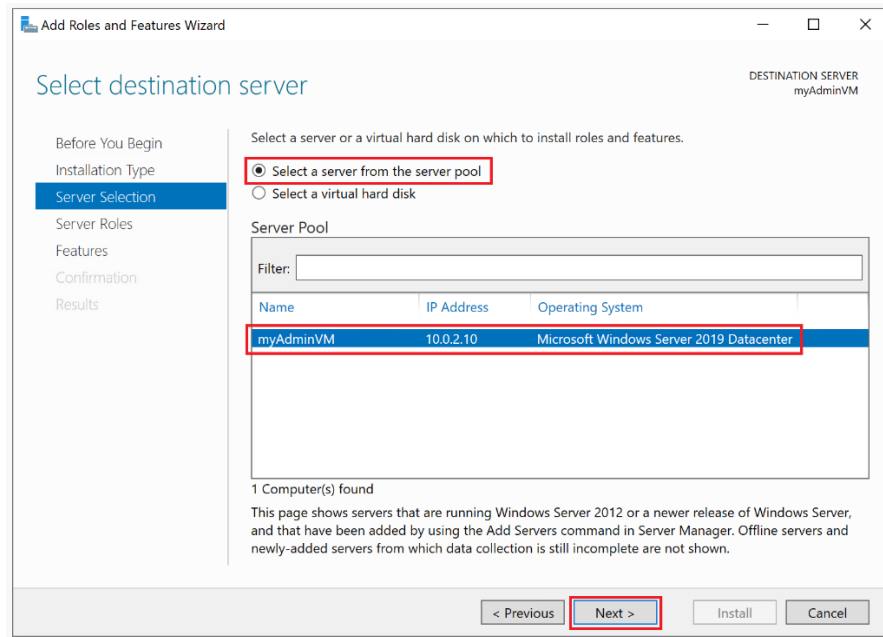
3. The *Before you begin* page displays. Verify that you have completed the tasks listed on the page and click **Next**.



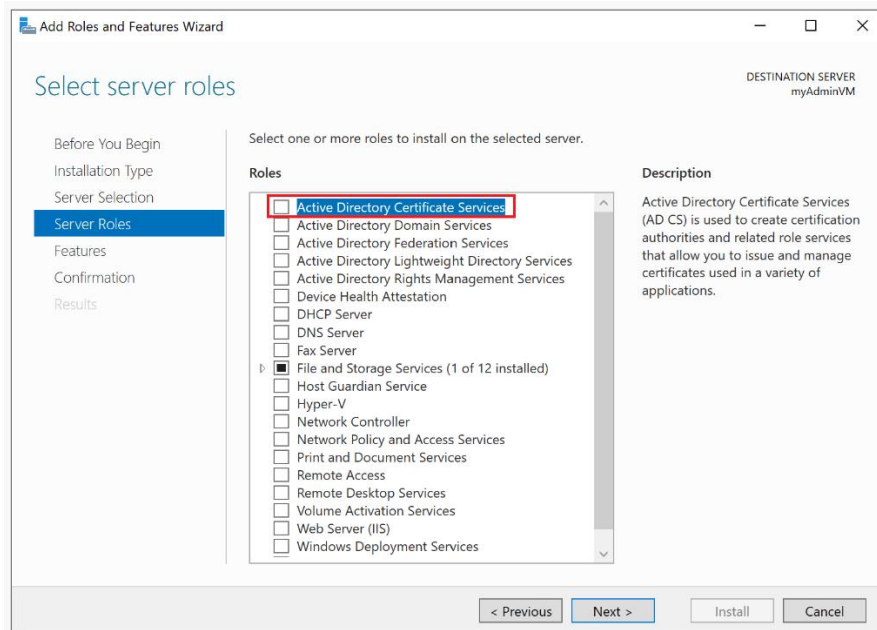
4. On the *Select installation type* page, make sure the default selection of Role Based or Feature Based Installation is selected and click **Next**.



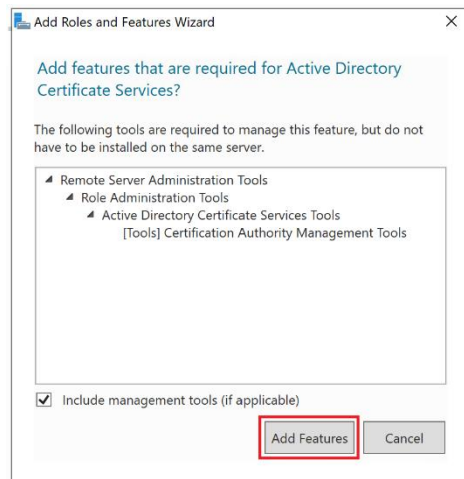
5. On the *Select destination server* page, select a server from the server pool and click **Next**.



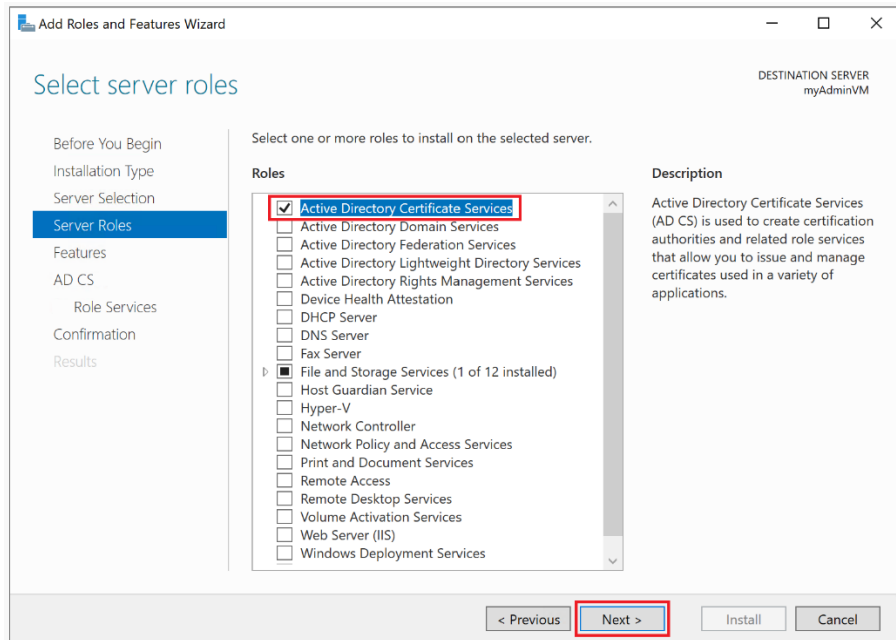
6. On the *Select server roles* page, select the **Active Directory Certificate Services** role.



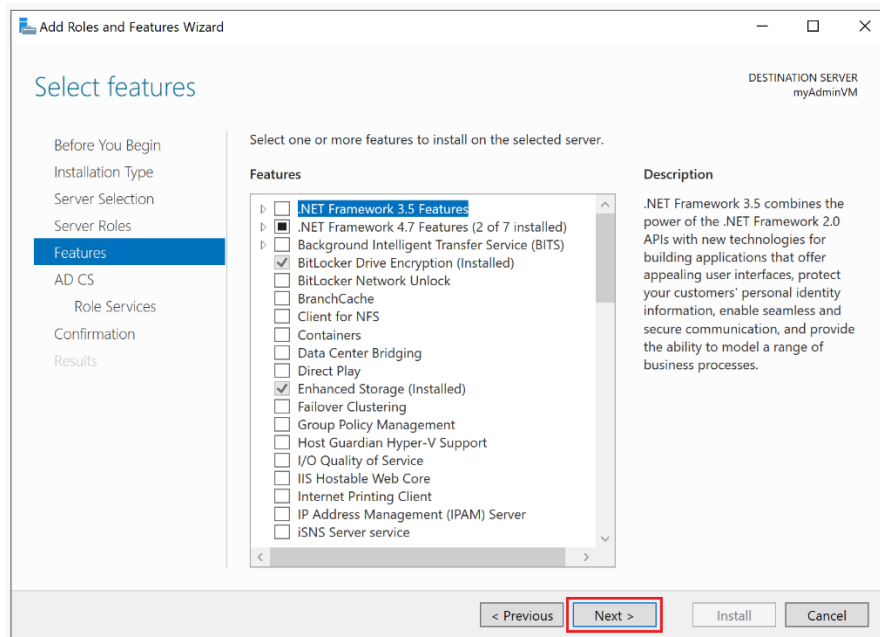
7. When prompted to install the **Remote Server Administration Tools**, click **Add Features**.



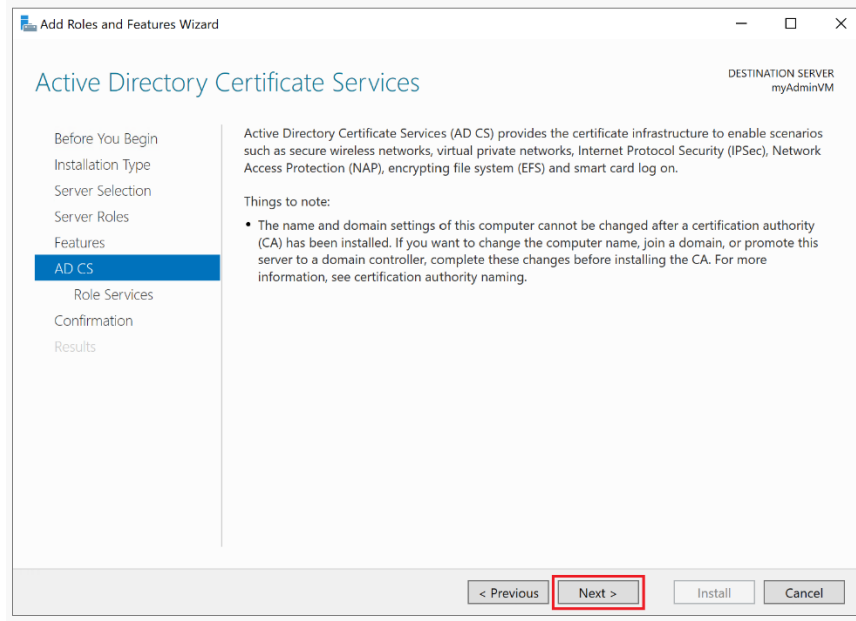
8. On the *Select server roles* page, click **Next**.



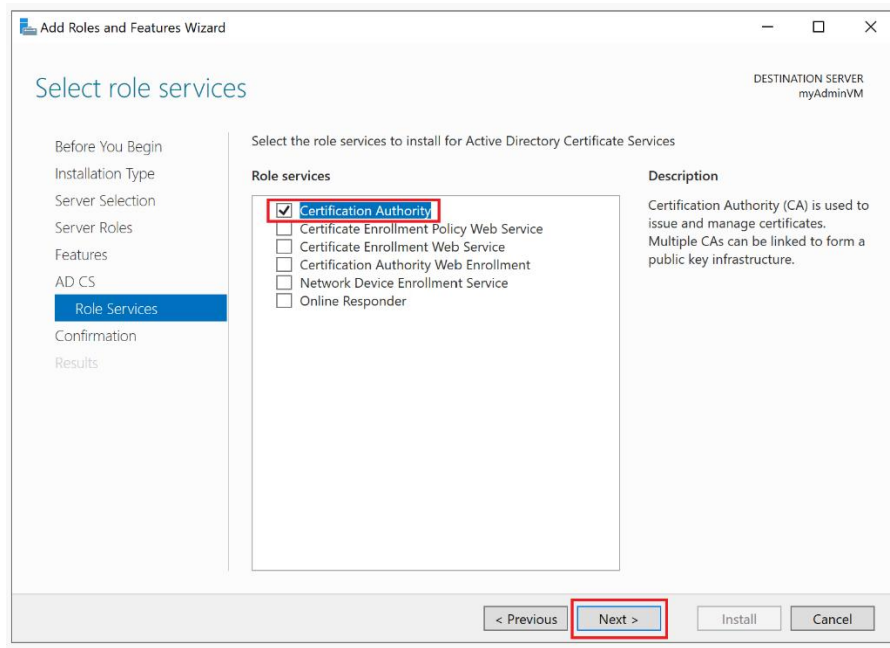
9. On the *Features* page, click **Next**.



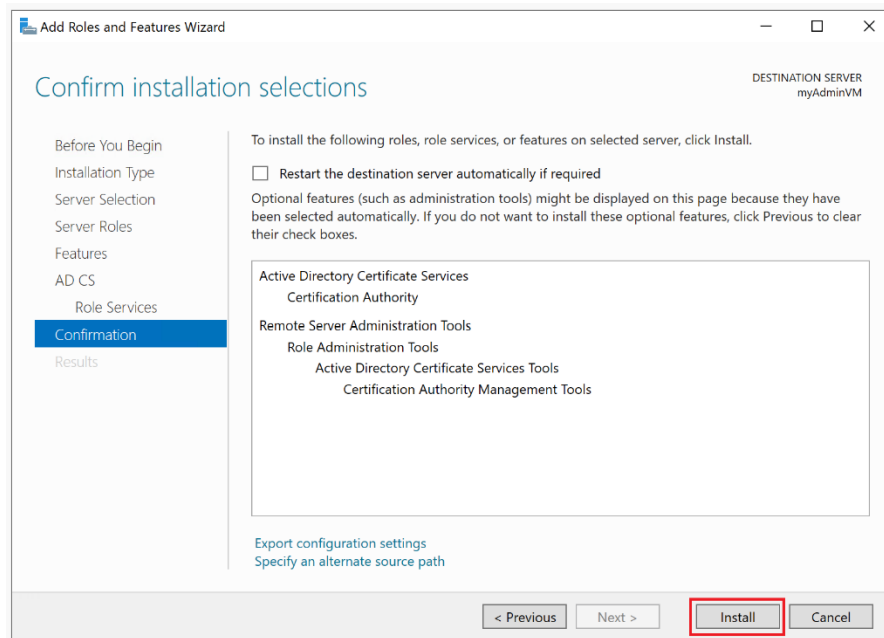
10. On the **Active Directory Certificate Services** page, click **Next**.



11. On the *Select role services* page, the Certification Authority role is selected by default. Leave the selection unchanged and click **Next**.



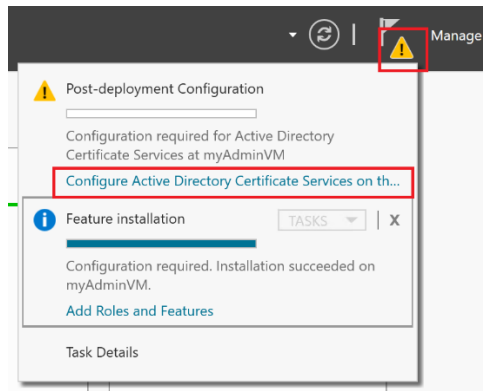
12. On the *Confirm installation selections* page, verify the information, and click **Install**.



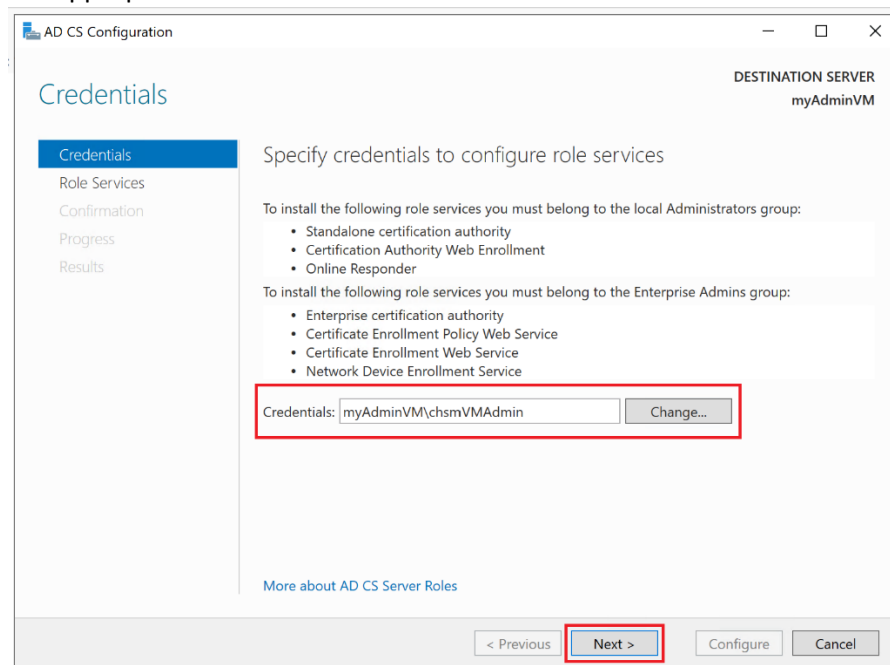
13. When installation is completed, click **Close**.

Configure Active Directory Certificate Services

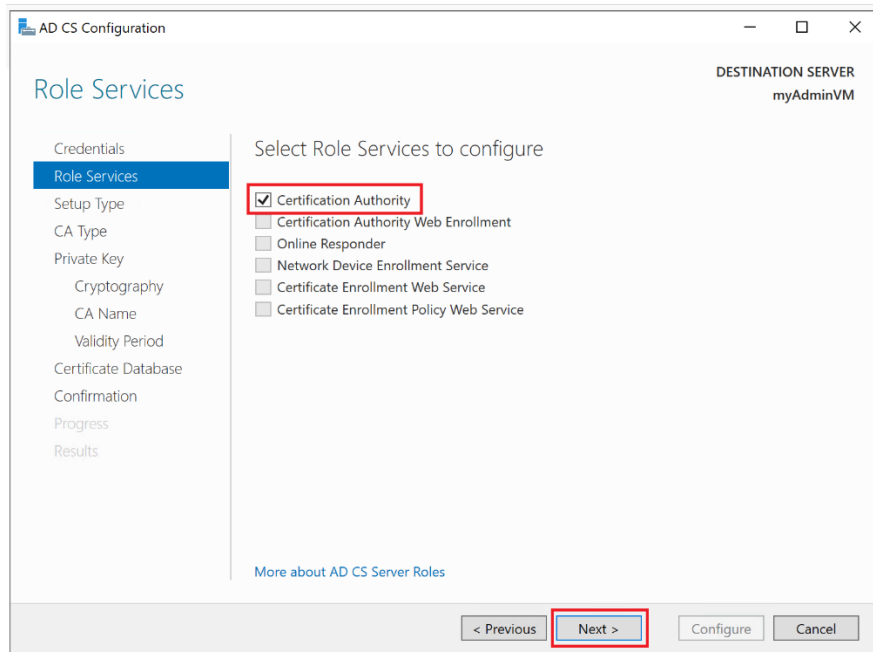
1. When the installation is completed, click the *warning symbol* in the upper-right corner and select **Configure Active Directory Certificate Services on the destination server**.



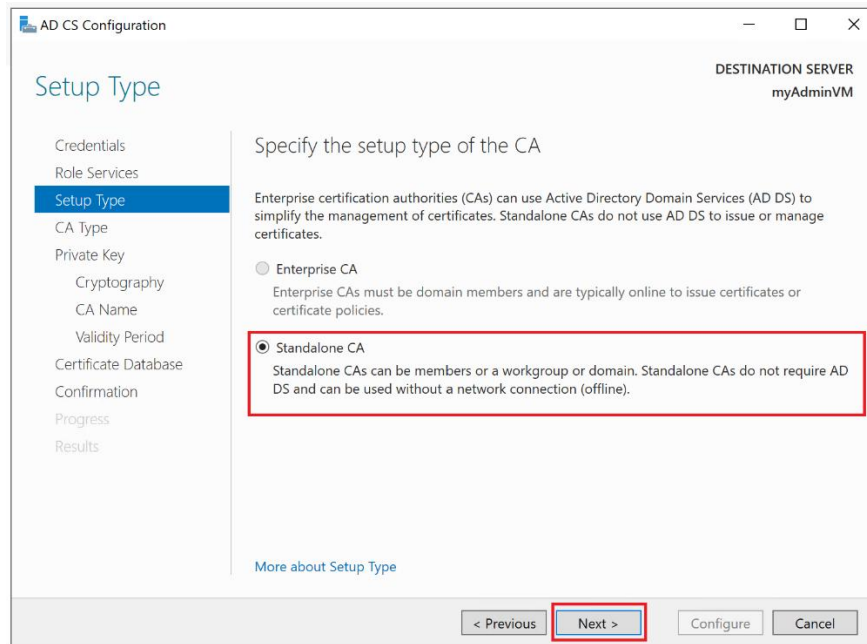
2. On the *Credentials* page, make sure that Administrator credentials are displayed in the **Credentials** box. If not, click **Change** and specify the appropriate credentials. Click **Next**.



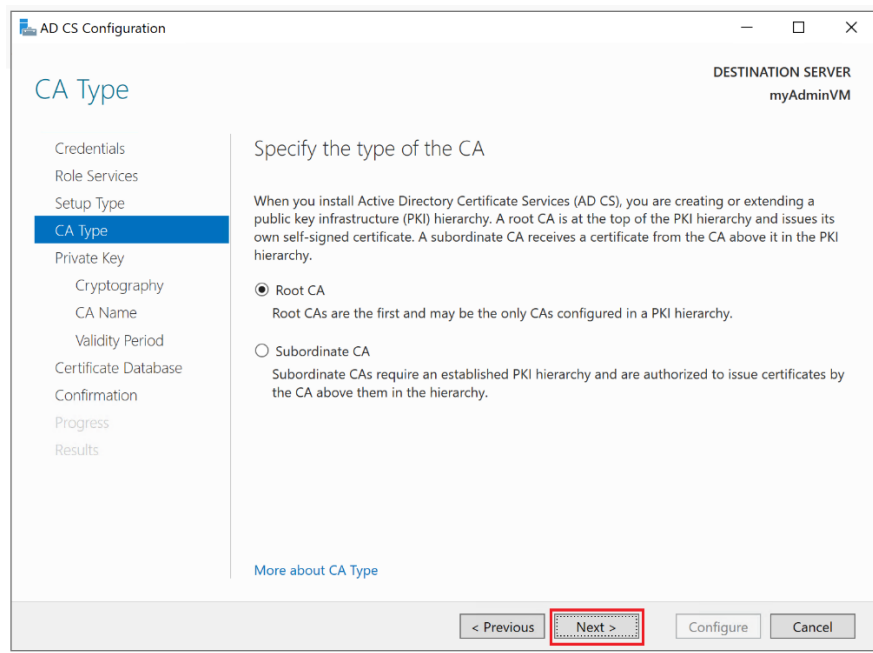
3. On the *Role Services* page, select **Certification Authority**. This is the only available selection when the certification authority role is installed on the server. Click **Next**.
- It can take several minutes for the **Next** button to become available after selecting Certification Authority.



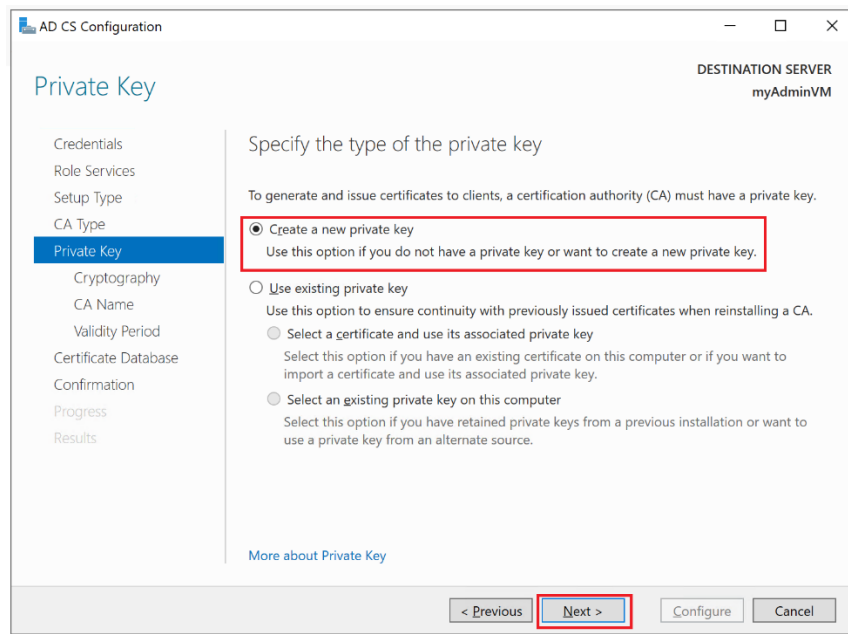
4. In the *Setup Type* page, select the appropriate **CA** setup type for your requirements. Click **Next**.
- For this configuration example “**Standalone CA**” was selected.



5. On the *CA Type* page, **Root CA** is selected by default. Leave the selection unchanged and click **Next**.



6. On the *Private Key* page, **Create a new private key** is selected by default. Leave the selection unchanged and click **Next**.



7. On the *Cryptography for CA* page, select the appropriate Azure Cloud HSM cryptographic provider along with the key type, key length, and suitable hash algorithm. Then click **Next**.
 - For this example, we selected *Cryptographic Provider* as **RSA#Cavium Key Storage Provider**, *Key length* as **2048** and *hash algorithm* as **SHA256**.
 - Click *check box* to enable, **Allow administrator interaction when the private key is accessed by the CA**.

AD CS Configuration

Cryptography for CA

DESTINATION SERVER
myAdminVM

Credentials
Role Services
Setup Type
CA Type
Private Key
Cryptography
CA Name
Validity Period
Certificate Database
Confirmation
Progress
Results

Specify the cryptographic options

Select a cryptographic provider: RSA#Cavium Key Storage Provider Key length: 2048

Select the hash algorithm for signing certificates issued by this CA:

SHA1
SHA256
SHA384
SHA512

☒ Allow administrator interaction when the private key is accessed by the CA.

[More about Cryptography](#)

< Previous Next > Configure Cancel

8. On the *CA Name* page, provide the appropriate CA name and click **Next**.

AD CS Configuration

DESTINATION SERVER
myAdminVM

CA Name

- Credentials
- Role Services
- Setup Type
- CA Type
- Private Key
- Cryptography
- CA Name**
- Validity Period
- Certificate Database
- Confirmation
- Progress
- Results

Specify the name of the CA

Type a common name to identify this certification authority (CA). This name is added to all certificates issued by the CA. Distinguished name suffix values are automatically generated but can be modified.

Common name for this CA:
myAdminVM-CA

Distinguished name suffix:

Preview of distinguished name:
CN=myAdminVM-CA

[More about CA Name](#)

< Previous **Next >** Configure Cancel

9. On the *Validity Period* page, enter the number of years for the certificate to be valid and click **Next**.

AD CS Configuration

Validity Period

DESTINATION SERVER
myAdminVM

Credentials
Role Services
Setup Type
CA Type
Private Key
Cryptography
CA Name
Validity Period
Certificate Database
Confirmation
Progress
Results

Specify the validity period

Select the validity period for the certificate generated for this certification authority (CA):

5 Years

CA expiration Date: 3/10/2028 11:21:00 PM

The validity period configured for this CA certificate should exceed the validity period for the certificates it will issue.

[More about Validity Period](#)

< Previous Next > Configure Cancel

10. On the *Certificate Database* page, provide the locations for both the certificates and logs and click **Next**.

AD CS Configuration

DESTINATION SERVER
myAdminVM

CA Database

- Credentials
- Role Services
- Setup Type
- CA Type
- Private Key
 - Cryptography
 - CA Name
 - Validity Period
 - Certificate Database**
 - Confirmation
 - Progress
 - Results

Specify the database locations

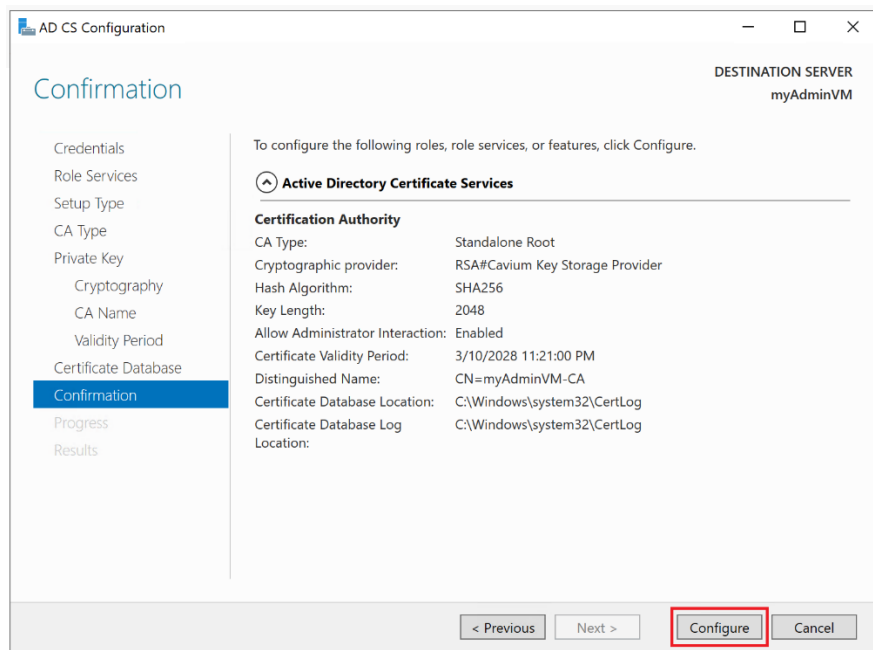
Certificate database location:
C:\Windows\system32\CertLog

Certificate database log location:
C:\Windows\system32\CertLog

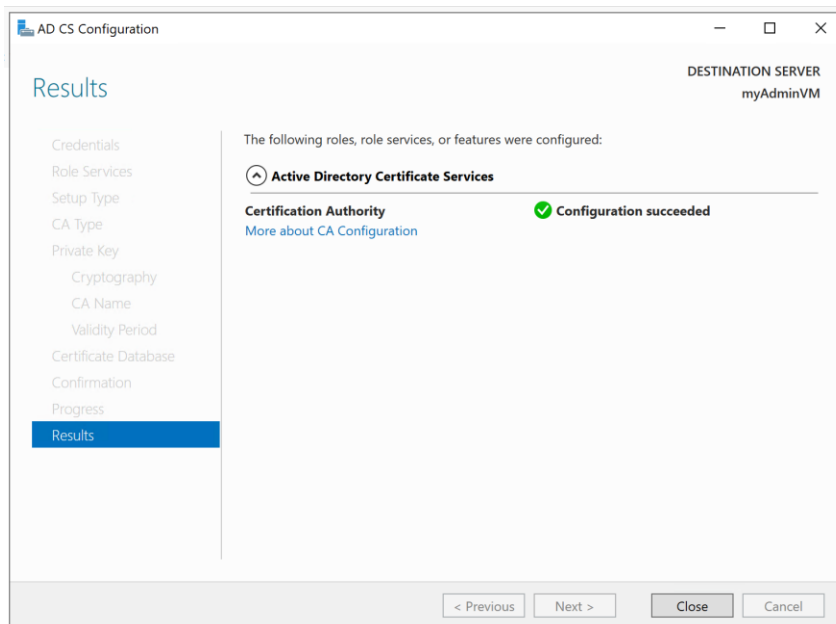
[More about CA Database](#)

< Previous **Next >** Configure Cancel

11. On the *Confirmation* page, click **Configure**.



12. When the configuration completes, a success message is displayed. Click **Close**.



Important Note: You can also check to see whether the CA has been installed correctly by executing **sc query certsvc** from the command line:

```
Administrator: Command Prompt
Microsoft Windows [Version 10.0.17763.4010]
(c) 2018 Microsoft Corporation. All rights reserved.

C:\Users\chsmVMAdmin>sc query certsvc

SERVICE_NAME: certsvc
        TYPE               : 110  WIN32_OWN_PROCESS (interactive)
        STATE                : 4    RUNNING
                           (STOPPABLE, PAUSABLE, ACCEPTS_SHUTDOWN)
        WIN32_EXIT_CODE       : 0    (0x0)
        SERVICE_EXIT_CODE   : 0    (0x0)
        CHECKPOINT           : 0x0
        WAIT_HINT            : 0x0
```

Configuring Certificate Services using an existing private key

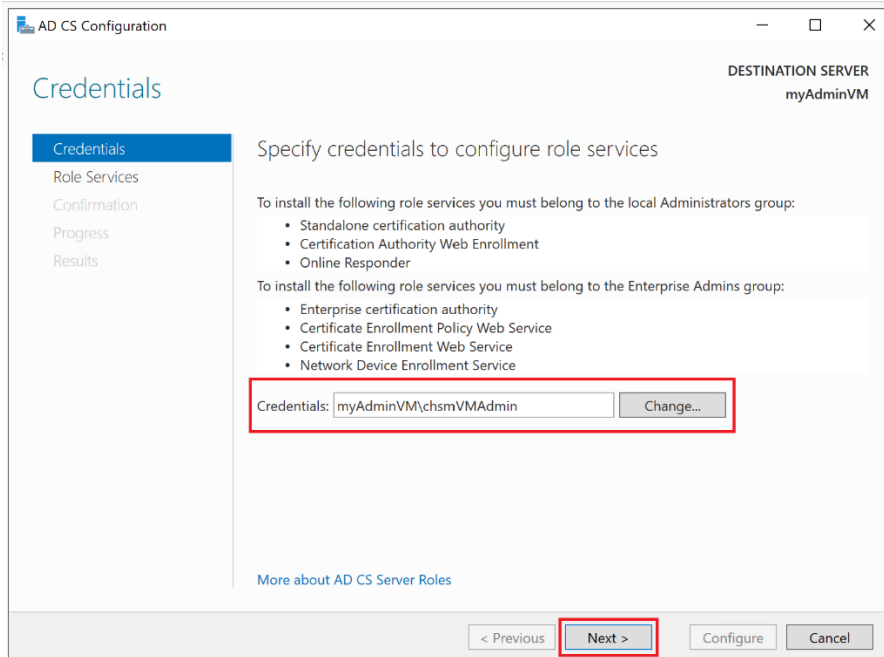
Prerequisites:

- The [Install Active Directory Certificate Services](#) steps must have been completed.

- The user has already generated a key from the KSP (the key label used in the example below is test).

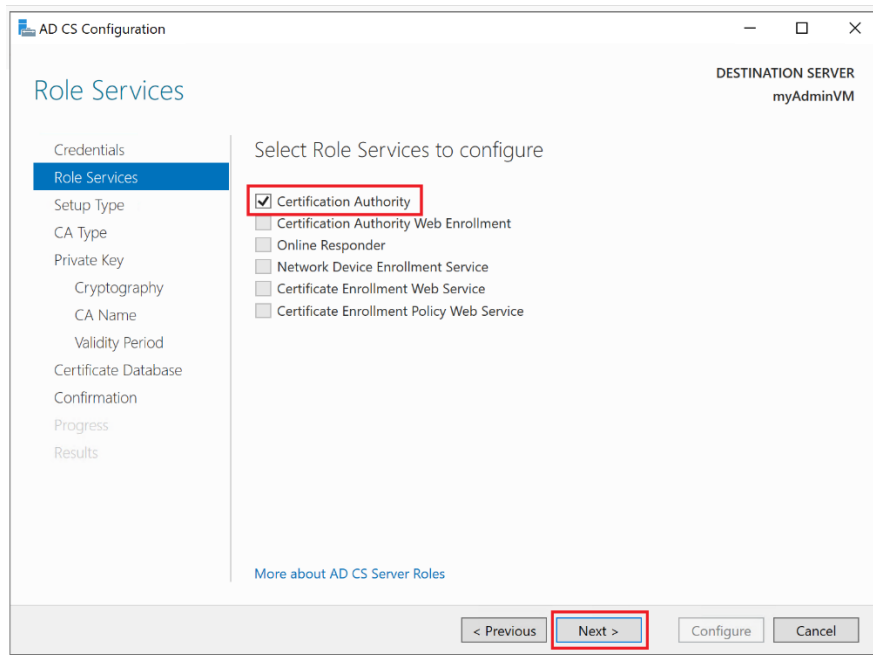
To configure the certificate server using the Azure Cloud HSM KSP with an existing key, complete the following steps.

1. Click the **Configure ADCS** link from the Server Manager and then click **Next**.

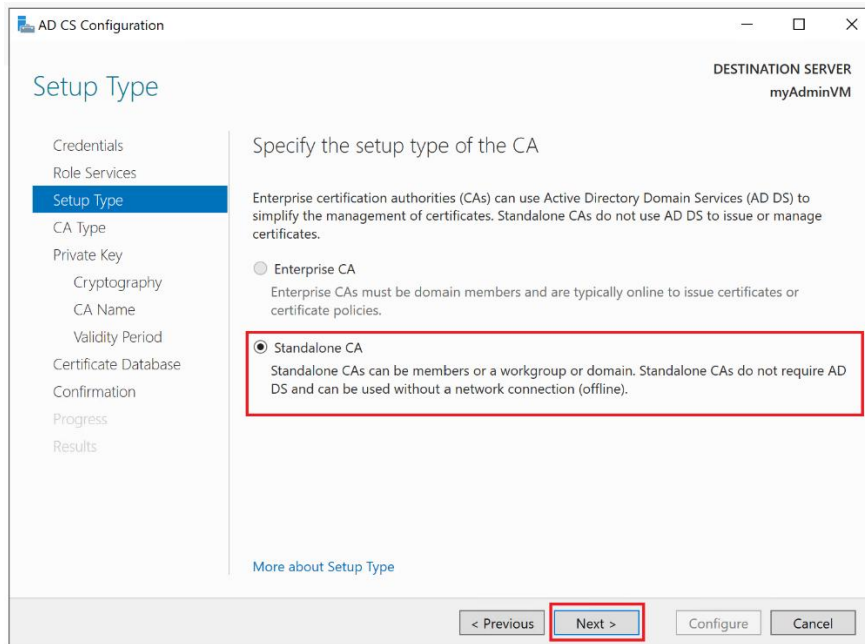


The screenshot shows the 'AD CS Configuration' wizard window. The title bar says 'AD CS Configuration'. The window has a sidebar on the left with the following links: 'Credentials' (highlighted in blue), 'Role Services', 'Confirmation', 'Progress', and 'Results'. The main area is titled 'Credentials' and contains the text 'Specify credentials to configure role services'. In the top right corner, it says 'DESTINATION SERVER myAdminVM'. Below this, there are two sections of role services that must be installed. The first section, 'To install the following role services you must belong to the local Administrators group:', lists: 'Standalone certification authority', 'Certification Authority Web Enrollment', and 'Online Responder'. The second section, 'To install the following role services you must belong to the Enterprise Admins group:', lists: 'Enterprise certification authority', 'Certificate Enrollment Policy Web Service', 'Certificate Enrollment Web Service', and 'Network Device Enrollment Service'. At the bottom of the main area, there is a 'Credentials:' label followed by a text box containing 'myAdminVM\chsmVMAdmin' and a 'Change...' button. A red rectangle highlights this text box and button. At the bottom of the window, there are four buttons: '< Previous', 'Next >' (highlighted with a red rectangle), 'Configure', and 'Cancel'. A link 'More about AD CS Server Roles' is located at the bottom left of the main area.

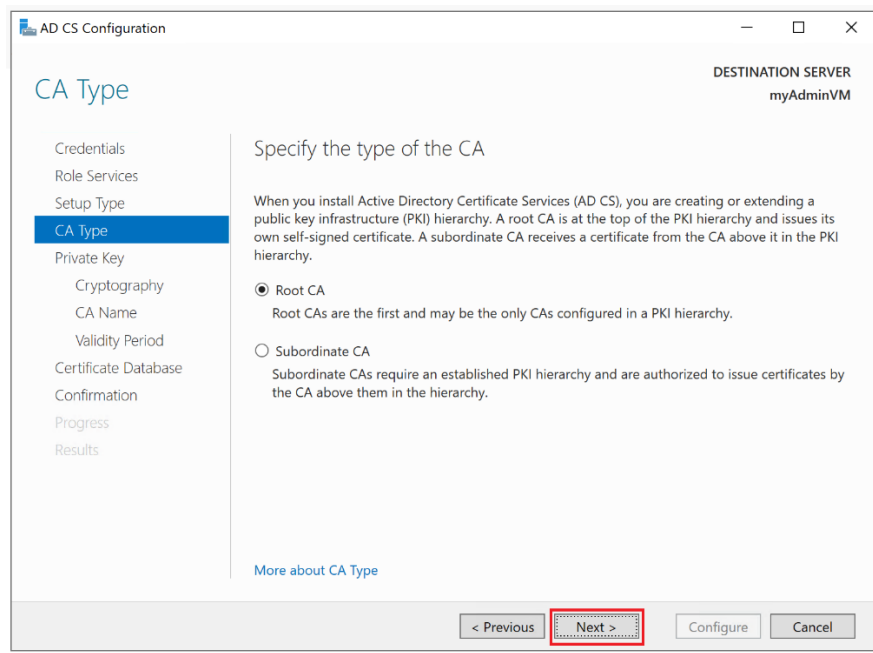
2. On the *Role Services* page, select the role services to configure and click **Next**.



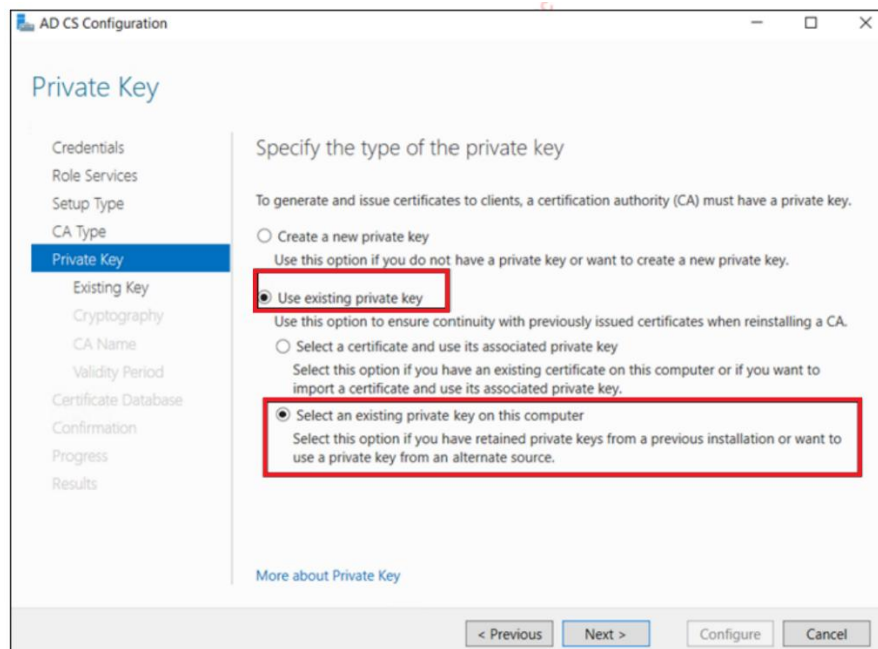
3. In the *Setup Type* page, select the appropriate **CA** setup type for your requirements. Click **Next**.
 - For this configuration example “**Standalone CA**” was selected.



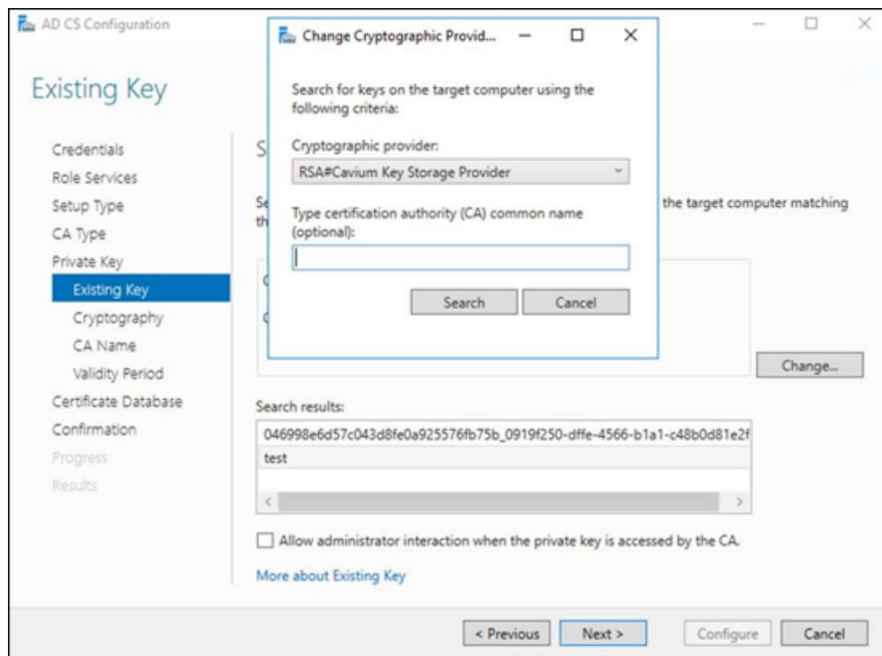
4. On the *CA Type* page, **Root CA** is selected by default. Leave the selection unchanged and click **Next**.



5. On the *Private Key* page, select **Use existing private key** and then select the option **Select the existing private key on this computer**.



6. On the **Change Cryptographic Provider** dialog, select the CSP that contains the created key. Delete the contents of the field **CA common name** and click **Search**. The search function finds the existing private key. Select the key, then select **Allow administrator interaction when the private key is accessed by the CA**. Click **Next**.



7. On the *Cryptography for CA* page, select the appropriate Azure Cloud HSM cryptographic provider along with the key type, key length, and suitable hash algorithm. Then click **Next**.
- For this example, we selected *Cryptographic Provider* as **RSA#Cavium Key Storage Provider**, *Key length* as **2048** and *hash algorithm* as **SHA256**.
 - Click *check box* to enable, **Allow administrator interaction when the private key is accessed by the CA**.

AD CS Configuration

Cryptography for CA

DESTINATION SERVER
myAdminVM

Credentials
Role Services
Setup Type
CA Type
Private Key
Cryptography
CA Name
Validity Period
Certificate Database
Confirmation
Progress
Results

Specify the cryptographic options

Select a cryptographic provider: RSA#Cavium Key Storage Provider Key length: 2048

Select the hash algorithm for signing certificates issued by this CA:

SHA1
SHA256
SHA384
SHA512

☒ Allow administrator interaction when the private key is accessed by the CA.

[More about Cryptography](#)

< Previous Next > Configure Cancel

8. On the *CA Name* page, provide the appropriate CA name and click **Next**.

The screenshot shows the 'AD CS Configuration' window with the 'CA Name' page selected in the left-hand navigation pane. The main area is titled 'Specify the name of the CA'. It contains a text box for 'Common name for this CA:' with the value 'myAdminVM-CA' entered. Below this is a text box for 'Distinguished name suffix:' which is empty. A 'Preview of distinguished name:' section shows 'CN=myAdminVM-CA'. At the bottom, there are four buttons: '< Previous', 'Next >', 'Configure', and 'Cancel'. The 'Next >' button is highlighted with a red box. A red box also highlights the 'Common name for this CA:' text box and its content.

AD CS Configuration

DESTINATION SERVER
myAdminVM

CA Name

- Credentials
- Role Services
- Setup Type
- CA Type
- Private Key
- Cryptography
- CA Name**
- Validity Period
- Certificate Database
- Confirmation
- Progress
- Results

Specify the name of the CA

Type a common name to identify this certification authority (CA). This name is added to all certificates issued by the CA. Distinguished name suffix values are automatically generated but can be modified.

Common name for this CA:
myAdminVM-CA

Distinguished name suffix:

Preview of distinguished name:
CN=myAdminVM-CA

[More about CA Name](#)

< Previous **Next >** Configure Cancel

9. On the *Validity Period* page, enter the number of years for the certificate to be valid and click **Next**.

AD CS Configuration

DESTINATION SERVER
myAdminVM

Validity Period

- Credentials
- Role Services
- Setup Type
- CA Type
- Private Key
 - Cryptography
 - CA Name
 - Validity Period**
 - Certificate Database
 - Confirmation
 - Progress
 - Results

Specify the validity period

Select the validity period for the certificate generated for this certification authority (CA):

5 Years

CA expiration Date: 3/10/2028 11:21:00 PM

The validity period configured for this CA certificate should exceed the validity period for the certificates it will issue.

[More about Validity Period](#)

< Previous **Next >** Configure Cancel

10. On the *Certificate Database* page, provide the locations for both the certificates and logs and click **Next**.

AD CS Configuration

DESTINATION SERVER
myAdminVM

CA Database

- Credentials
- Role Services
- Setup Type
- CA Type
- Private Key
 - Cryptography
 - CA Name
 - Validity Period
- Certificate Database**
- Confirmation
- Progress
- Results

Specify the database locations

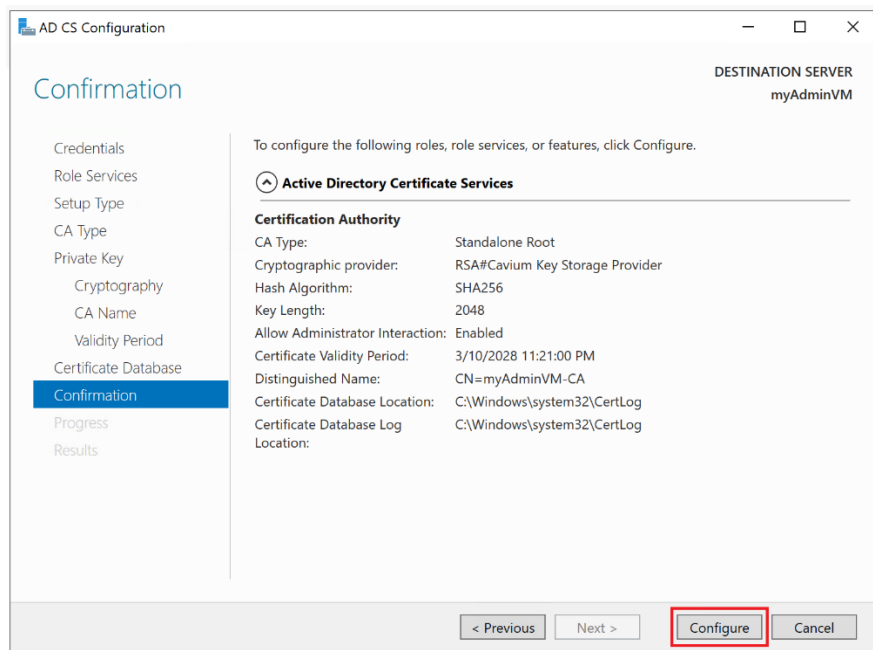
Certificate database location:
C:\Windows\system32\CertLog

Certificate database log location:
C:\Windows\system32\CertLog

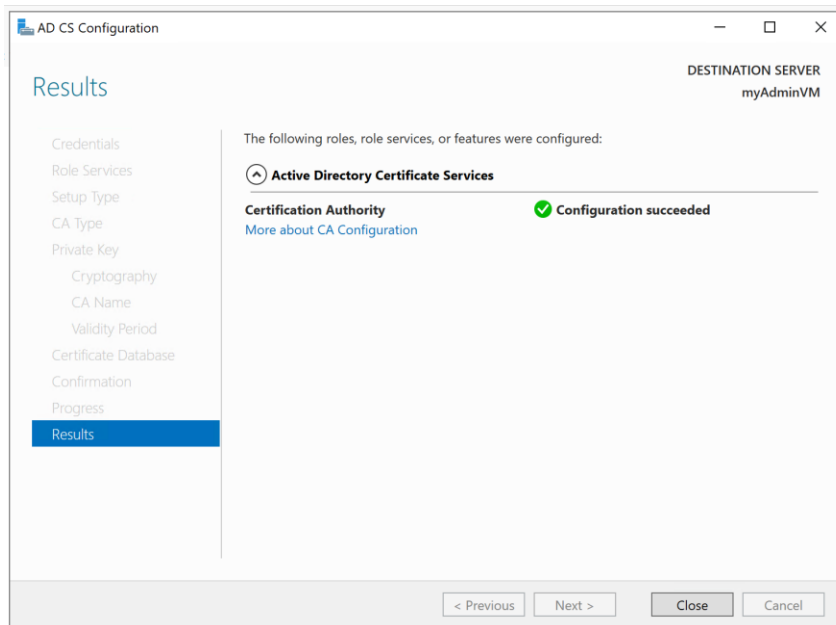
[More about CA Database](#)

< Previous **Next >** Configure Cancel

11. On the *Confirmation* page, click **Configure**.



12. When the configuration completes, a success message is displayed. Click **Close**.



Important Note: You can also check to see whether the CA has been installed correctly by executing **sc query certsvc** from the command line:

```
Administrator: Command Prompt
Microsoft Windows [Version 10.0.17763.4010]
(c) 2018 Microsoft Corporation. All rights reserved.

C:\Users\chsmVMAdmin>sc query certsvc

SERVICE_NAME: certsvc
        TYPE               : 110  WIN32_OWN_PROCESS (interactive)
        STATE                : 4    RUNNING
                           (STOPPABLE, PAUSABLE, ACCEPTS_SHUTDOWN)
        WIN32_EXIT_CODE       : 0    (0x0)
        SERVICE_EXIT_CODE   : 0    (0x0)
        CHECKPOINT           : 0x0
        WAIT_HINT            : 0x0
```

Validate Azure Cloud HSM KSP with ADCS

Customers typically use Key Storage Providers (KSP) rather than Cryptographic Next Generation (CNG), providers with Active Directory Certificate Services (ADCS). This preference is primarily due to the enhanced security and regulatory compliance requirements often associated with ADCS deployments. KSP, especially those implemented with hardware security modules (Azure Cloud HSM), offer several advantages for

ADCS environments. The Azure Cloud HSM KSP implementation bestows users with the necessary privileges to establish communication with their Azure Cloud HSM.

1. Generate a CSR File

You will need to ensure the `azcloudhsm_application.cfg` is in the directory you are running `certreg` from, else you will receive a `azcloudhsm_application.cfg` is not present exception.

```
certreq -new request.inf request.req
```

- *Sample request.inf file.*
 - *KeySpec 1 indicates AT_KEYEXCHANGE, 2 indicates AT_SIGNATURE.*
 - *ProviderName value "Cavium Key Storage Provider" for KSP,*
 - *ProviderType value 32 for KSP (Cavium Key Storage Provider).*

```
[Version]
Signature="$Windows NT$"

[NewRequest]
Subject = "CN=Test, OU=Security, O=Microsoft, L=Redmond, S=WA, C=US"
KeySpec = 2
KeyLength = 2048
ProviderName = "Cavium Key Storage Provider"
ProviderType = 32
RequestType = PKCS10
HashAlgorithm = SHA256
```

2. Verify CSR file generated by Azure Cloud HSM using "Cavium Key Storage Provider".

```
certutil -dump .\request.req
```

Output:

```
PKCS10 Certificate Request:
Version: 1
Subject:
  CN=Test
  OU=Security
```


O=Microsoft

L=Redmond

S=WA

C=US

...

Provider = Cavium Key Storage Provider

...

3. Request for a New Certificate.
 - a. In the Certification Authority MMC snap-in, expand the Certification Authority node to reveal your CA server.
 - b. Right-click on the "CA", select "All Tasks" > "Submit New Request."
4. Approve the Certificate Request
 - In the Certification Authority MMC snap-in, navigate to the "Pending Requests" folder.
 - Right-click on the pending certificate request corresponding to the one you just submitted.
 - Select "All Tasks" > "Issue."
5. Retrieved the Issued Certificate.
 - Once the request is approved and the certificate is issued, it will move from the "Pending Requests" folder to the "Issued Certificates" folder.
 - You can now retrieve the issued certificate by locating it in the "Issued Certificates" folder. Double-click on it to view its details and compare it against the certutil -dump you performed earlier they should match.

Request ID	Requester Name	Binary Certificate	Certificate Template	Serial Number	Certificate Effective Date	Certificate Expiration Date	Issued Country/Region	Issued Organization
17	myADCSVM\chsmVMAAdmin	-----BEGIN CERTI...		300000007a2cb2...	3/27/2024 2:47 AM	3/27/2025 2:57 AM	US	Microsoft

Certificate

General Details Certification Path

Show: <All>

Field	Value
Issuer	myADCSVM-CA
Valid from	Wednesday, March 27, 2024 ...
Valid to	Thursday, March 27, 2025 2:5...
Subject	Test, Security, Microsoft, Red...
Public key	RSA (2048 Bits)
Public key parameters	05 00
Subject Key Identifier	2950d8d8ff6199b4289e3ec113c987b1df646741
Authority Key Identifier	KeyID: 11811f192556a46b...

2950d8d8ff6199b4289e3ec113c987b1df646741

Edit Properties... Copy to File...

OK

Select Administrator: Command Prompt

```

Certificate Extensions: 1
2.5.29.14: Flags = 0, Length = 16
Subject Key Identifier
2950d8d8ff6199b4289e3ec113c987b1df646741

Attribute[2]: 1.3.6.1.4.1.311.21.20 (Client Information)
Value[2][0], Length = 32
Client Id = 9
ClientIdCertReq -- 9
User: myADCSVM\chsmVMAAdmin
Machine: myADCSVM
Process: certreq.exe

Attribute[3]: 1.3.6.1.4.1.311.13.2.2 (Enrollment CSP)
Value[3][0], Length = 40
CSP Provider Info
KeySpec = 0
Provider = Cavium Key Storage Provider
Signature: UnusedBits=0
Signature Algorithm:
Algorithm ObjectId: 1.2.840.113549.1.1.11 sha256RSA
Algorithm Parameters:
05 00
Signature: UnusedBits=0
0000 47 2f 29 54 ef 75 a1 ab 29 36 aa 8c 45 b6 96 59
0010 72 eb cf 5c 6e b7 0d 38 f3 3a 5e b5 22 87 4a 74
0020 99 33 ef 98 1f 9a c1 9f d9 0c e3 12 78 0f ef 25
0030 c6 d9 db ba f1 81 cc 41 3a 0b ee 72 0d 38 e9 6f
0040 d2 37 b0 4c 58 38 1f e5 e3 9a ee 16 5b f2 b0 89
0050 ef 61 80 f7 af d0 01 7d fd 74 c3 de 29 e5 82 53
0060 c0 56 fd 8b d1 b0 08 d7 c0 a4 95 c8 5b 23 48 bd
0070 63 c8 dc e1 9d c8 6d 5f 45 ba 9e aa fd 4a e5 95
0080 14 85 aa 37 fb 46 44 29 aa 60 0c 1a 13 71 15 c9
0090 4e e7 68 6c 9f d8 72 06 98 5d 0a 04 53 ba 98 4c
00a0 ff c6 ab fd 52 5c 28 5f e1 31 4f bf b5 f6 83 9b
00b0 8c 3f ad c1 00 ab fe 84 2c 1d c2 c7 c3 c4 ba dd
00c0 10 96 f3 c6 cb 96 01 ac 52 7f 43 83 d1 20 00 05
00d0 d1 9d 90 2c da fd ed 7b 9c 90 6f 13 f7 d4 43 8e
00e0 3a 98 c2 be 92 1a 99 54 8b cb 5b ef 6c 53 c5 b7
00f0 b0 33 5e fd f4 28 56 f9 38 21 08 56 7f 5c d0 35

Signature matches Public Key
Key Id Hash(rfc-sha1): 2950d8d8ff6199b4289e3ec113c987b1df646741
Key Id Hash(sha1): 6a5d1911543af153eac4041a7b12a4dd379870f00
Key Id Hash(bcrypt-sha1): 0897b3d9eaa660ebd930d65ba6f24d815d28dfa5
Key Id Hash(bcrypt-sha256): 1f5fc98075e925627d9948daf8d538cd67550eb7335df8d38f5024b5b113ce94
CertUtil: -dump command completed successfully.

```

Representing Cloud HSM Keys in the KSP

This section shows the process of representing keys generated within Azure Cloud HSM and putting them into the KSP using the Cloud HSM SDK tool `azcloudhsm_ksp_import_key.exe`.

Creating a single key pair in the HSM and representing It in the KSP.

1. Generate an RSA key pair. Make notes of the private and public key handles. These are used in the next steps.

```
azcloudhsm_util.exe singlecmd loginHSM -u CU -s cu1 -p user1234 genRSAKeyPair -m 2048 -e 65537 -l testKspRSA
```

2. Import keys from your Cloud HSM into the Cloud HSM Key Storage Provider (KSP).

```
azcloudhsm_ksp_import_key.exe -from HSM -privateKeyHandle {privateKeyHandle} -publicKeyHandle {publicKeyHandle}
```

3. List keys stored in the Azure Cloud HSM Key Storage Provider (KSP)

```
certutil -key -csp "Cavium Key Storage Provider"
```

```
Version info, Client Version: 2.09.07.00, SDK API Version: 2.09.07.00

Cfm3Initialize() returned app id : 01084000

session_handle 1084021

Current FIPS mode is: 00000002

Cfm3LoginHSM returned: 0x00 : HSM Return: SUCCESS

Cluster Status:
Node id 1 status: 0x00000000 : HSM Return: SUCCESS
Node id 2 status: 0x00000000 : HSM Return: SUCCESS
Node id 3 status: 0x00000000 : HSM Return: SUCCESS
Command: genRSAKeyPair -m 2048 -e 65537 -l testKspRSA

Cfm3GenerateKeyPair returned: 0x00 : HSM Return: SUCCESS

Cfm3GenerateKeyPair: public key handle: 524326 private key handle: 524327

Cluster Status:
Node id 1 status: 0x00000000 : HSM Return: SUCCESS
Node id 2 status: 0x00000000 : HSM Return: SUCCESS
Node id 3 status: 0x00000000 : HSM Return: SUCCESS
PS C:\AzureCloudHSM-ClientSDK\AzureCloudHSM-ClientSDK-Windows-1.0.3.0> .\libs\ksp\azcloudhsm_ksp_import_key.exe -from HSM -privateKeyHandle 524327 -publicKeyHandle 524326

Represented 1 keypairs in Cavium Key Storage Provider.
PS C:\AzureCloudHSM-ClientSDK\AzureCloudHSM-ClientSDK-Windows-1.0.3.0> certutil -key -csp "Cavium Key Storage Provider"
Cavium Key Storage Provider:
myADCSVM-CA
RSA

testKspRSA-524324-524325-a0d620
RSA
```

Representing All Cloud HSM Keys in the KSP

1. Generate multiple RSA key pairs within the Azure Cloud HSM.

```
azcloudhsm_util.exe singlecmd loginHSM -u CU -s cu1 -p user1234 genRSAKeyPair -m 2048 -e 65537 -l testKspRSA2
```

```
azcloudhsm_util.exe singlecmd loginHSM -u CU -s cu1 -p user1234 genRSAKeyPair -m 2048 -e 65537 -l testKspRSA3
```

2. Import all keys from your Cloud HSM into the Cloud HSM Key Storage Provider (KSP).

```
azcloudhsm_ksp_import_key.exe -from HSM -all
```

3. List keys stored in the Azure Cloud HSM Key Storage Provider (KSP)

```
certutil -key -csp "Cavium Key Storage Provider"
```

```
C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs\ksp>azcloudhsm_ksp_import_key.exe -from HSM -all  
Represented 2 keypairs in Cavium Key Storage Provider.  
C:\Program Files\Microsoft Azure Cloud HSM Client SDK\libs\ksp>certutil -key -csp "Cavium Key Storage Provider"  
Cavium Key Storage Provider:  
myAdminVM-CA  
RSA  
  
testKspRSA-262172-262173-c5da54  
RSA  
  
testKspRSA2-524296-524297-04eee2  
RSA  
  
testKspRSA3-786442-786443-760fac  
RSA  
  
tq-997670c3-4680-409d-93d5-0387f155a658  
RSA  
  
CertUtil: -key command completed successfully.
```

Migrating a Certificate from Microsoft KSP to Cloud HSM KSP

The following sections explain how to migrate certificate and keys created with Microsoft Software Key Storage Provider to the Azure Cloud HSM Key Storage Provider (KSP). For this example, we will be following Option 2.

Important Note: To migrate a certificate from Microsoft KSP or another 3rd Party KSP to Azure Cloud HSM KSP, you must first create a User-Generated KEK. This KEK is crucial for the migration process. When transitioning to Cloud HSM KSP, migration involves an import operation, which establishes private and public key handles in Cloud HSM linked to the migrated certificate. If you haven't yet created a User-Generated KEK, please refer to the provided instructions for [creating a User-Generated KEK](#) before proceeding with the migration.

1. **Generate a self-signed certificate.**

Make note of the thumbprint for your certificate. It will be used in the next steps.

a. **Option 1: Generate self-signed certificate (Personal)**

```
# Generate the self-signed certificate  
New-SelfSignedCertificate -KeyLength 2048 -KeyAlgorithm RSA -Subject "CN=TestKSPUpdate" -  
Provider "Microsoft Software Key Storage Provider" -KeyExportPolicy Exportable -Container  
TestKSPKeyOpt1 -CertStoreLocation Cert:\LocalMachine -HashAlgorithm SHA256
```

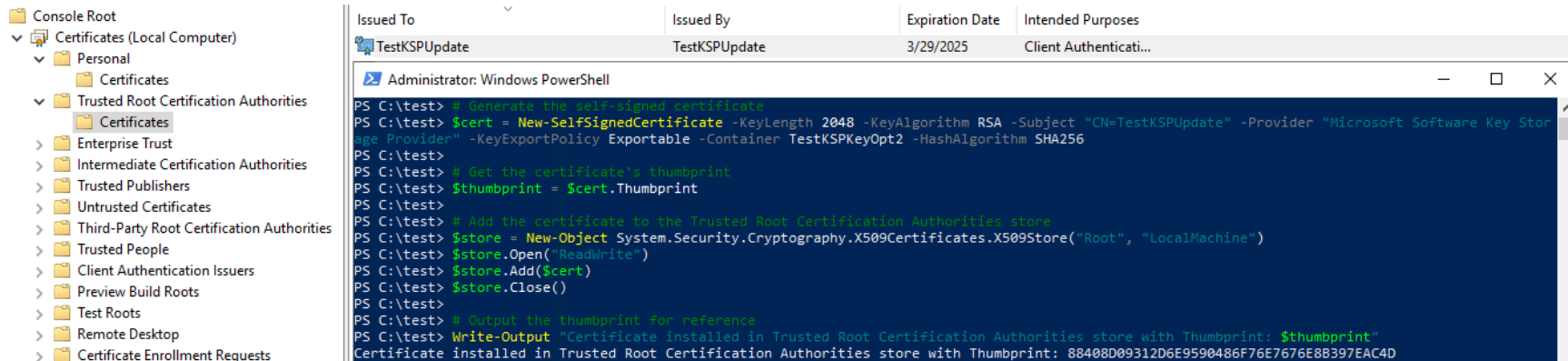
a. Option 2: Generate self-signed RootCA certificate (Trusted Root Certification Authorities)

```
# Generate the self-signed certificate
$cert = New-SelfSignedCertificate -KeyLength 2048 -KeyAlgorithm RSA -Subject "CN=TestKSPUpdate"
-Provider "Microsoft Software Key Storage Provider" -KeyExportPolicy Exportable -Container
TestKSPKeyOpt2 -HashAlgorithm SHA256

# Get the certificate's thumbprint
$thumbprint = $cert.Thumbprint

# Add the certificate to the Trusted Root Certification Authorities store
$store = New-Object System.Security.Cryptography.X509Certificates.X509Store("Root",
"LocalMachine")
$store.Open("ReadWrite")
$store.Add($cert)
$store.Close()

# Output the thumbprint for reference
Write-Output "Certificate installed in Trusted Root Certification Authorities store with Thumbprint:
$thumbprint"
```



2. Import keys from Microsoft KSP into the Cloud HSM Key Storage Provider (KSP).

```
.\libs\ksp\azcloudhsm_ksp_import_key.exe -from MSKSP -RSA TestKSPKeyOpt2
```

```
Administrator: Windows PowerShell
PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK> .\libs\ksp\azcloudhsm_ksp_import_key.exe -from MSKSP -RSA TestKSPKeyOpt2
Successfully imported the key to Cavium Key Storage Provider.
```

3. Validate the creation of new Key Handles in Cloud HSM.

```
(Get-ChildItem -Recurse
C:\Users\Default\AppData\Roaming\Microsoft\Crypto\CaviumKSP\GlobalPartition) | Select-Object
Name, @{label = "keyHandles"; expression = { $keyBytes = [System.IO.File]::ReadAllBytes($_.FullName);
@([System.BitConverter]::ToInt64($keyBytes, 16), [System.BitConverter]::ToInt64($keyBytes, 24)) }} |
Where-Object keyHandles -ne $null
```

```
Administrator: Windows PowerShell
PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK> (Get-ChildItem -Recurse C:\Users\Default\AppData\Roaming\Microsoft\Crypto\CaviumKSP\GlobalPartition) | Select-Object Name, @{label = "keyHandles"; expression = { $keyBytes = [System.IO.File]::ReadAllBytes($_.FullName); @([System.BitConverter]::ToInt64($keyBytes, 16), [System.BitConverter]::ToInt64($keyBytes, 24)) }} | Where-Object keyHandles -ne $null

Name                                     keyHandles
----                                     -
myAdminVM-CA                            {262171, 262170}
TestKSPKeyOpt2                          {524301, 524300}
```

4. Import keys from Microsoft KSP into the Cloud HSM Key Storage Provider (KSP).
 - a. If you selected option 1, generate self-signed certificate execute the following command.

```
certutil -store my {CertificateThumbprint}
```
 - b. If you selected option 2 generate self-signed RootCA certificate execute the following command.

```
certutil -store root {CertificateThumbprint}
```
5. Initiate the repair operation for the specified certificate, to update and utilize the "Cavium Key Storage Provider" for Cloud HSM.
 - a. If you selected option 1, generate self-signed certificate execute the following command.

```
certutil.exe -f -csp "Cavium Key Storage Provider" -repairstore my {CertificateThumbprint}
```

- c. If you selected option 2 generate self-signed RootCA certificate execute the following command.

```
certutil.exe -f -csp "Cavium Key Storage Provider" -repairstore root {CertificateThumbprint}
```


6. Verify "Cavium Key Storage Provider" for Cloud HSM was applied.

- a. If you selected option 1, generate self-signed certificate execute the following command.

```
certutil -store my {CertificateThumbprint}
```

- d. If you selected option 2 generate self-signed RootCA certificate execute the following command.

```
certutil -store root {CertificateThumbprint}
```

 Administrator: Windows PowerShell

```
PS C:\Program Files\Microsoft Azure Cloud HSM Client SDK> certutil -store root $thumbprint
root "Trusted Root Certification Authorities"
===== Certificate 10 =====
Serial Number: 5ed8f7eb3e6afe9347dd69b562c7c7a8
Issuer: CN=TestKSPUpdate
NotBefore: 7/30/2024 11:43 PM
NotAfter: 7/31/2025 12:03 AM
Subject: CN=TestKSPUpdate
Signature matches Public Key
Root Certificate: Subject matches Issuer
Cert Hash(sha1): 69db49cc1eeabe97cef60db8c8b5aa0cf405c2c6
Key Container = TestKSPKeyOpt2
Provider = Cavium Key Storage Provider
Private key is NOT exportable
Encryption test passed
CertUtil: -store command completed successfully.
```

Creating a User Generated KEK

Creating a User-Generated KEK is necessary only for ADCS customers who are trying to migrate certificates from Microsoft KSP, or other 3rd Party KSP to Azure Cloud HSM KSP.

1. Creating a user KEK handle involves initial steps where customers execute the `azcloudhsm_client`, connect to their Cloud HSM using the `azcloudhsm_util`, and subsequently log in to their HSM. The `azcloudhsm_client` must be running for `azcloudhsm_util` to execute. The provided example illustrates the process of generating a user KEK and obtaining its handle.

Important Note: Please keep track of your Key Handle ID generated. You'll require this Key Handle ID to finalize the process. A User-Generated KEK can be created with extractable and trusted, or non-extractable but trusted.

Option 1: User KEK with extractable and trusted. The example below we're setting *-l* (key label) as *userkek*, *-t* (key type) and *-s* (key size) as AES, 32 bytes.

```
./azcloudhsm_util.exe  
loginHSM -u CU -s cu1 -p user1234  
genSymKey -l userkek -t 31 -s 32 -wrap_with_trusted 1
```

```
Command: genSymKey -l userkek -t 31 -s 32 -wrap_with_trusted 1  
  
Cfm3GenerateSymmetricKey returned: 0x00 : HSM Return: SUCCESS  
  
Symmetric Key Created. Key Handle: 262259  
  
Cluster Status:  
Node id 1 status: 0x00000000 : HSM Return: SUCCESS  
Node id 2 status: 0x00000000 : HSM Return: SUCCESS  
Node id 3 status: 0x00000000 : HSM Return: SUCCESS
```

Option 2: User KEK with non-extractable but trusted. The example below we're setting *-l* (key label) as *userkek*, *-t* (key type) and *-s* (key size) as AES, 32 bytes and setting the key as non-extractable.

```
./azcloudhsm_util.exe  
loginHSM -u CU -s cu1 -p user1234  
genSymKey -l userkek -t 31 -s 32 -nex
```



```

Command: loginHSM -u CU -s cu1 -p user1234

Cfm3LoginHSM returned: 0x00 : HSM Return: SUCCESS

Cluster Status:
Node id 1 status: 0x00000000 : HSM Return: SUCCESS
Node id 2 status: 0x00000000 : HSM Return: SUCCESS
Node id 3 status: 0x00000000 : HSM Return: SUCCESS

Command: genSymKey -l userkek -t 31 -s 32 -nex

Cfm3GenerateSymmetricKey returned: 0x00 : HSM Return: SUCCESS

Symmetric Key Created. Key Handle: 262150

Cluster Status:
Node id 1 status: 0x00000000 : HSM Return: SUCCESS
Node id 2 status: 0x00000000 : HSM Return: SUCCESS
Node id 3 status: 0x00000000 : HSM Return: SUCCESS

```

2. After the key has been generated, customers will need to set the correct attributes on their key so that it can be used as a KEK. Firstly, you will need to end your azcloudhsm_util session. Customers will then run the management util and login as the Crypto Officer. You must be logged in as the Crypto Officer when setting the attributes on the Key.

```

.\azcloudhsm_mgmt_util.exe .\azcloudhsm_resource.cfg
loginHSM CO admin adminpassword

```

3. Upon assuming the role of the Crypto Officer and logging in, proceed to configure the attributes of the previously generated key. Obtain the key handle from the previous step and execute the following command to establish its attributes, utilizing your KeyHandleID.

Usage: setAttribute <KeyHandle> <AttributeID> <AttributeValue>. AttributeID 134 sets OBJ_ATTR_TRUSTED. AttributeValue 1 sets OBJ_ATTR_AUTH_FACTOR which is 1FA. Customers must use 134 1. No other values are supported as we only support 1FA.

```

setAttribute <KeyHandleID> 134 1

```

```
cloudmgmt>setAttribute 262150 134 1
*****CAUTION*****
This is a CRITICAL operation, should be done on all nodes in the
cluster. Cav server does NOT synchronize these changes with the
nodes on which this operation is not executed or failed, please
ensure this operation is executed on all nodes in the cluster.
*****

Do you want to continue(y/n)?y
setAttribute success on server 0(10.0.2.4)
setAttribute success on server 1(10.0.2.5)
setAttribute success on server 2(10.0.2.6)
cloudmgmt>
```

4. After configuring the attributes for the generated key, you can utilize it as a KEK (Key Encryption Key) by modifying the USER_KEK_HANDLE in your azcloudhsm_application.cfg file with the corresponding KeyHandleID.

```
DAEMON_ID=1
SOCKET_TYPE=UNIXSOCKET
PORT=1111
USER_KEK_HANDLE=262150
```

Appendix

Frequently Asked Questions

- **Why am I getting a *Certificate ERROR: [certificate signature failure]* when running azcloudhsm_mgmt_util?**
This error commonly occurs when a customer created and initialized their Azure Cloud HSM from another VM and attempts to install the Cloud HSM Client SDK and run from another VM that is missing or does not have the correct PO.crt from the Admin VM you initialized from. If you copy the PO.crt from your Admin VM to your new VM and rerun the azcloudhsm_mgmt_util you should see a successful connection to your HSM.
- **Why am I getting an *INF: shutdown_ssl_socket: SSL_shutdown sent close_notify alert* when running azcloudhsm_client?**
This error commonly occurs when a customer created and initialized their Azure Cloud HSM from another VM and attempts to install the Cloud HSM Client SDK and run from another VM that is missing or does not have the correct PO.crt from the Admin VM you initialized from. If you copy the PO.crt from your Admin VM to your new VM and rerun the azcloudhsm_client you should see a successful connection to your HSM.

- **Why am I getting NCryptImportKey failed:- C0000001. Failed to import the key to Cavium Key Storage Provider.**
This error commonly occurs when a user-generated KEK has not been created and the USER_KEK_HANDLE in the azcloudhsm_application.cfg file has not been updated. To enable key import functionality, you must create a user-generated KEK.
- **Why am I getting a can't open openssl-ca.cnf file when trying to migrate a certificate from Microsoft KSP from provided example?**
This error commonly occurs when the openssl-ca.cnf does not exist. You can create one yourself or obtain it from another source.
- **Can we use our own signing servers in our corporate network which consumes Azure Cloud HSM as SaaS solution?**
Azure Cloud HSM is IaaS only. You can use your own signing servers in your corporate network, however. You can configure Site-to-Site or Point-to-Site VPN connection from your local network gateway. This is the most common method, and it's suitable for most use cases. Set up a VPN connection between your corporate network's on-premises and Azure to where Azure Cloud HSM is deployed.
 - [Tutorial - Connect an on-premises network and a virtual network: S2S VPN: Azure portal - Azure VPN Gateway | Microsoft Learn](#)
 - You can have ADCS for your signing servers on-prem. What is required is SDK must be on your on-prem host and the client be reachable to your Azure VNET Private IPs.
 - i. The customer needs to run the azcloudhsm_client on the same machine where Cavium CNG provider exists.
 - ii. The azcloudhsm_client should be able to reach out to the Customers Azure VNET private IPs.
- **When testing ADCS we generated an RSAKeyPair then used CFM to Sign.**
 - Are the only accepted methods to sign/verify through Cloud HSM / LS providers (i.e azcloudhsm_util, etc.)?
 - No. Our recommendation is to use the Azure Cloud HSM SDK and the interfaces (PKCS#11, CNG, KSP, JCE, OpenSSL Engine, Etc.) it provides. You can use the Sign Tool for sign/verify operations as well.
 - ADCS is configured to use Azure Cloud HSM CNG/KSP. Can we use the signing / verify from Cloud HSM via signtool.exe?
 - Yes. The Sign Tool will automatically go to your Cloud HSM. There is no need to use azcloudhsm_util for that. We just included azcloudhsm_util in the instructions above as a way for customers to quickly test and validate their ADCS configuration.
- **Can we use self-signed certs based on the key-pair in Cloud HSM for testing or have it be issued?**
 - Yes. You can use self-signed certificates based on the key-pair for testing purposes.
- **Is there an integration or way to make available the certs via the local windows certificate store in windows?**
 - There is a tool called certreq.exe that can be used for this purpose.

- **Why am I getting an error message when trying to use the CNG and KSP provider?**
 - The Azure Cloud HSM SDK MSI package automatically registers the CNG and KSP provider for Windows. In the event the Azure Cloud HSM CNG and KSP provider failed to register or where removed you can run the following commands to register and validate configuration.
 - Register the Azure Cloud HSM CNG provider.
 - Open PowerShell and cd to the `.\libs\cng` directory under “C:\Program Files\Microsoft Azure Cloud HSM Client SDK”
 - Run: `.\azcloudhsm_cng_config.exe -register`
 - Validate CNG was registered by running `.\azcloudhsm_cng_config.exe -enum` which will show as ‘Cavium CNG Provider’.
 - Register the Azure Cloud HSM KSP provider.
 - From the same open PowerShell window cd to the `.\libs\ksp` directory under C:\AzureCloudHSM-ClientSDK
 - Run `.\azcloudhsm_ksp_client.exe -register`
 - Validate KSP was registered by running `.\azcloudhsm_ksp_client.exe -enum` which will show as ‘Cavium Key Storage Provider’.
- **What algorithms do the Azure Cloud HSM CNG and KSP providers support?**
 - RSA encryption/decryption.
 - RSA signing with SHA1, SHA256, SHA384, SHA512, and MD5 Hash algorithms.
 - ECC curves ECDSA_P256, ECDSA_P384, and ECDSA_P521.
- **How do I change or manage private key permissions to non-administrative users on Windows?**
 - When generating a key using the Azure Cloud HSM KSP or CNG, only the Administrator is granted access to the private key. You may encounter difficulties in viewing security information or modifying permissions via MMC. This behavior is intentional. By default, when utilizing KSP or CNG, access to the private key file for a new key is restricted to SYSTEM and Administrators. If there is a need to provide access to a non-administrative user for a specific private key file, you can achieve this by identifying the private key filename and assigning permissions directly. The private keys are in the directory C:\Users\Default\AppData\Roaming\Microsoft\Crypto\CaviumKSP on Windows for Cloud HSM keys.
- **What does azcloudhsm_ksp_import_key.exe do?**

azcloudhsm_ksp_import_key.exe allows customers to import or represent an asymmetric key/keys in Cloud HSM KSP.

- Supported algorithms are RSA(2048 to 4096 in multiples of 256), ECDSA and ECDH. For ECDSA and ECDH supported curves are P256, P384 and P521. Once a key is imported or represented in Cloud HSM KSP, the key should only be managed from Cloud HSM KSP.
- **What is the recommended way of “connection” to Cloud HSM from the Corporate Network (Operation/Admin tasks)?**
 - e. Customers can connect through their VNET.
 - azcloudhsm_mgmt_util executes operations (admin tasks on the HSM) which requires PCO (partition crypto officer) credentials.
 - azcloudhsm_client (client daemon) connects via PCU (partition crypto user).
 - The azcloudhsm_client and customers application need to both run on the same VM within that VNET. This is because the application connects to the client process via RPC.
 - a. The Azure Cloud HSM service listens on port 443 (azcloudhsm_client requests), 444 (azcloudhsm_mgmt_util Requests) and 445 (server-server communication).
 - b. Front end ports are 2224, 2225
 - i. TCP over TLS protocol and Ports 2224 and 2225
 - ii. Ports 2224 and 2225 are for customers only.

Recommended Readings on Azure Security Best Practices

- [Security best practices for IaaS workloads in Azure](#)
- [Enable just-in-time access on Virtual Machines](#)
- [Adopt a Zero Trust approach](#)