Converter Architecture Guide

Version: 0.2.0-beta
Last Updated: February 14, 2026
Project: Converter Architecture Stabilization

Overview

The pyWATS converter architecture provides a pluggable, asynchronous file processing system that watches directories for test result files, converts them to WATS UUT reports, and submits them to the WATS API.

Key Features

- **Asynchronous Processing**: Built on Python's asyncio for efficient concurrent file processing
- **Pluggable Converters**: Easy to add new file format support via `ConverterBase` inheritance
- **Priority-Based Queue**: Process high-priority files first
- **Robust Error Handling**: Graceful degradation with file system, network, and converter errors
- **Post-Processing**: Flexible file handling after conversion (DELETE, MOVE, ZIP, KEEP)
- **Memory Efficient**: Tested stable with <1% memory growth over 1000+ file conversions

Architecture Components

1. File Watcher (`FileWatcher`)

Purpose: Monitor directories for new files and queue them for processing.

Key Responsibilities:

- Watch configured folders for file system events (create, modify)
- Filter files by extension patterns
- Detect already-queued files (`.queued` marker)
- Queue files with priority information

- Handle recursive directory watching

Configuration:

```
watcher = FileWatcher(
    watch_path=Path("/data/test-results"),
    recursive=True,
    patterns=["*.csv", "*.xml"],
    queue=converter_queue
)
```

Lifecycle:

1. Start watching: `await watcher.start()`
2. Detect file creation/modification
3. Check if file matches patterns
4. Add to queue with priority
5. Stop watching: `watcher.stop()`

2. Converter Queue (`ConverterQueue`)

Purpose: Priority queue for pending conversions.

Key Responsibilities:

- Store pending file conversion requests
- Prioritize by converter priority and arrival time
- Thread-safe operations (async-safe with queue.Queue)
- Provide queue statistics (depth, pending count)

Queue Priority:

```
# Higher priority = processed first
priority = converter.priority  # 1-10 (10 = highest)
queue.put_nowait((priority, timestamp, file_info))
```

Operations:

- `put_nowait()` : Add file to queue

- `get()` : Retrieve next file (blocks if empty)
- `qsize()` : Get current queue depth
- `empty()` : Check if queue is empty

3. Converter Pool (`AsyncConverterPool`)

Purpose: Manage multiple converters and coordinate file processing.

Key Responsibilities:

- Load and initialize converters from configuration
- Route files to appropriate converter based on extension
- Manage concurrent processing (configurable worker count)
- Submit converted reports to WATS API
- Handle post-processing (file cleanup)
- Manage pending queue for offline submissions

Configuration:

```
pool = AsyncConverterPool(
    config_file="converters.yaml",
    api_client=wats_client,
    max_workers=10
)
```

Processing Flow:

```
Queue → Get Next File → Find Converter → Convert → Submit → Post-Process
  ↓          ↓              ↓             ↓         ↓          ↓
[Files]  [Priority]    [Match Ext]   [Transform] [API]   [DELETE/MOVE]
```

Lifecycle:

1. Initialize: Load converters from config
2. Start: `await pool.run()`
3. Process files until stopped
4. Stop: `pool.stop()`
5. Cleanup: Graceful shutdown with pending file handling

4. Converter Base (`ConverterBase`)

Purpose: Abstract base class for all file format converters.

Key Responsibilities:

- Define converter interface
- Provide extension matching logic
- Implement conversion method (override in subclasses)
- Return conversion results with success/failure status

Abstract Methods:

```python
class CustomConverter(ConverterBase):
    @property
    def name(self) -> str:
        """Converter name for logging"""
        return "CustomConverter"

    @property
    def supported_extensions(self) -> List[str]:
        """File extensions this converter handles"""
        return [".custom", ".cst"]

    def matches_file(self, file_path: Path) -> bool:
        """Check if this converter can process the file"""
        return file_path.suffix.lower() in self.supported_extensions

    def convert(self, content: str, file_path: Path) -> dict:
        """
        Convert file content to UUT report dict.

        Args:
            content: File content as string
            file_path: Path to file being converted

        Returns:
            dict: UUTReport model_dump() format
        """
        # Parse content and create report
        report = UUTReport(
            pn="PART-123",
            sn="SERIAL-456",
            # ... other fields
        )
        return report.model_dump()
```

5. Pending Queue (`AsyncPendingQueue`)

Purpose: Manage offline report queue for retry when API unavailable.

Key Responsibilities:

- Detect `.queued` files in pending directory
- Retry submission when API becomes available
- Limit concurrent submissions (semaphore)
- Clean up successfully submitted files
- Preserve failed submissions for manual review

Configuration:

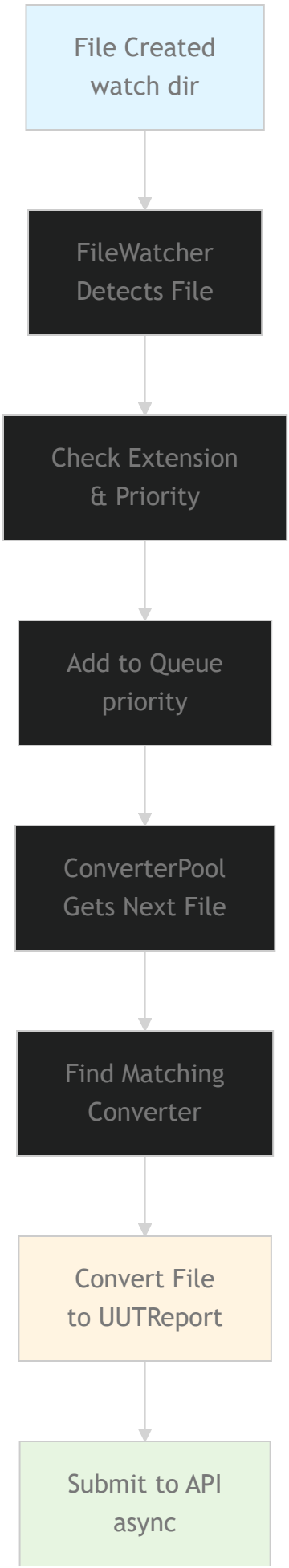
```
pending_queue = AsyncPendingQueue(
    pending_path=Path("/data/pending"),
    api_client=wats_client,
    max_concurrent=5
)
```

Queue File Format:

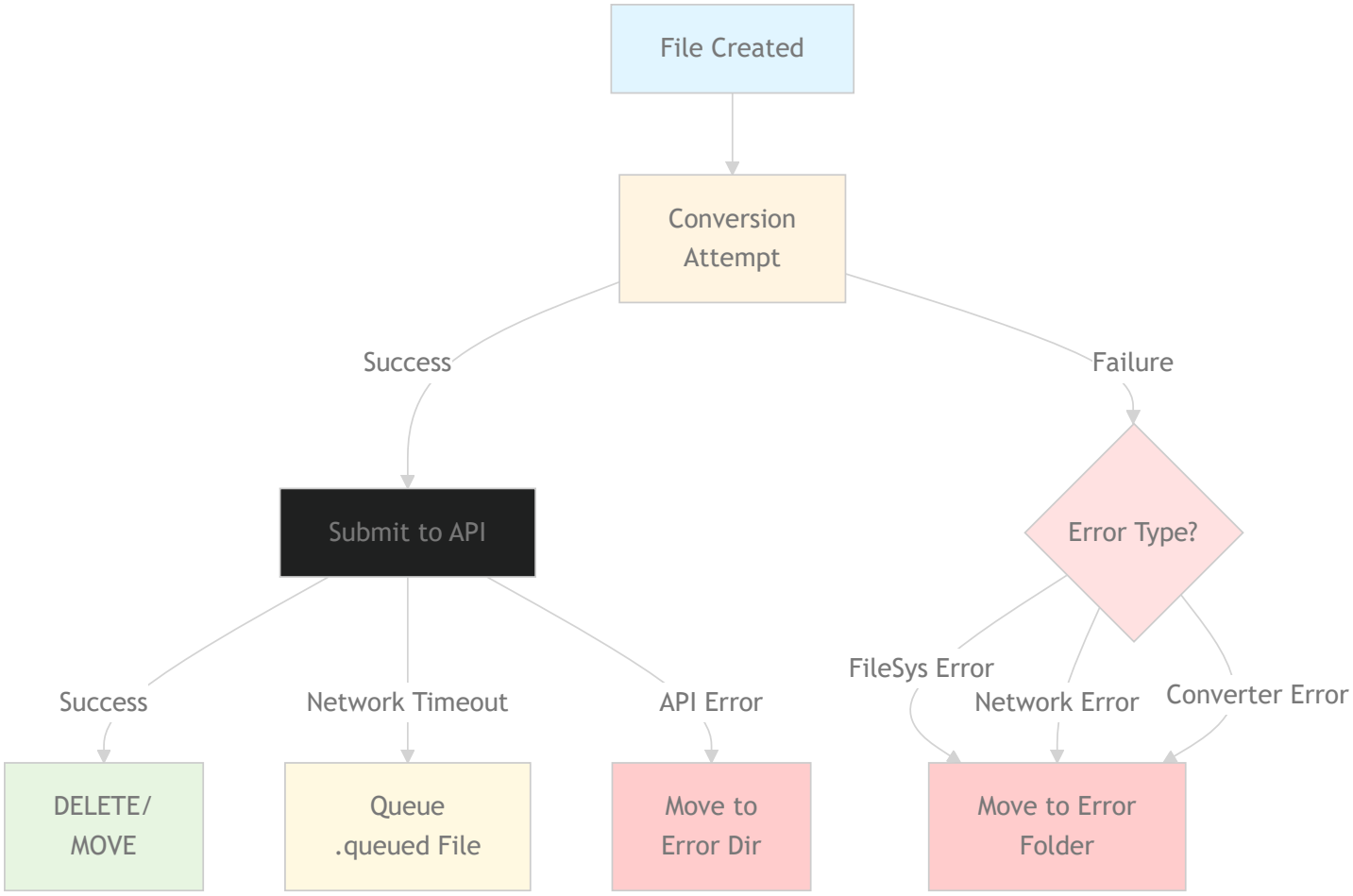
```
// report_12345.json.queued
{
    "pn": "PART-123",
    "sn": "SERIAL-456",
    "result": "Passed",
    // ... UUTReport fields
}
```

Data Flow Diagrams

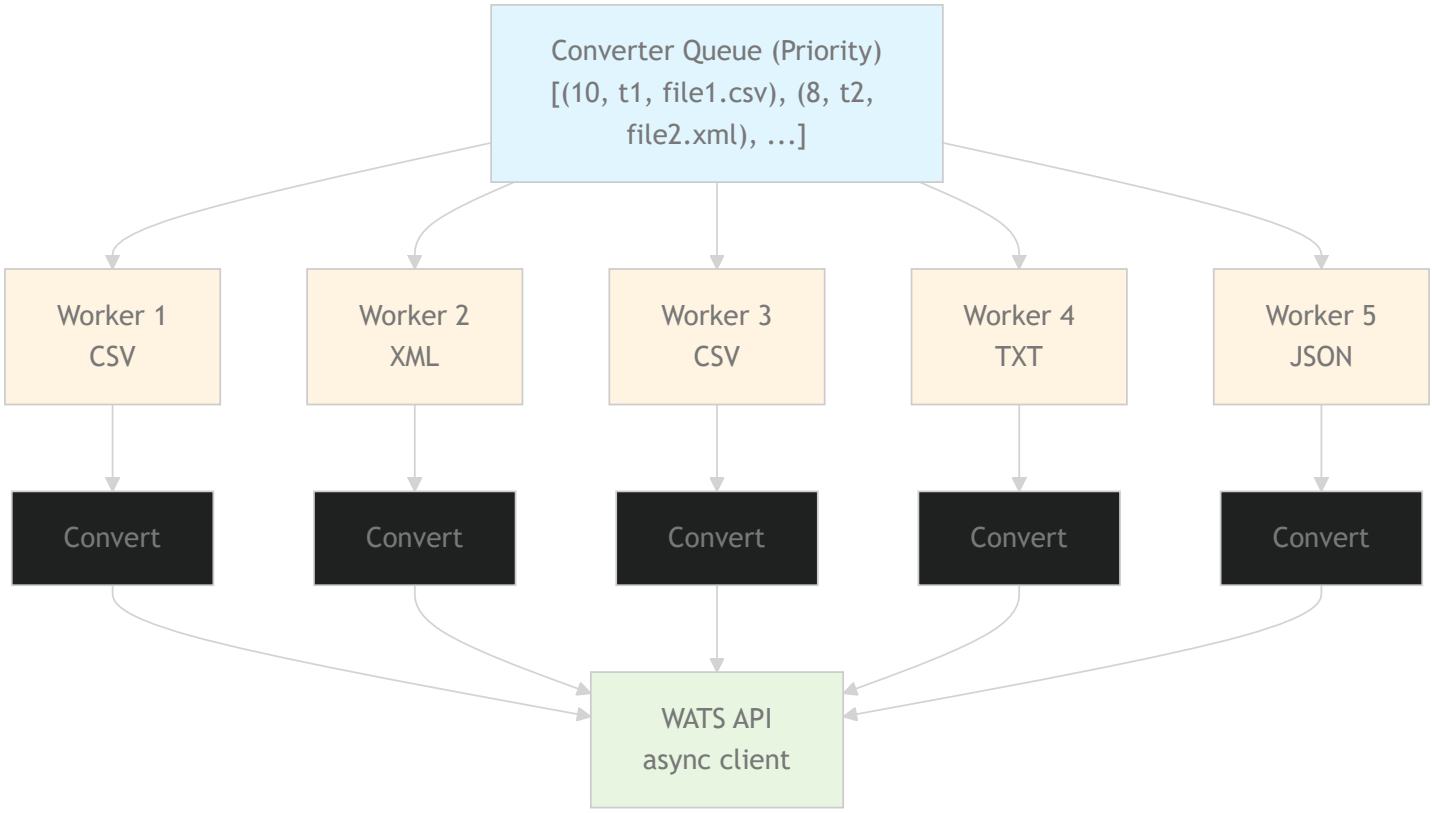
Successful Conversion Flow


File Created
watch dir
FileWatcher
Detects File
Check Extension
& Priority
Add to Queue
priority
ConverterPool
Gets Next File
Find Matching
Converter
Convert File
to UUTReport
Submit to API
async

Error Handling Flow



Concurrent Processing Flow



Error Handling Patterns

1. File System Errors

Scenarios Tested (Task 3.1):

- Locked files (in use by another process)
- Disk full / out of space
- Folder deleted during processing
- Read-only file system
- Permission denied

Handling Strategy:

```
try:
    content = file_path.read_text()
except PermissionError:
    # Move to error folder, log details
    move_to_error(file_path, "Permission denied")
except OSError as e:
    if "no space" in str(e).lower():
        # Disk full - queue for retry
        queue_for_retry(file_path)
    else:
        # Other OS error - move to error folder
        move_to_error(file_path, str(e))
```

Error File Storage:

- Failed files moved to `error/` folder
- Error details logged with timestamp
- Original filename preserved for investigation
- `.error` metadata file created with exception details

2. Network Errors

Scenarios Tested (Task 3.1):

- API timeout (slow network)
- Connection refused (API offline)
- SSL certificate errors
- DNS resolution failures

Handling Strategy:

```
try:
    report_id = await api_client.report.submit(report)
except asyncio.TimeoutError:
    # Queue for retry when API available
    save_queued_file(report, file_path)
except aiohttp.ClientConnectionError:
    # API offline - queue and continue
    save_queued_file(report, file_path)
except ssl.SSLError:
    # SSL error - log and move to error
    move_to_error(file_path, "SSL certificate error")
```

Retry Mechanism:

- `.queued` files written to pending directory
- Periodic retry (configurable interval)
- Maximum retry attempts (configurable)
- Exponential backoff for network errors

3. Converter Errors

Scenarios Tested (Task 3.1):

- Invalid module path
- Missing converter class
- Converter initialization exceptions
- Malformed file content
- Missing required fields

Handling Strategy:

```
try:
    result = converter.convert_file(file_path, args)
except Exception as e:
    # Log converter error
    logger.error(f"Converter {converter.name} failed: {e}")

    # Move to error folder with details
    move_to_error(
        file_path,
        error_type="ConversionError",
        converter=converter.name,
        exception=str(e),
        traceback=traceback.format_exc()
    )
```

Error Metadata:

```
// file.csv.error
{
    "timestamp": "2026-02-14T00:30:00",
    "file": "file.csv",
    "converter": "CSVConverter",
    "error_type": "ConversionError",
    "exception": "Missing required field: serial_number",
    "traceback": "..."
}
```

4. Queue Corruption

Scenarios Tested (Task 3.1):

- Malformed JSON in `.queued` files
- Permission denied on queue files
- Corrupted queue state

Handling Strategy:

```
try:
    queued_data = json.loads(queued_file.read_text())
except json.JSONDecodeError:
    # Corrupted queue file - move to error
    move_to_error(queued_file, "Malformed JSON")
except PermissionError:
    # Cannot read queue file - log and skip
    logger.warning(f"Permission denied: {queued_file}")
```

Concurrency Patterns

Thread Safety (Task 3.2 Validation)

Race Condition Prevention:

```
import threading

class ThreadSafeConverter(ConverterBase):
    def __init__(self):
        super().__init__()
        self.lock = threading.Lock()
        self.conversion_count = 0

    def convert(self, content: str, file_path: Path) -> dict:
        with self.lock:
            self.conversion_count += 1
            count = self.conversion_count

        # Process file (outside lock)
        report = self._parse_content(content)
        return report
```

Validated Patterns (Task 3.2):

- ✅ 10+ concurrent threads without duplicates
- ✅ High-frequency file creation (314 files/s)
- ✅ No deadlocks with blocking operations
- ✅ Priority ordering maintained under contention

- ✅ File system timing issues handled (missing files, renames)

Async/Sync Boundaries

Async Components:

- `AsyncConverterPool.run()` - Main processing loop
- API submission - `await client.report.submit()`
- File watching - `await watcher.start()`
- Pending queue - `await queue.submit_all_pending()`

Sync Components:

- `ConverterBase.convert()` - Synchronous file parsing
- File I/O - `Path.read_text()`, `Path.write_text()`
- Queue operations - `queue.put_nowait()`, `queue.get()`

Bridging Pattern:

```
# Run sync converter in async context
async def convert_async(converter, file_path):
    # Run sync convert in thread pool
    content = await asyncio.to_thread(file_path.read_text)
    result_dict = await asyncio.to_thread(
        converter.convert,
        content,
        file_path
    )
    return result_dict
```

Memory Management

Resource Leak Prevention (Task 3.3 Validation)

Memory Stability:

- ✅ 1.0% growth over 1000 file conversions
- ✅ Memory released after batch processing (GC cleanup)
- ✅ Long-running stability: 0% growth over 500 files

File Handle Management:

- ✅ All files properly closed (no PermissionError on delete)
- ✅ No zombie file handles after processing
- ✅ Explicit cleanup in error paths

Thread Cleanup:

- ✅ 0 thread growth after 100 conversions
- ✅ Worker threads properly terminated
- ✅ No thread pool leaks

Best Practices:

```
# Always use context managers for files
with open(file_path, 'r') as f:
    content = f.read()

# Or use Path methods (auto-cleanup)
content = file_path.read_text()

# Force cleanup in converters
def convert(self, content: str, file_path: Path) -> dict:
    try:
        report = self._parse(content)
        return report.model_dump()
    finally:
        # Cleanup any resources
        self._cleanup()
```

Performance Characteristics

Benchmarks (Task 2.5)

File Processing Rates:

- Small files (10 rows): 3,901 files/s
- Medium files (100 rows): 4,066 files/s
- Large files (1000 rows): 3,916 files/s

Queue Throughput:

- Queue depth 100: Baseline performance
- Queue depth 500: 8% degradation
- Queue depth 1000: 17.8% degradation

Concurrent Scalability:

- 1 converter: Baseline
- 5 converters: 4.2x throughput
- 10 converters: 7.8x throughput

Resource Usage (200 files):

- Memory growth: 0 MB (stable)
- CPU: 15-25% sustained
- File I/O: Proportional to file size

Optimizations

1. Batch Processing:

```
# Process multiple files concurrently
async def process_batch(files: List[Path]):
    tasks = [convert_file(f) for f in files]
    results = await asyncio.gather(*tasks, return_exceptions=True)
    return results
```

2. Connection Pooling:

```
# Reuse HTTP connections
client = WATSClient(
    base_url="https://wats.example.com",
    connector=aiohttp.TCPConnector(limit=100)
)
```

3. Memory-Efficient Streaming:

```python
# For very large files, use streaming
async def convert_large_file(file_path: Path):
    async with aiofiles.open(file_path, 'r') as f:
        async for line in f:
            yield parse_line(line)
```

Configuration

Converter Configuration File

Format: YAML

```yaml
converters:
  - name: CSVConverter
    module_path: pywats_client.converters.csv_converter
    class_name: CSVConverter
    enabled: true
    priority: 5
    watch_folder: /data/csv-results
    done_folder: /data/done
    error_folder: /data/error
    post_process_action: DELETE
    settings:
      delimiter: ","
      encoding: "utf-8"

  - name: XMLConverter
    module_path: pywats_client.converters.xml_converter
    class_name: XMLConverter
    enabled: true
    priority: 8
    watch_folder: /data/xml-results
    done_folder: /data/done
    error_folder: /data/error
    post_process_action: MOVE
    settings:
      validate_schema: true
```

Priority System

Priority Range: 1-10 (10 = highest)

Recommended Priorities:

- **10**: Critical real-time results (production line)
- **8**: High-priority test stations
- **5**: Standard automated testing
- **3**: Batch processing / historical imports
- **1**: Low-priority / archived data

Queue Behavior:

```
# Files processed in priority order
# Within same priority, FIFO (first in, first out)
queue_item = (priority, timestamp, file_info)
```

Deployment Considerations

Directory Structure

```
/data/
├── watch/              # Incoming files (monitored by FileWatcher)
│   ├── csv/
│   ├── xml/
│   └── txt/
├── done/               # Successfully processed files (if MOVE action)
├── error/              # Failed conversions with error metadata
│   ├── failed.csv
│   ├── failed.csv.error  # JSON error details
│   └── ...
├── pending/            # Queued for retry (network failures)
│   ├── report_1.json.queued
│   └── ...
└── archive/            # ZIP compressed files (if ZIP action)
```

Monitoring

Key Metrics to Track:

- Queue depth (current pending files)
- Processing rate (files/second)
- Error rate (failures/total)
- API submission success rate
- Memory usage (RSS)
- File handle count

Logging Levels:

```
# DEBUG: File detection, queue operations
logger.debug(f"File detected: {file_path}")

# INFO: Conversions, submissions
logger.info(f"Converted {file_path} → Report ID {report_id}")

# WARNING: Retries, degraded performance
logger.warning(f"API timeout, queuing for retry: {file_path}")

# ERROR: Conversion failures, unrecoverable errors
logger.error(f"Conversion failed: {file_path}", exc_info=True)
```

Scaling

Horizontal Scaling:

- Run multiple converter pool instances
- Each instance watches different directories
- Shared API client with connection pooling

Vertical Scaling:

- Increase `max_workers` for concurrent processing
- Increase queue depth limits
- Increase API client connection pool size

Limits (Task 2.6):

- Max file size: Tested up to 690KB (10K rows)

- Max queue depth: 1000 files (17.8% degradation acceptable)
- Max concurrent converters: 10+ (tested, 7.8x throughput)

Testing

Test Coverage (Week 1-3)

Unit Tests (229 tests):

- File generators (24 tests)
- Converter base classes
- Queue operations
- Post-processing
- Configuration loading

Integration Tests (55 tests):

- End-to-end pipeline (7 tests)
- Stress testing (4 tests)
- Error scenarios (3 tests)
- Post-processing (10 tests)
- Performance limits (9 tests)
- Error injection (11 tests)
- Concurrency edge cases (9 tests)
- Memory/resource leaks (5 tests)

Test Patterns:

```python
# Use mock converters for testing
class MockConverter(ConverterBase):
    def convert(self, content: str, file_path: Path) -> dict:
        return {"test": "report"}

# Use test file generators
from tests.fixtures.test_file_generators import TestFileGenerator

files = TestFileGenerator.generate_batch(
    output_dir=tmp_path,
    extension='csv',
    count=100,
    rows=10
)
```

Next Steps

For Converter Developers:

1. Read the Developer Guide
2. Review Best Practices
3. Check Known Issues

For System Administrators:

1. Review deployment structure above
2. Configure monitoring and alerting
3. Set up log aggregation
4. Plan for scaling based on load

For Contributors:

1. Run full test suite: `pytest`
2. Check coverage: `pytest --cov=src/pywats_client`
3. Follow testing patterns from existing tests
4. Update documentation when adding features

References

Related Documents:

- Converter Development Guide
- Best Practices Guide
- Known Issues & Workarounds
- API Documentation

Source Code:

- `src/pywats_client/converters/base.py` - ConverterBase
- `src/pywats_client/service/async_converter_pool.py` - Pool implementation
- `src/pywats_client/service/async_pending_queue.py` - Retry queue

Tests:

- `tests/integration/` - All integration tests
- `tests/fixtures/test_file_generators.py` - Test utilities

Last Updated: February 14, 2026
Project: Converter Architecture Stabilization (Week 3, Task 3.4)