# Practical HPCQC Integration with QDMI: A Real-Hardware Case Study with IQM Systems


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***Abstract*—Quantum computers are moving into HPC centers, and the main challenge is now integration rather than pure hardware access. Many current software paths still depend on vendor-specific adapter chains between user SDKs, schedulers, and backend APIs. This pattern makes operations more complex than necessary and slows the transition from pilots to production workflows.**

**We present a practical integration path centered on the Quantum Device Management Interface (QDMI). Using IQM superconducting systems as a hardware case study, we implement an IQM-backed QDMI layer and connect it to two software layers that HPC centers working with quantum computers already care about: Slurm-based job execution and Qiskit-facing user workflows. The implementation is publicly available at github.com/iqm-finland/QDMI-on-IQM.**

**The key message is simple: integrating quantum hardware into HPC does not have to be a bespoke engineering effort for each backend. Once the software-hardware boundary is standardized, large parts of the stack become reusable across providers and deployment styles. Our results do not claim that standardization eliminates all HPCQC challenges. They show that this specific boundary can already be standardized today in a way that is practical for users, operators, and vendors.**



***Index Terms*—quantum computing, high-performance computing, system integration, standardization**


## I. Introduction

HPC centers are used to integrating new accelerators without rewriting their entire software stack every few years. The reason this works is that interfaces are stable: users keep familiar tools, operators keep manageable workflows, and hardware diversity is handled with clear system boundaries [1], [2], [3].

Quantum computing is now entering the same environment, but many integration paths remain fragile, as substantial parts of the quantum software ecosystem are not designed for HPC requirements [4], [5]. Teams often build bespoke backend-specific connections from frontend SDKs to vendor APIs and then add custom scheduler glue on top. This is workable for a short proof of concept, but it becomes expensive when a center wants to support multiple vendor backends, maintain workflows over time, or share tools across sites [6], [7], [8].

For HPC operators, the problem shows up quickly. Each backend-specific path brings its own authentication behavior, status model, and error semantics. Each of these differences must then be reflected in scripts, monitoring, and user support. For users, this often means that changing the backend implies changing the entire code and job setup, even when the actual scientific workflow is unchanged.

In practice, this is where many HPCQC efforts slow down. The challenge is not only qubit quality or algorithm maturity; it is the amount of bespoke integration code that accumulates in the middle of the stack [9]. Recent deployments and architecture work make this explicit: operations around calibration updates, maintenance, and scheduling semantics are now first-class concerns [10], [11], [12]. At the same time, research on resource management is converging on the idea that quantum resources should be managed through familiar HPC mechanisms rather than ad hoc side channels [13], [14].

This paper addresses one concrete boundary in that larger picture: the device-management interface between HPC software layers and quantum backends. We use QDMI [15], [16] as the standardization target for this boundary and evaluate it through a real integration effort with IQM hardware. The goal is deliberately practical. We are not proposing a full HPCQC architecture or middleware from scratch. Instead, we show that this central boundary can already be standardized in a way that immediately reduces integration effort and can directly benefit other groups seeking to integrate quantum hardware into HPC environments [17].

The core contribution is a full implementation and integration path publicly available at github.com/iqm-finland/QDMI-on-IQM. First, we build and analyze an IQM-backed QDMI implementation that maps real backend behavior into QDMI session, query, and job semantics. Second, we connect that layer to common HPC software paths: Slurm-based execution and a Qiskit-facing frontend adapter that targets QDMI rather than a single vendor API. Third, we validate the path with an end-to-end QSCI workflow that runs through the same components users and operators would use in practice.

Our central claim is intentionally modest and actionable: integrating quantum hardware into HPC need not be scary or vendor-locked. The software layers above the device-

```
IQM_QDMI_device_initialize();

IQM_QDMI_Device_Session session;
IQM_QDMI_device_session_alloc(&session);
// Session configuration [...]
IQM_QDMI_device_session_init(session);

IQM_QDMI_Device_Job job;
IQM_QDMI_device_session_create_device_job(session, &job);
// Job configuration [...]
IQM_QDMI_device_job_submit(job);
IQM_QDMI_device_job_get_results(job, ...);

IQM_QDMI_device_job_free(job);
IQM_QDMI_device_session_free(session);
IQM_QDMI_device_finalize();
```

Figure 1. Minimal QDMI interaction pattern; device, session, and job lifecycle.

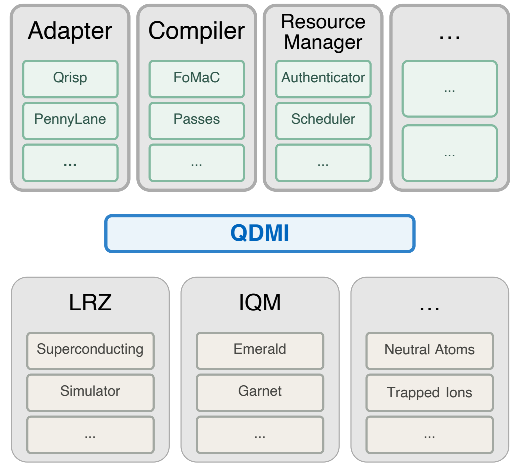


Figure 2. QDMI as the standardized software-hardware boundary, facilitating interaction between various software components and diverse hardware platforms.

management boundary can be shared once that boundary is sufficiently standardized. IQM is the concrete case study platform, but the integration pattern is broader than one vendor.

This claim does not imply that all integration work disappears. Physical devices still have vendor-specific payload formats, calibration behavior, and operational constraints. The point is that these differences can be isolated within a device plugin, rather than leaking through every layer of the HPCQC software stack.

The remainder of the paper is structured as follows. Sec. II introduces the required background and operational context. Sec. III explains the IQM QDMI implementation in detail. Sec. IV describes how the standardized device layer is connected to HPCQC workflows. Sec. VI walks through an end-to-end execution of the QSCI algorithm through the proposed infrastructure. Sec. V elaborates three potential deployment scenarios. Finally, Sec. VII summarizes practical takeaways for centers and vendors.

## II. Preliminaries

To keep this paper self contained, this section focuses on reviewing two central components: QDMI as the interface proposed for standardization and IQM systems as the hardware platform targeted in our case study.

### A. QDMI as an HPC-Facing Boundary

QDMI [15], [16] is designed to standardize the software-hardware boundary for quantum devices, providing a stable, vendor-agnostic API for backend integration. This device-level abstraction is complementary to middleware solutions, which operate above QDMI to enable resource scheduling, job orchestration, and unified management of quantum and classical resources within HPC environments. By focusing on the device interface, QDMI enables researchers to build portable, extensible solutions for hybrid quantum-classical workflows.

QDMI is written in C, which makes it straightforward to wrap and implement in a large variety of languages (C++, Fortran, Rust, or Python), stable enough for long-lived integration code, and explicit about resource ownership and error handling.

Conceptually, QDMI provides three function groups. *Session* functions create and initialize an authenticated execution context for a selected backend. *Query* functions expose device properties ranging from static architecture data to calibration-sensitive values. *Job* functions manage program submission, job status tracking, cancellation, and result retrieval.

**Example 1.** *Figure 1 demonstrates a typical QDMI interaction pattern involving the aforementioned function groups. Note that, modulo the leading IQM identifier, the exact same pattern applies to any QDMI device regardless of the specific backend details. First, a device is initialized. Next, an authenticated session can be configured and established with the device. This session can then be used to create a job. After configuration, the job can be submitted for execution and its results can be retrieved. Finally, once they are no longer needed, the job as well as the session are explicitly freed and the device is finalized.*

The hourglass view in Figure 2 illustrates the central argument of this paper. The upper layers of the HPCQC software stack, such as frontend adapters, compilers, or ressource managers, can evolve independently of vendor APIs as long as they target QDMI. The lower layers remain free to expose hardware-specific capabilities behind the interface.

It is also important to be explicit about scope. QDMI standardizes the control boundary, not the complete scientific workflow. It does not decide which transpiler (or compiler) to use, which algorithm framework to pick, or how a center schedules mixed classical and quantum resources globally. Those concerns remain in higher layers, but they arguably become easier to build and maintain when the hardware boundary is stable.

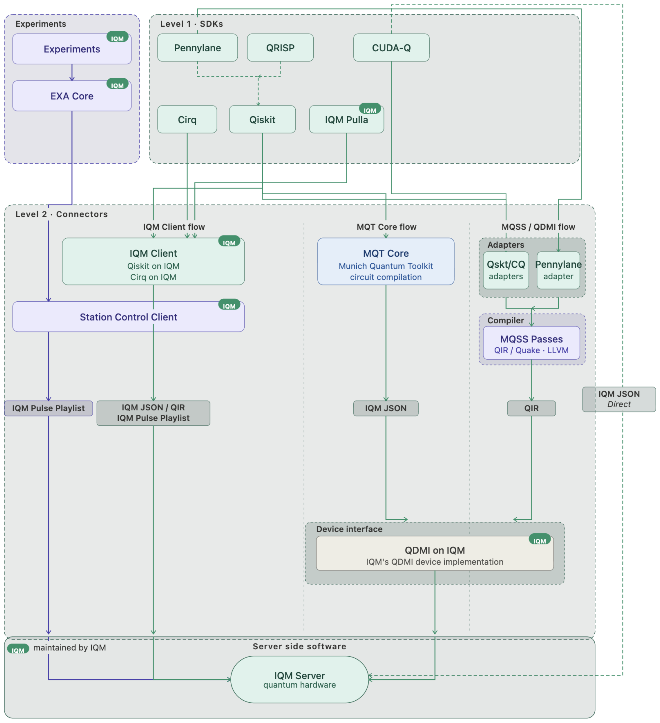


Figure 3. A high level architecture diagram showing three abstraction layers for the IQM software stack. Quantum circuits are submitted from level 1 as Qiskit [20] code to MQT Core [21], which converts circuits to IQM JSON, which is sent to QDMI-on-IQM. This interfaces with IQM Server

## B. IQM Systems and Server API Context

Our case study uses a superconducting quantum computer because they represent a realistic HPC integration target: operational quantum hardware, recurring calibration updates, and both remote and on-premises deployment modes [18], [19]. This lets us evaluate whether QDMI is expressive enough to cover different deployment styles and whether the same software path can survive across them. As an established vendor in the HPCQC landscape, IQM systems come with an existing software stack into which QDMI must be embedded. Figure 3 shows an overview of the corresponding software stack with QDMI placed as a shared interface between middleware components and the backend IQM Server API.

At the lowest level sits the IQM Server API, which exposes the backend primitives needed for the QDMI device implementation. It allows discovering a list of available backends that can be exposed through QDMI. On the query side, it exposes static architecture information (e. g., device topology, site identifiers, and operational availability) and dynamic quality metrics (e. g., qubit coherence times and gate fidelities). On the execution side, it provides job submission, status inspection, artifact access, and, where applicable, cancellation behavior.

In the following section, we will describe how these concepts map to the concepts of QDMI and how they can be successfully abstracted behind this common interface.

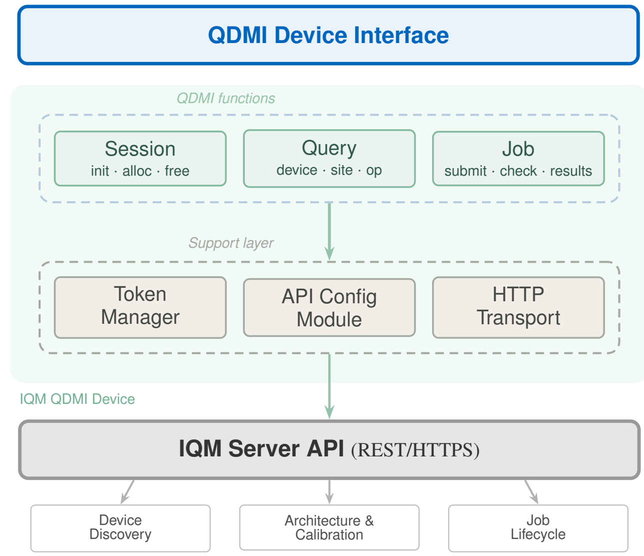


Figure 4. Architecture of the IQM QDMI device implementation.

## III. Implementing the IQM QDMI Device

With the high-level context in place, this section describes the implementation in the IQM-backend QDMI device and explains the rationale for specific engineering choices. The goal is to make the integration path reproducible, not to present a conceptual sketch. The implementation is available as open source at github.com/iqm-finland/QDMI-on-IQM, enabling other centers to inspect and adapt the pattern rather than rebuilding it from zero. Table I summarizes the functional implementation presented in this section.

### A. Implementation Architecture

The IQM QDMI device is built as a shared library that exposes all QDMI functions for session management, property queries, and job handling. In the implementation, most of the device logic is concentrated in a single core implementation file, while authentication, endpoint construction, and HTTP transport are factored into a small support layer. Figure 4 summarizes this structure.

The implementation centers on two internal data structures: the session object and the job object. The session stores connection-related information, including authentication parameters, HTTP client, token manager, and API configuration. It also holds the selected quantum computer identifier, the active calibration set identifier, and metadata cached during session initialization. The job object stores a reference to its session, along with the submitted program information, backend-specific execution options, the current job status, and cached result data. Most of the QDMI calls operate internally on these two objects.

The support layer is deliberately small. A token manager resolves credentials and supplies the bearer token used for all requests to the IQM Server API. The API configuration module maps symbolic backend operations, such as static-architecture queries, dynamic-architecture queries for calibration-sensitive values that may change during runtime, job submission, and

Table I. FUNCTIONAL MAPPING BETWEEN QDMI ENTRY POINTS AND IQM SERVER API.

| QDMI Function(s) | IQM Server API Interaction |
|---|---|
| `QDMI_device_session_init()` | **Discovery and session warm-up.** Performs remote backend discovery, resolves the selected target by ID, alias, or first available backend, materializes static architecture, loads dynamic architecture for the default calibration set, loads calibration metrics, and probes whether calibration jobs are supported. |
| `QDMI_device_session_query_device_property()`, `QDMI_device_session_query_site_property()`, `QDMI_device_session_query_operation_property()` | **Cache-backed metadata access.** These functions return already normalized and cached session state; they do not trigger remote API calls or perform refreshes. |
| `QDMI_device_job_submit()` | **Job submission.** Builds the IQM payload from QDMI job state and submits it through the standard circuit-execution path or, for calibration jobs, through the calibration-specific service path. Calibration submission is only allowed when support was detected during session initialization. |
| `QDMI_device_job_check()`, `QDMI_device_job_wait()`, `QDMI_device_job_cancel()` | **Job lifecycle management.** For submitted jobs, `check()` polls the circuit-job or calibration-job status endpoint, depending on the job type, and maps native IQM states to QDMI job semantics. `wait()` repeatedly invokes `check()` with exponential backoff, while `cancel()` uses the corresponding circuit-cancel or calibration-abort path and updates local job state accordingly. |
| `QDMI_device_job_get_results()` with `QDMI_JOB_RESULT_SHOTS`, `QDMI_JOB_RESULT_HIST_KEYS`, `QDMI_JOB_RESULT_HIST_VALUES`, or `QDMI_JOB_RESULT_CUSTOM1` | **Job-result retrieval.** For completed circuit jobs, the first uncached access fetches measurement artifacts or measurement counts, derives histogram data locally when non-empty shot data is already cached, converts the result into QDMI formats, and caches it for subsequent accesses.<br>For completed calibration jobs with `QDMI_JOB_RESULT_CUSTOM1`, the first uncached access rereads calibration-job status, extracts the new calibration-set identifier, refreshes the session's dynamic architecture and calibration metrics to that calibration set, and retries that refresh once after 120 s if the first attempt fails. |

result retrieval, to concrete IQM Server API routes. Finally, the HTTP transport implements a simple `GET`/`POST` interface on top of `libcurl`, performs the requests, and translates HTTP responses into QDMI status codes.

A key requirement for the entire architecture is that standardization must not come at the prize of performance. In particular, it must not add unnecessary latency compared to directly calling the vendor-specific IQM Server API. As will become clear in the following sections, there is a very large overlap in the capabilities of the QDMI and IQM Server APIs. This allows the QDMI implementation to form a thin wrapper around proprietary calls, without heavy processing in between, and, hence, meet the requirement of negligible overhead.

### B. *Session Bootstrapping and Authentication*

The first cornerstone and entry point to QDMI is the implementation of the QDMI session functions. In this context, a session represents an authenticated connection to the IQM Server plus a resolved target backend. Figure 5 shows a typical session setup workflow, using the configuration parameters listed in Table II. The session configuration accepts a base endpoint, a credential source, and an optional backend selector. Initializing the session then triggers API configuration, HTTP client setup, and instantiation of the token manager.

First, the token manager validates the authentication configuration and supplies valid bearer tokens for all subsequent API calls to the IQM Server. Second, the authenticated session queries the IQM Server for a target backend using an explicit selector (via custom QDMI parameters, as shown in Table II) or a default device when no selector is provided. Third, it retrieves initial architecture and quality metadata and stores a normalized representation in the session state.

Since HPC systems heavily rely on injecting credentials via environment variables, authentication information can either be passed explicitly through QDMI session parameters or through environment variables. As a result, the same code can run unchanged, e. g., in an interactive terminal or as a Slurm batch job [3].

Table II. SELECTED SESSION AND JOB PARAMETERS IN THE IQM QDMI DEVICE IMPLEMENTATION

| QDMI Parameter | Description |
|---|---|
| `BASEURL` | Base URL of the IQM Server. This must be set before `IQM_QDMI_device_session_init`. |
| `TOKEN` | Explicit bearer token. |
| `AUTHFILE` | Path to the IQM tokens file. |
| `CUSTOM1` | Quantum computer ID selector. |
| `CUSTOM2` | Quantum computer alias selector. If neither ID nor alias is set, the first available QC is used. |
| `PROGRAMFORMAT` | Selects the program format. Supported values are `IQMJSON`, `QIRBASESTRING`, and `CALIBRATION` when calibration jobs are available. |
| `PROGRAM` | Program payload. This must be set before `IQM_QDMI_device_job_submit`. |
| `SHOTSNUM` | Number of shots. |
| `CUSTOM1` | Heralding mode. Accepted values are `"none"` and `"zeros"`. |
| `CUSTOM5` | Qubit mapping in the form `logical:physical,logical:physical,...`. Primarily relevant for QIR jobs. |

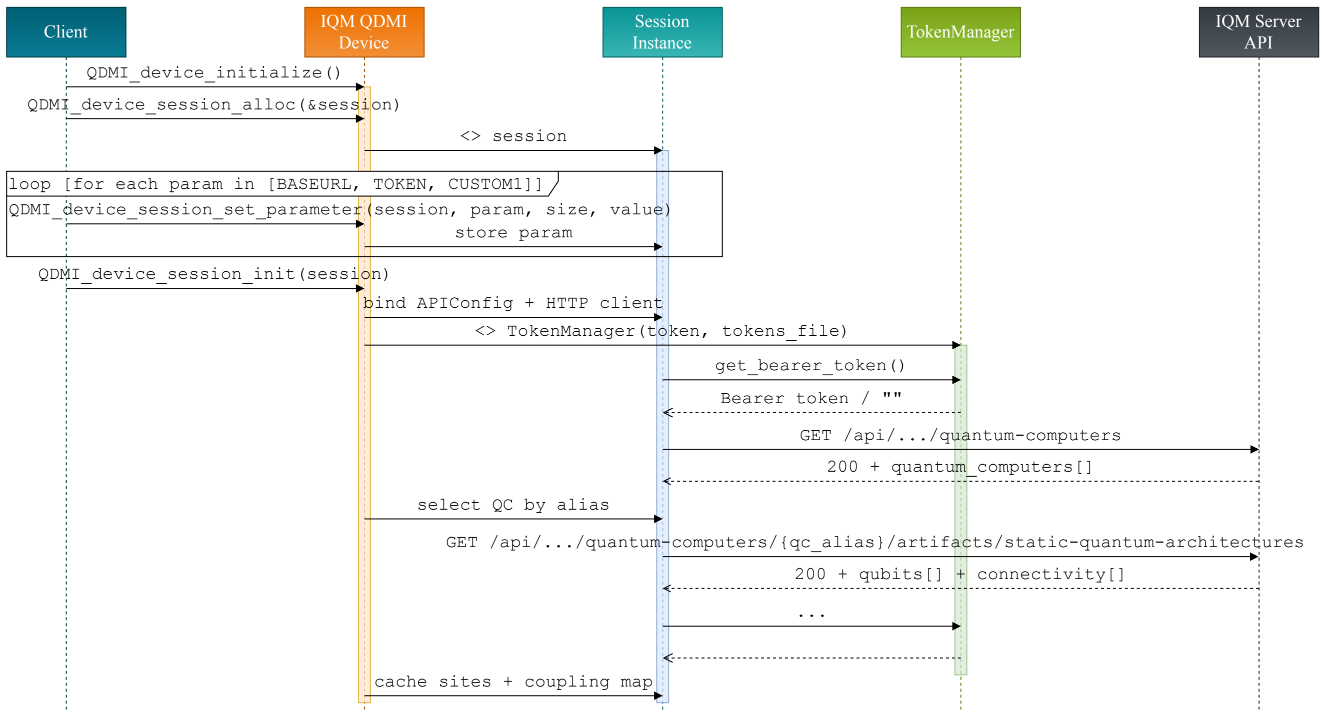


Figure 5. IQM QDMI device session setup sequence and resulting interaction with IQM Server API.

### *C. Capability and Calibration Queries*

The second cornerstone of the implementation, and the primary mechanism through which a caller collects device, site, and operation properties, is the query functions. Queries follow a strict split between mostly static architecture data and dynamic quality data. Static properties include device topology, site identifiers, and operation availability. Dynamic properties include calibration-sensitive metrics such as qubit coherence times and gate fidelity indicators.

```
size_t s_size = 0;
IQM_QDMI_device_session_query_device_property(
    session, QDMI_DEVICE_PROPERTY_SITES,
    0, NULL, &s_size);

vector<IQM_QDMI_Site> sites(s_size / sizeof(IQM_QDMI_Site));
IQM_QDMI_device_session_query_device_property(
    session, QDMI_DEVICE_PROPERTY_SITES,
    sites_size, sites.data(), NULL);

uint64_t t1;
QDMI_device_session_query_site_property(
   session, sites[0], QDMI_SITE_PROPERTY_T1,
   sizeof(uint64_t), &t1, NULL);
```

Figure 6. Property query sequence for IQM QDMI device.

Both classes are normalized into QDMI properties, so upper layers never parse vendor payloads directly. Normalization includes unit and type conversion, as needed, so QDMI callers receive stable and comparable values. This is one of the most important portability wins in practice: compilers, transpilation passes, and scheduler-side checks can share a single query format across backends.

**Example 2.** *The procedure shown in Figure 6 illustrates two query patterns using the same interface function. The first pattern is used for properties whose size is not known in advance: the caller passes a null pointer and a size of zero to obtain the required buffer size. A second call then uses the returned size to allocate a buffer and retrieve the actual data, in this case, a vector of site (that is, qubit) identifiers. The final query demonstrates direct retrieval of a fixed-size property by obtaining the T1 value for a specific site in a single call.*

Data freshness is handled differently for static metadata and for calibration information that can change dynamically during runtime. Static data is loaded once during initialization and only reloaded when the session is reinitialized or switched to a different backend. Dynamic data is also cached during session initialization, but can be refreshed through initiating calibration jobs. This avoids stale data without requiring every query to incur an expensive network round-trip.

The split can be useful in batch-oriented HPC setups, for example, when consecutive jobs are launched through a scheduler. Metadata that is unlikely to change during a run over multiple jobs can be cached once, while values that may drift

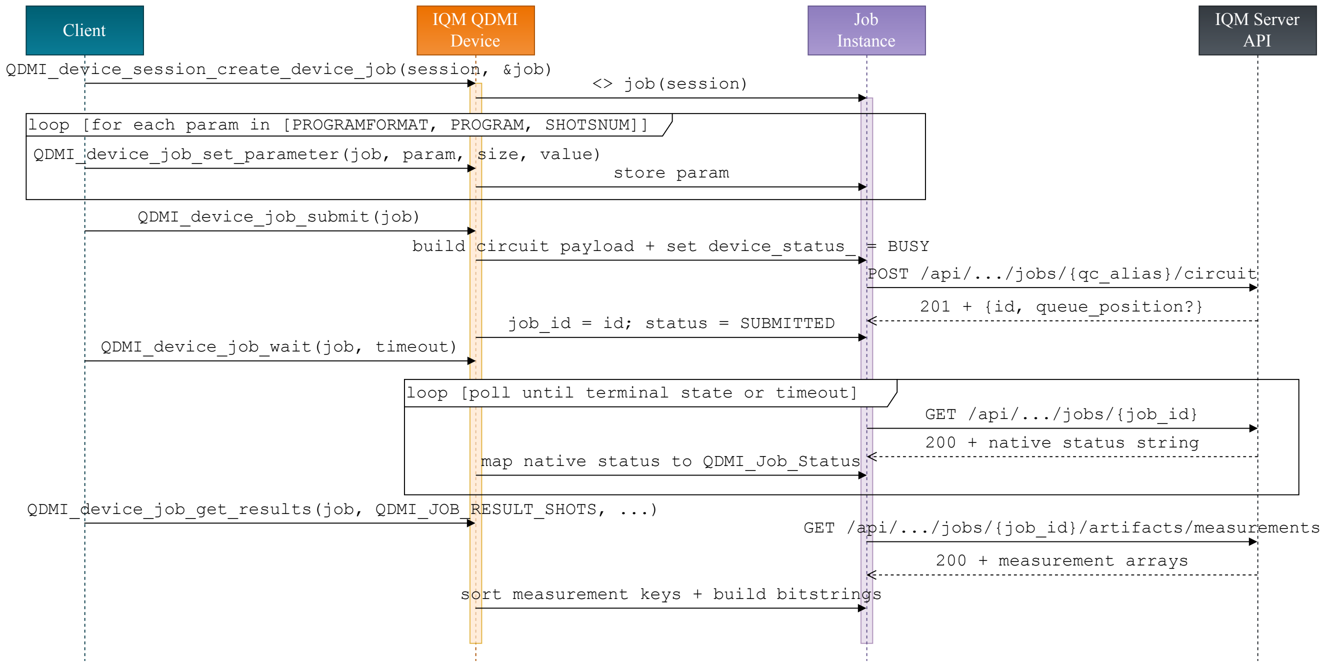


Figure 7. IQM QDMI device job setup sequence and resulting interaction with IQM Server API.

over time can be refreshed after each execution. For example, if updated error rates indicate that the quality of certain qubits has degraded, subsequent jobs may need to be rerouted around these parts of the device, which can in turn increase swap overhead and thus runtime. Dynamic queries thereby make runtime costs more predictable and allow later jobs to react to relevant device updates.

### D. Job Lifecycle, Status Mapping, and Results

Finally, job handling represents the third cornerstone of the implementation. We map proprietary IQM Server endpoints to standardized QDMI job functions. Figure 7 demonstrates a typical job lifecycle comprising a client creating a job handle, specifying program and execution parameters, and requesting job submission via QDMI functions. Internally, this triggers device-status updates and authentication via the token manager (omitted from the figure for simplicity), followed by a submission call to the IQM Server API. Subsequent QDMI calls facilitate progress monitoring and, once a terminal state is reached, result retrieval.

The implementation maps backend-specific status values to QDMI job states. Even though a one-to-one mapping is not always possible, as the IQM Server API has more fine-grained status values than QDMI, a semantically consistent mapping is achievable, as shown in Table III. This includes normal completion as well as cancellation and failure paths.

Program data and execution options are passed through typed QDMI job parameters. When backend-specific options are needed, they are carried through extension fields, as demonstrated in Example 3, rather than leaking proprietary structures into upper layers. This keeps the common path clean while still allowing advanced backend features.

**Example 3.** *The quantum program itself, its format, and the number of shots are passed through the standardized QDMI parameters as shown in Figure 7. Additionally, the QDMI device implementation supports IQM-specific execution options, which can be attached via extension fields. For instance, a client may request heralding mode* `"zeros"` *via QDMI_DEVICE_JOB_PARAMETER_CUSTOM1, or a logical-to-physical qubit mapping such as* `"q0:QB1,q1:QB2"` *via QDMI_DEVICE_JOB_PARAMETER_CUSTOM5. During submission, these values are then translated into IQM Server API fields such as* `heralding_mode`*, and* `qubit_mapping`*.*

Table III. STATUS AND ERROR MAPPING FOR IQM QDMI JOBS.

| QDMI Status | IQM Server API |
|---|---|
| QDMI_JOB_STATUS_SUBMITTED | received |
| QDMI_JOB_STATUS_QUEUED | queued, waiting |
| QDMI_JOB_STATUS_RUNNING | validation_started, validation_ended |
| QDMI_JOB_STATUS_RUNNING | fetch_calibration_started, fetch_calibration_ended |
| QDMI_JOB_STATUS_RUNNING | compilation_started, compilation_ended |
| QDMI_JOB_STATUS_RUNNING | save_sweep_metadata_started, save_sweep_metadata_ended |
| QDMI_JOB_STATUS_RUNNING | pending execution, pending_execution |
| QDMI_JOB_STATUS_RUNNING | execution_started, execution_ended |
| QDMI_JOB_STATUS_RUNNING | post_processing_pending, post_processing_started, post_processing_ended |
| QDMI_JOB_STATUS_RUNNING | running, processing, accepted, pending compilation, compiled |
| QDMI_JOB_STATUS_DONE | ready, completed |
| QDMI_JOB_STATUS_CANCELED | aborted, cancelled |
| QDMI_JOB_STATUS_FAILED | failed |

Furthermore, the implementation supports both blocking and polling-style usage. A blocking call via `QDMI_device_job_wait()` is convenient in simple scripts, where execution should pause until a job has finished. By contrast, polling via `QDMI_device_job_check()` is more useful in orchestration settings, where many tasks may need to be tracked simultaneously. Internally, both operations follow the same status-check path: `wait` repeatedly invokes `check()`, which performs the backend status query and maps native IQM status values to QDMI job states.

Notably, the job functions support both circuit execution jobs and calibration jobs (depending on the specified `QDMI_PROGRAM_FORMAT`), which are mapped to distinct backend endpoints in the background.

Result retrieval supports both aggregated measurement counts and, where available, individual shot data. If shot data has already been fetched for a job, histogram counts are derived locally without issuing an additional backend request. For calibration jobs, the first uncached result access rereads the calibration-job status, extracts the new calibration-set identifier, refreshes the session's dynamic architecture and calibration metrics to that calibration set, or retries that refresh once after 120 s if the first attempt fails.

## IV. HPC Integration with QDMI

With a working device implementation, the question shifts: how do existing HPC and quantum software layers connect to QDMI? As sketched in Figure 2, everything above the QDMI boundary can, in principle, be shared across backends. Everything below remains vendor-specific. This section describes three columns where that reuse is most concrete: language bindings, a Qiskit-facing frontend adapter, and Slurm-based scheduler integration.

### A. Language Interoperability

QDMI is defined as a C interface, which makes it straightforward to call from C and C++ code. For higher-level languages, however, direct C interop is cumbersome. We therefore provide idiomatic C++ and Python bindings that wrap the C entry points, manage object lifetimes, and expose QDMI sessions, queries, and jobs through native language constructs.

The C++ layer maps QDMI handles to RAII-managed objects and translates error codes into exceptions where appropriate. The Python layer builds on the C++ bindings via nanobind.

These bindings are not IQM-specific. Any QDMI device plugin, regardless of vendor, can be loaded and used through the same C++ or Python API. In practice, this means that workflow code written against the Python bindings works even when the underlying device changes from IQM to a different backend.

### B. Frontend Integration: Qiskit over QDMI

The Qiskit adapter builds on the Python bindings and implements Qiskit's `BackendV2` interface on top of QDMI (cf., Figure 8). Concretely, property queries during transpilation target construction, circuit submission, and result retrieval all map to QDMI session and job calls rather than to any vendor-specific client library.

```
class QDMIBackendAdapter(BackendV2):
   def __init__(self, qdmi_device, config):
      self.session = open_qdmi_session(qdmi_device, config)

   def run(self, circuits, shots):
      jobs = [submit_qdmi_job(self.session, c, shots)
              for c in circuits]
      wait_for_jobs(jobs)
      return [convert_from_qdmi(fetch_results(j))
              for j in jobs]
```

Figure 8. Qiskit-facing adapter skeleton over QDMI.

Beyond the backend interface, the adapter also provides `SamplerV2` and `EstimatorV2` implementations of Qiskit's primitive abstractions. Because both primitives delegate to QDMI internally, they work with any QDMI device, not only with IQM hardware. From a user's perspective, Qiskit code requires no modification: circuits are transpiled, executed, and measured through the usual Qiskit workflow. The difference is that the backend can now also be an HPC-accessible quantum computer interfaced through QDMI, not only a cloud endpoint managed by a vendor-specific provider package.

This design consolidates adapter maintenance at the QDMI boundary. Without it, every hardware vendor would need to ship and maintain its own Qiskit provider, and every Qiskit API change would need to be propagated independently across those providers. With a single QDMI-targeting adapter, frontend evolution and backend evolution are decoupled.

### C. Scheduler Integration in Practice

From a user's perspective, moving from interactive QDMI usage to Slurm-dispatched execution requires few changes. The application code is the same; only the launch method differs. Users write a standard `sbatch` script, and quantum calls inside the application go through the same QDMI session and job path as in an interactive shell.

The more interesting design question is on the operator side: how and where are endpoint URLs and credentials injected? We considered two approaches. The first is script-level configuration, where each job script sets the required environment variables explicitly. This works well for exploratory testing and early onboarding. The second is centralized injection through a SPANK plugin that runs inside the Slurm prolog. In this mode, the plugin reads a site-level configuration file, resolves the correct IQM endpoint and token path for the allocated partition, and exports the corresponding environment variables before the user's application starts. Users never touch endpoint URLs or credential paths directly.

The SPANK-based approach has two practical advantages. First, credential rotation and endpoint changes become operator-level configuration updates rather than user-facing changes. Second, the plugin can enforce site policies, e. g. restricting

```
#SBATCH --partition=quantum
#SBATCH --time=00:15:00
#SBATCH --job-name=qsci-demo

export QDMI_ENDPOINT="${QDMI_ENDPOINT:?}"
export QDMI_AUTH_FILE="${QDMI_AUTH_FILE:?}"
export QDMI_BACKEND_ALIAS="aurora-default"

srun python run_qsci.py --shots 10000
```

Figure 9. Illustrative Slurm submission pattern for QDMI-enabled execution.

which partitions may access which backends, or verifying that the token file is valid before the job starts. Both reduce the support burden that comes with manual environment setup across many users. At the same time, it has the downside of relying on SPANK as a plugin system, which might be prohibitive for some HPC centers.

Figure 9 shows a minimal submission script. The user specifies only Slurm resource parameters and the application command; all QDMI-related configuration is injected automatically.

## V. Deployment Scenarios and Tradeoffs

Across the components described in the previous section, user code and adapter logic remain the same regardless of how a center deploys its quantum resources; only endpoint and credential configuration change. This consistency is the direct payoff of standardizing at the QDMI boundary and motivates the deployment styles we evaluate here.

### A. Cloud QPU

The first style is loose coupling: classical computation runs in a standard environment while quantum execution is forwarded to a remote (cloud) backend through QDMI. This is often the fastest way to get started and is useful for early user onboarding. This approach remains valuable for interactive development, allowing end users to craft hardware-specific algorithms, improve compilation and optimization performance of their algorithms, and conduct full pipeline testing prior to production.

Much early work followed such a pattern without unified resource orchestration. Quantum computers were accessed via cloud, and the resulting data was uploaded to a separate, disconnected HPC center [22]. Running iterative loops with this disconnection is difficult, and workflows were typically executed sequentially without feedback from earlier steps. In practice, this means either blocking classical and quantum resources for the entire workflow duration or releasing them for indefinite periods. For a quantum computer, releasing the resource returns the job to the general-purpose queue inside the QPU, increasing wall-clock time.

Using this deployment scenario, illustrated in Figure 10, allows users to retain full internal accountability and traceability over system resources. Furthermore, leveraging existing local

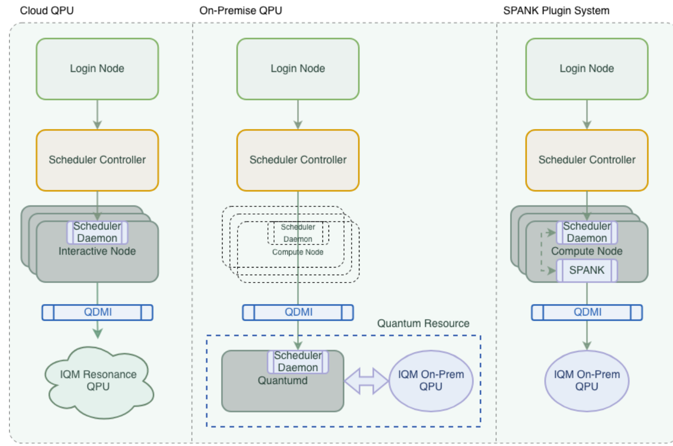


Figure 10. Deployment scenarios enabled by the same QDMI-based integration path.

infrastructure to interface with on-premises or cloud quantum resources is cost-effective, as it avoids extra authorization software layers. Operationally, this strategy ensures that standard cluster tools remain available for troubleshooting, significantly streamlining user support. Establishing a clean QDMI boundary can facilitate the refinement of interconnection interfaces.

### B. On-Premise QPU

The second style is tight coupling with scheduler-managed quantum access in a working-node mode. Users stay within the center workflow, submit quantum jobs through the same scheduling and accounting paths as other workloads, and provide the required backend configuration from their usual HPC job environment. This lets the HPC center co-schedule classical and quantum resources, reducing idle time on scarce QPU hardware. Shirakawa *et al.* [23] demonstrated this style in practice: the QPU samples distributions representing electron orbitals in parallel with classical nodes computing new variational parameters, closing the optimization loop without leaving the scheduler.

This style is operationally heavier, requiring partition configuration, accounting integration, and credential management. However, it aligns best with production policies and enables iterative hybrid workflows that loose coupling cannot support efficiently. At the same time, since the majority of the components required for the system's proper operation are already part of the HPC center, the result is a robust execution platform where a QPU can be connected with minimal interference.

This model fits batch-oriented systems and supports iterative hybrid jobs, but more complex workflows that coordinate multiple HPC and quantum resources will likely require richer orchestration mechanisms.

The same scheduler-managed model is also a natural starting point for future workflows that coordinate multiple QPUs or combine several classical and quantum resources under one orchestration layer, even though such scenarios are beyond the scope of this paper.

### C. SPANK Plugin Integration

The third style extends tight coupling with scheduler-side automation. Here, a SPANK plugin injects configuration and enforces guardrails at job launch time, as described in subsection IV-C. By relying on automation mechanisms already standard in HPC centers, this approach extends established operational practices to quantum workloads rather than introducing a separate control path. This eliminates repetitive user-side setup, gives operators direct control over endpoint selection, credential management, and access policies, and makes it easier to incorporate quantum jobs into existing workflow managers and site orchestration tools.

This scheduler-level automation enables user workflows to scale up while maintaining operator control over guardrails to ensure proper usage of this shared system. Consequently, this capability allows for seamless scaling to a larger number of on-premise quantum computers, supports greater concurrency between classical nodes and scarce quantum resources, and facilitates the implementation of more sophisticated scheduling methods.

## VI. Demonstration: End-to-End QSCI Workflow

One of the most promising near-term workflows that combines quantum and HPC resources is Quantum Selected Configuration Interaction (QSCI) [24], [25]. In the quantum-chemistry setting, QSCI approximates the low-lying spectrum of a many-electron Hamiltonian by using quantum samples to identify a reduced configuration subspace and then diagonalizing the corresponding truncated Hamiltonian classically. The workflow starts with a molecular problem definition, maps the second-quantized Hamiltonian to qubits, prepares a parameterized trial state, samples it on a simulator or QPU, selects the dominant bitstring configurations consistent with the target particle-number sector, and finally solves the reduced eigenproblem on classical resources. The key systems point is that this sequence naturally splits across heterogeneous resources: chemistry preprocessing and orchestration on the login node, quantum execution on the QPU-facing path, and reduced-subspace construction and diagonalization on classical compute nodes.

QSCI is therefore a natural use case to showcase the workflow flexibility enabled by QDMI for two reasons. First, it combines tightly coupled classical and quantum stages rather than submitting a single isolated circuit. In our implementation, the initial state is prepared with a Hartree–Fock reference and a UCCSD ansatz, the variational parameters are optimized with VQE, the optimized state is sampled, and the resulting counts drive a reduced-space diagonalization. This is representative of the orchestration pattern relevant to HPC centers: the quantum step is only one component of a larger workflow whose control logic, data movement, and post-processing remain classical.

Second, the same workflow must be able to target multiple execution environments. During development, users want to validate the quantum path locally against a simulator; during integration, they may offload the same computation to a cloud QPU; and in production, they may direct it to an on-premise QPU endpoint. Independently, the classical post-processing may remain local for small molecules or be dispatched to cluster resources for larger workloads. QDMI makes the application-side code largely independent of this deployment mode. The algorithm code and adapter wiring can, therefore, be reused across local development, scheduled execution, and hardware-backed runs.

```
def run_qsci(atom, basis, offload, simulator):
    problem = PySCFDriver(atom=atom, basis=basis).run()
    ansatz, observable = build_ansatz(problem)

    # VQE optimization: local or Slurm-dispatched
    params = estimate(
            ansatz, observable,
            local=not offload, simulator=simulator)

    # QPU sampling: same toggle
    counts = sample(
            ansatz.assign_parameters(params),
            shots=10000,
            local=not offload, simulator=simulator)

    # Classical post-processing: local or Slurm
    postprocess = (postprocess_slurm if offload
            else postprocess_local)
    return postprocess(atom, basis, counts)
```

Figure 11. Simplified QSCI control flow showing execution-mode toggling. The `offload` and `simulator` flags are the only parameters that differ between local simulation, Slurm-dispatched simulation, local hardware, and Slurm-dispatched hardware execution.

This makes the benefit of our demonstration apparent. We are not looking to demonstrate a benchmark number; rather, we demonstrate a single integration path that allows seamless integration of local execution, Slurm-dispatched execution, and real hardware access. The execution mode is toggled in the application code, while the endpoint and credential contexts are injected at runtime via the backend configuration and authentication environment. In our implementation, this context includes the IQM endpoint, the authentication token or token file, and an optional quantum-computer selector, but the QSCI algorithm itself remains unchanged.

Figure 11 details a corresponding QSCI usage example. The `offload` flag selects between local execution and Slurm-dispatched execution; the `simulator` flag selects between a classical simulator and the real QPU. Both the VQE parameter-estimation step and the sampling step use the same pair of flags, so switching from a local simulation run to a Slurm-dispatched hardware run requires changing two Boolean arguments and nothing else. The algorithm code, the QDMI session path, and the adapter integration path remain identical across all four configurations.

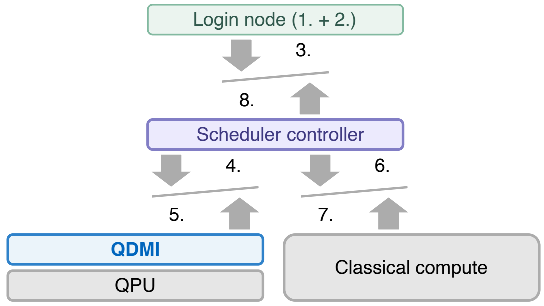


Figure 12. Schematic end-to-end workflow for QSCI execution. Numbers represent the workflow's sequence of operations and are explained in the main text. QDMI facilitates the communication in steps 4 and 5.

Our QSCI workflow is shown in Fig. 12. The numbers in the figure represent steps of the algorithm as follows:

(1) The molecular problem is formulated, typically on the login node. For the QSCI workflow, this means building the problem and deriving the corresponding qubit Hamiltonian.
(2) A parameterized input state is constructed. In our implementation, this uses a Hartree–Fock initial state and a UCCSD ansatz, followed by a VQE optimization loop to obtain circuit parameters.
(3) If offloading is enabled, the ansatz and operator are serialized on shared storage and submitted through Slurm to the quantum partition; otherwise, the same logic executes locally in process.
(4) On the quantum path, the Qiskit-facing adapter invokes the QDMI-backed IQM device, which submits the circuit to either a simulator or the target QPU depending on the runtime context.
(5) The optimized circuit is sampled, and the resulting bitstring counts are returned through the same adapter and scheduler path.
(6) The sampled configurations define the reduced QSCI basis. Classical post-processing constructs the truncated Hamiltonian in that basis and diagonalizes it either locally or through Slurm-dispatched classical execution.
(7) The approximate eigenvalue(s) and eigenvector(s) are returned to the workflow controller.
(8) The application returns the QSCI result to the user while preserving the same execution contract across all deployment modes.

In our setup, classical preparation runs in Python on the login node. Quantum execution requests go through the Qiskit-facing adapter, into QDMI bindings, through the IQM QDMI device, and finally to the IQM backend. The returned results follow the same path back to the application for optimization and post-processing. The scientific claim of this section is therefore modest but important for HPC practice: not that this example sets a chemistry benchmark, but that one execution contract spans local development, scheduler-mediated execution, and real hardware access without rewriting the application-level workflow.

## VII. Conclusion

This paper examined a practical HPCQC integration path built around a standardized device-management boundary. Using IQM systems as a real-hardware case study, we implemented an IQM-backed QDMI device layer and connected it to Slurm execution and Qiskit-facing frontend workflows. The implementation is publicly available at github.com/iqm-finland/QDMI-on-IQM.

The central result is straightforward. When the device-management boundary is standardized, software above that boundary can be reused across deployment settings. In our implementation, this includes language bindings, the Qiskit-facing adapter, the Slurm integration pattern, and the associated deployment paths.

The end-to-end QSCI study provides operational evidence for this point. The same application-side path was used for local simulation, Slurm-dispatched simulation, local hardware access, and Slurm-dispatched hardware access; only execution mode and backend configuration changed. The contribution is therefore not a chemistry performance result, but an integration result: one interface boundary can support multiple execution contexts without rewriting the workflow.

This does not remove all HPCQC integration work. Backend-specific payloads, calibration behavior, and operational constraints remain. Our result is narrower and more practical: these differences can be contained within the device-management boundary rather than propagating through user code, frontend tooling, and scheduler integration.

For HPC centers, this yields deployment flexibility rather than a single prescribed model: cloud access for early exploration, scheduler-managed on-premise access in working-node mode, and SPANK-automated access when tighter operator control is required. The application-side software path stays the same across these options.

Overall, the case study indicates that device-management standardization is already feasible on production hardware and useful in day-to-day integration work. It offers centers, vendors, and software maintainers a common integration point without forcing one deployment style. Future work can build on this boundary to study broader scheduling policies and multi-resource orchestration.

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