



Exception-based Maintenance for Natural Gas Measurement Stations

2026 CEESI Gas Ultrasonic Meter User's Conference

Outline/Agenda

- Introduction
- Definitions
- Drivers
- Readiness - Technical Capabilities/Resources that apply
- Regulatory/Contractual Acceptability
- The Roadmap
- Urgency/Timing
- Conclusions



Introduction

Introduction

- C-SMART Analytics started in 2011 to provide cost effective remote measurement station audit services
- Evolution of the Virtual Check Meter™
 - ▶ Worked out solutions for **data collection and aggregation**
 - ▶ Developed structure for **secure data bases**
 - ▶ Provided **graphical data views** for manual analysis tools
 - ▶ Developed **data filtering for condition context**
 - ▶ Developed **digital twins** for **automated real time analysis** and comparison to calibration data
 - ▶ Added **automated error quantification**
 - ▶ Introduced simplified **dashboard UI**
 - ▶ Introduced **automated reporting structure**
 - ▶ Introduced **UI for customer Event tracking and management**
- Assets – an automated Measurement Health Management System and **a wealth of historical information** (>5,000 meter-years), proven machinery and processes



Important Definitions

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- **Condition –Based Maintenance (CBM)** is a maintenance strategy where equipment is monitored and serviced **only when its actual condition shows signs of deterioration**, rather than on a fixed schedule. In simple terms: **you maintain assets when data says they need it**, not just because time has passed.

When is condition-based maintenance used?



When the asset has a condition that can be monitored and measured.



When the asset is critical to production or the success of the business.



When changes in the asset's condition can be observed in time to address failure.



When you can capture, analyze, and make decisions based on performance data.

Important Definitions

- **Predictive Maintenance(PdM)** – predicts future failures and estimates remaining useful life (RUL) so maintenance can be planned optimally



CBM Compared to PdM

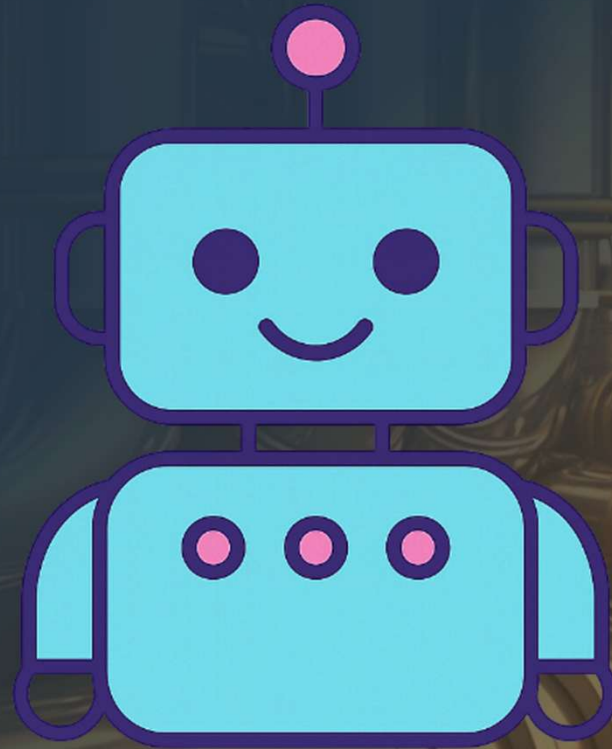
Aspect	Condition-based Maintenance	Predictive Maintenance
Focus	Current Condition	Future Failure
Questions Answered	“Is something wrong now?”	“When will it fail?”
Decision Method	Thresholds and alarms, possibly models	Models and Predictions
Data Usage	Mostly Real Time	Historical + Real Time
Analytics Level	Low to moderate	Moderate to advanced
Planning Horizon	Short/Immediate	Medium to long-term
Implementation Difficulty	Easier	More Complex

Important Definitions

- PdM builds on CBM:
 - ▶ CBM provides the condition data – Hourly/Daily in this case
 - ▶ PdM analyzes patterns over time
 - ▶ CBM alarms handle urgent issues
 - ▶ PdM optimizes long-term scheduling
- Normally, users would start with CBM and evolve into predictive maintenance as data maturity increases,
- ***but if you can tap into a wealth of historical information.....***

Important Definitions

- **Bots, or Agents** - a software application designed to execute repetitive tasks automatically without human intervention, following predefined instructions or algorithms . Bots can operate across websites, apps, and networks, performing actions such as loading pages, clicking links, submitting forms, or interacting with users, often much faster and more efficiently than a human could. They are widely used to automate processes, gather data, or provide services.



What is a Measurement Asset Health Management System?

■ Measurement Asset Health Management (MAHM)

A system or people, procedures, and practices that validate standard volume measurement and produces maintenance actions to correct any emergent issues on measurement assets.

- Think **API MPMS** or **ISO 10012**, which provides requirements and guidance to ensure that:
 - ▶ Measurements are **reliable and accurate**
 - ▶ Measuring equipment is **properly controlled and calibrated**
 - ▶ Measurement processes are **fit for purpose**
 - ▶ Decisions based on measurements are **valid and traceable**

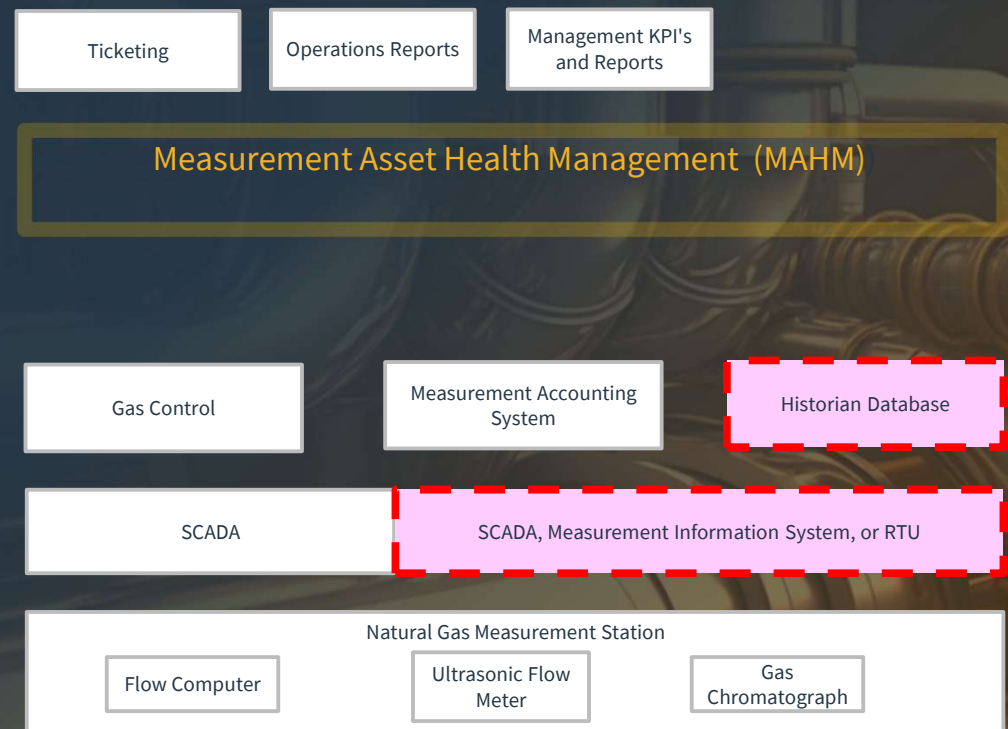


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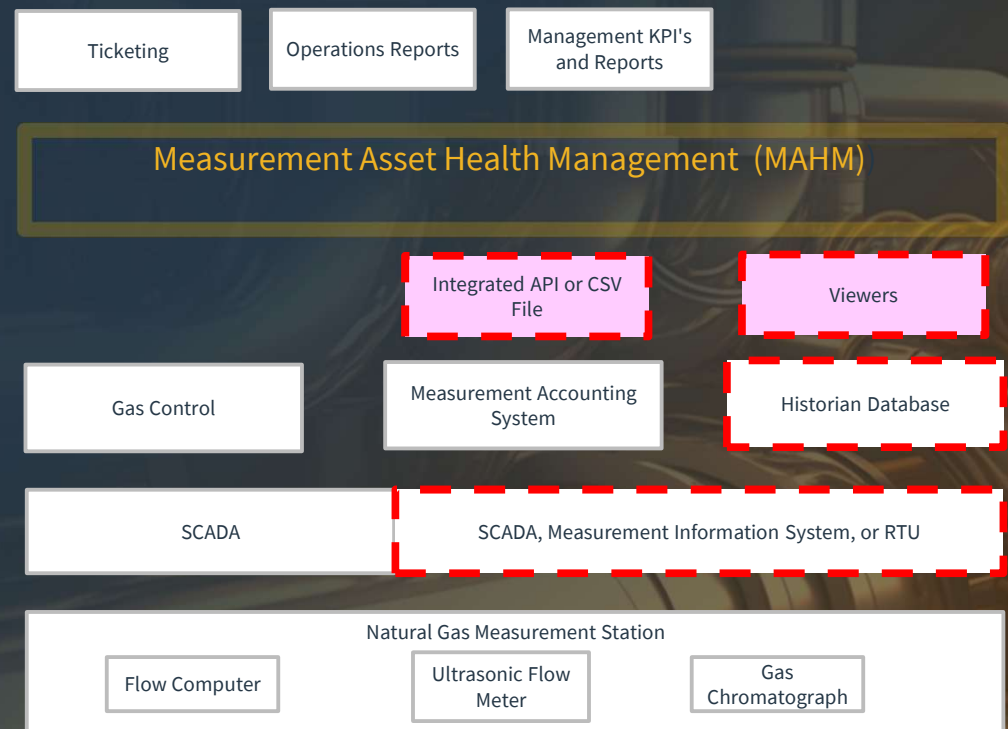


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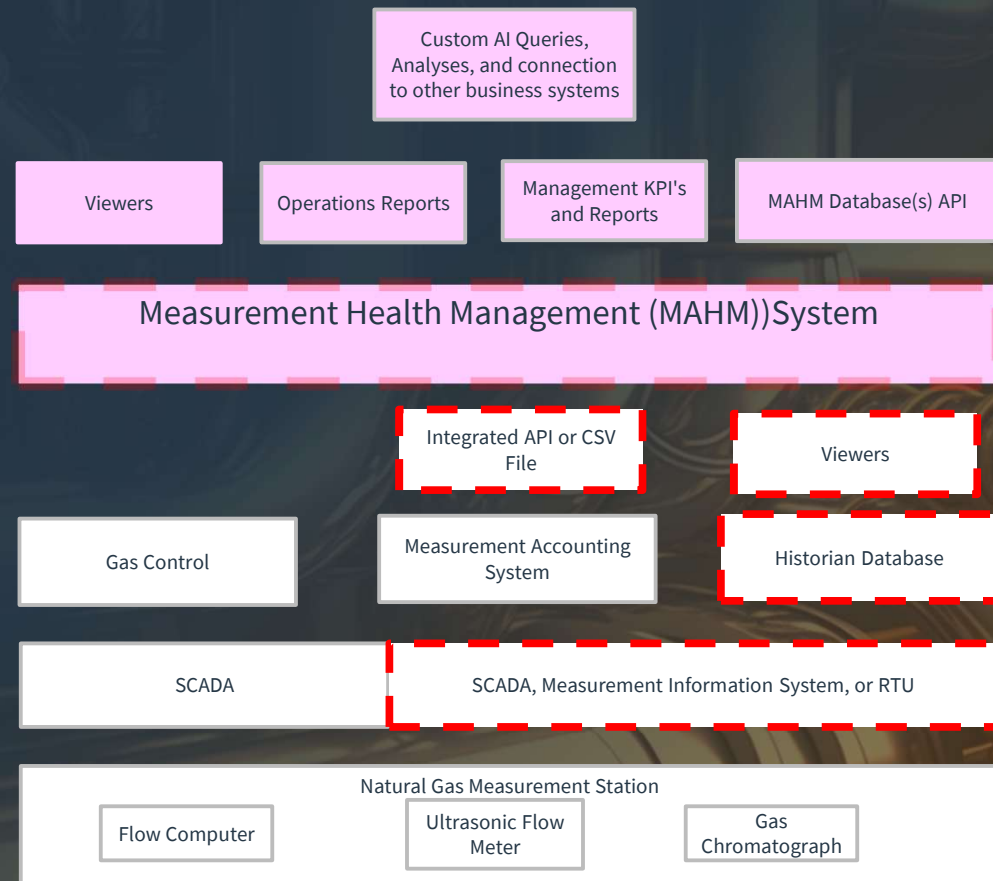


Important Definitions

■ Measurement Asset Health Management (MAHM) System

An *automated agent* that validates standard volume measurement and produces maintenance actions using data integrity, historical context, and holistic diagnostics—*enabling* condition-based and predictive maintenance of measurement assets.

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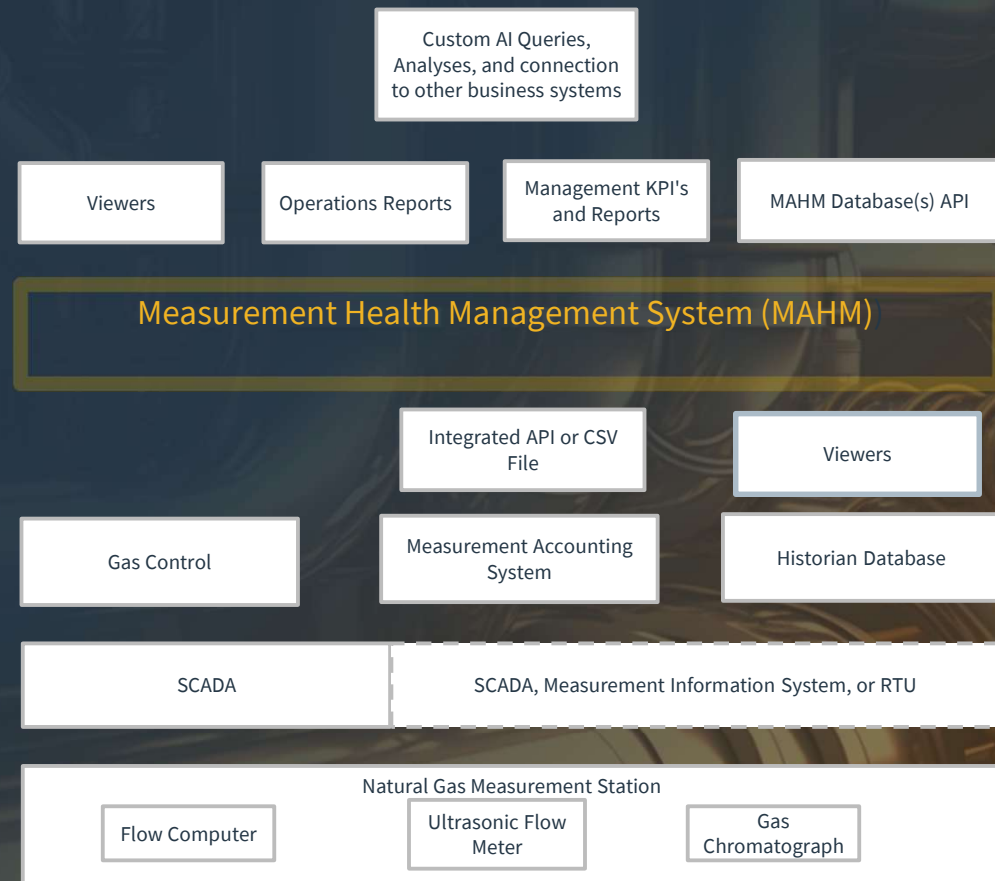


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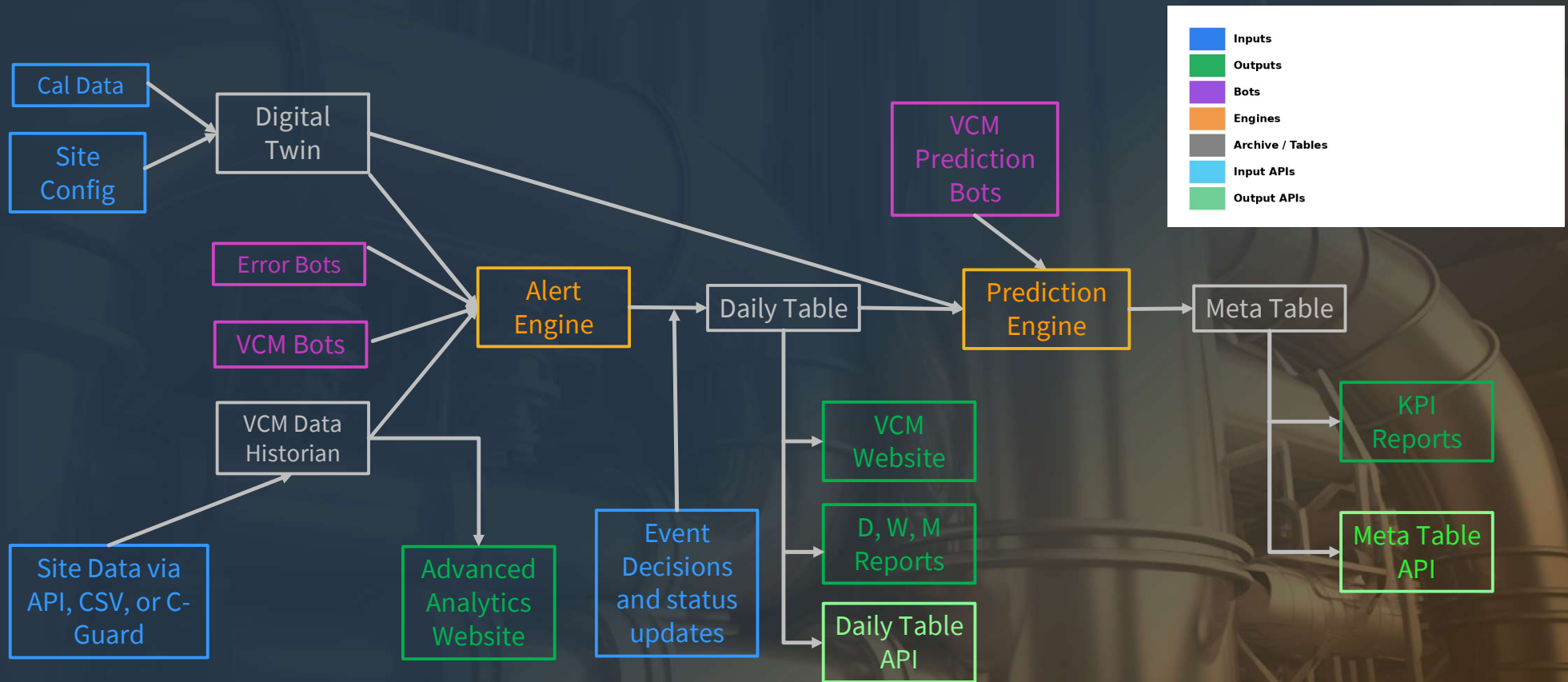
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Under the Hood of Virtual Check Meter





Drivers

Drivers - Optimization Drives Earnings Performance

■ *What Energy Leaders Are Saying*

“Our continued focus on operational excellence is allowing us to extract incremental value from existing assets without incremental capital.”

— Jack Fusco, President & CEO, Cheniere Energy
Earnings Call

■ **“Operational excellence initiatives remain a key lever for margin improvement as we scale without proportionally increasing our cost structure.”**

— Pierce Norton II, President & CEO, ONEOK
Earnings Commentary

■ **“Improved operational execution translated directly into higher EBITDA and stronger earnings performance.”**

— David Bauer, President & CEO, National Fuel Gas
Earnings Call

Drivers - Optimization Drives Earnings Performance

■ Executive Signal to the Organization

- ▶ **Optimize** existing assets
- ▶ **Reduce** unplanned intervention
- ▶ **Decouple** expected significant growth from headcount
- ▶ **Improve** ROI and earnings reliability

■ Why This Matters

- ▶ **CBM and PdM Operations and Analytics directly support the priorities CEOs are already communicating to investors and boards.**



Readiness

Readiness – What have we got?

■ CBM ➡ PDM Transition Checklist (Measurement Assets)

▶ Foundation (CBM must already do this)

- ★ Stable, Traceable asset IDs (Meter run, USM, GC, FC, P, T, Configuration) = Digital Twin
- ★ Time-Synchronized data (FC, GC, USM)
- ★ Contextualized alarm rationalization completed (no nuisance alarms)
- ★ Calibration, validation, and audit history preserved
- ★ Environmental & operating context captured

▶ PdM Readiness Checks

- ★ Raw Measurements stored (not only pass/fail results)
- ★ Drift trends calculated (not just threshold checks)
- ★ Events labeled (calibration, maintenance, errors detected)
- ★ Failures (Alerts) distinguished from error deviations
- ★ Data retained ≥ 12 -24 months

■ If any boxes are unchecked, you are not yet ready to apply AI

Key Readiness Takeaways for Natural Gas USM Stations

■ Readiness

- ▶ Data is generated at device and station level
- ▶ Data collection and storage tools are mature and readily available
- ▶ Secure data handling options are readily available
- ▶ Mature automated analysis and reporting systems like Virtual Check Meter™ are readily and economically available

■ PdM for gas measurements **is not** about predicting “failure” ➡ PdM **is** about predicting:

- ▶ When custody transfer error, calibration validity, or compliance risk will be exceeded
- ▶ CBM protects **today**
- ▶ PdM protects **contracts, audits, and revenue**



Regulatory and Contractual Acceptability

Regulatory and Contractual Acceptability

■ Q1. Does continuous verification replace required custody transfer measurement equipment?

- ▶ **No.** All custody transfer measurement equipment (meters, flow computers, gas chromatographs, pressure and temperature devices) remain unchanged and continue to operate in accordance with applicable standards, approvals, and tariffs.
- ▶ The continuous verification system **does not perform measurement**. It evaluates existing measurement data to verify integrity and identify potential exceptions.

■ Q2. Does the use of automated analytics modify API-approved volume calculations?

- ▶ **No.** All volumetric and energy calculations continue to be performed using approved API MPMS calculation methods implemented in the flow computer or supervisory calculation systems.
- ▶ The verification methodology:
 - Does not alter measurement inputs
 - Does not modify volume or energy calculations
 - Does not override custody transfer data
 - It functions solely as a **verification and diagnostic layer**.

Regulatory and Contractual Acceptability

■ Q3. How does CBM align with API MPMS Chapter 21.1?

- ▶ API MPMS Chapter 21.1 emphasizes:
 - Measurement integrity
 - Verification and validation
 - Auditability and traceability
 - Early identification of measurement errors
 - Use of redundancy and analytical checks
- ▶ Continuous verification supports these objectives by:
 - Providing **ongoing redundancy verification**
 - Identifying deviations earlier than periodic review
 - Documenting performance trends and corrective actions
 - Maintaining full audit records of verification outputs

Insert Verification Shot Here from
Weekly Report?

Regulatory and Contractual Acceptability

■ Q4. Is calendar-based verification still required?

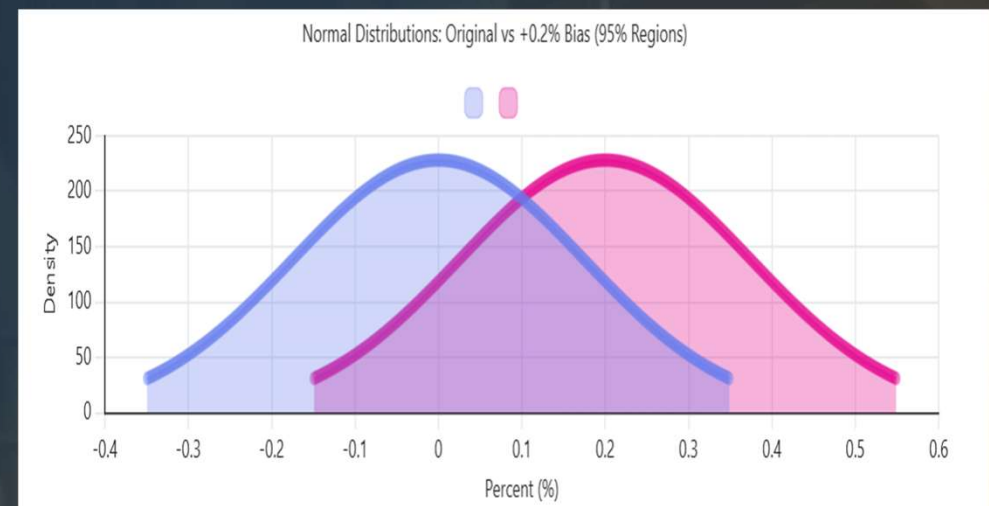
- ▶ API MPMS Chapter 21.1 does **not mandate calendar-based verification intervals** independent of measurement performance.
 - ▶ Where continuous redundancy verification demonstrates:
 - Stable measurement integrity, and
 - Documented confidence in measurement accuracy,
 - ▶ verification intervals may be **risk-adjusted**, consistent with the intent of the standard.
- Periodic verification is not eliminated; it is **focused on confirmed exceptions** rather than applied uniformly without regard to measurement condition.

Insert Calendar automation with monthly verifications first and then populated with verifications every day

Regulatory and Contractual Acceptability

■ Q5. How is “measurement confidence” determined and documented?

- ▶ Measurement confidence is derived from:
 - Multiple independent diagnostic and redundancy checks
 - Historical performance correlations
 - Current operating conditions
 - Statistical thresholding and trending
- ▶ Confidence assessments:
 - Are bounded and conservative
 - Are fully traceable to underlying measurement data
 - Are recorded as part of the permanent audit trail



Regulatory and Contractual Acceptability

■ Q6. Does predictive or forward-looking analysis introduce regulatory risk?

- ▶ No. Forward-looking assessments are used to:
 - Identify emerging measurement integrity risks
 - Support proactive corrective actions
 - Prevent duration of measurement uncertainty
- ▶ These assessments do **not**:
 - Change custody transfer quantities
 - Replace verification or audits
 - Automate corrective actions without human review
- ▶ They serve the preventive intent of API 21.1.

Regulatory and Contractual Acceptability

■ Q7. Who retains responsibility for measurement accuracy?

- ▶ Responsibility remains unchanged.
- ▶ The operating company retains full responsibility for:
 - Measurement accuracy
 - Verification compliance
 - Corrective action decisions
 - Audit readiness
- ▶ The system provides **decision support**, not autonomous control.

Regulatory and Contractual Acceptability

■ Q8. Are audit records preserved and accessible?

- ▶ Yes. The system retains:
 - All verification outputs
 - Identified exceptions
 - Trending analyses
 - Corrective action outcomes
 - Time-indexed performance records
- ▶ These records are:
 - Immutable
 - Traceable
 - Available for audit and review upon request

Regulatory and Contractual Acceptability

■ Q9. How are false positives handled?

- ▶ Verification outputs distinguish between:
 - Informational diagnostics
 - Non-material anomalies
 - Confirmed measurement exceptions
- ▶ This reduces unnecessary interventions while preserving complete documentation. No data is suppressed or deleted.

■ Q10. Does this approach disadvantage either party to a custody transfer?

- ▶ No. Continuous verification:
 - Improves transparency for both parties
 - Reduces undiscovered error duration
 - Lowers dispute risk and investigation costs
 - Enhances confidence in reported quantities
- ▶ Both parties benefit from earlier detection and documented resolution of measurement issues.

Regulatory and Contractual Acceptability

■ Q11. Is Exception-Based Maintenance permitted under existing contracts?

- ▶ Where contracts reference **API MPMS Chapter 21.1**, exception-based maintenance is permitted because:
 - Redundancy verification is explicitly accepted
 - Continuous verification enhances measurement integrity
 - No contractual calculation or settlement terms are altered
- ▶ No contract modification is required when verification intent is preserved.

■ Q12. Why is this preferable to periodic manual verification alone?

- ▶ Periodic verification provides **point-in-time assurance**. Continuous verification provides:
 - Time-based assurance
 - Earlier identification of issues
 - Reduced error duration
 - Improved auditability
- ▶ Together, they represent a **stronger compliance posture** than periodic verification by itself.



Roadmap



The Roadmap

- We have seen that CBM and PdM serve the corporate needs of our CEO's and Boards as expressed to shareholders
- We have seen that the resources, tools and data are ready to be put to work
- We have seen that CBM and PdM are acceptable for existing regulations, contracts and standards
- Measurement Teams may proceed immediately by:
 - ▶ Confirming Data collection and storage, or choosing an acceptable solution among many
 - ▶ Securely making data available to AI driven analytics engines (MAHM's) like the Virtual Check Meter™
 - ▶ Build company and asset specific history on shoulders of a wealth of existing data
 - ▶ Implement Condition-Based and Predictive Maintenance practices based upon real-time data and verification

The Roadmap

■ Continuously improve by:

- ▶ Adding Predictive Maintenance layers to plan maintenance work for exceptions which are not yet producing error
- ▶ Provide ongoing training for measurement technicians and engineers with real alert case studies with quantified implications
- ▶ Produce new, heretofore unavailable metadata KPI's including:
 - **Measurement Risk Velocity (MRV)** – Rate at which monetary measurement risk accumulates before mitigation
 - **Alert to Economic Resolution Ratio (AERR)** – Percentage of alerts that lead to economically meaningful corrective action
 - **Mean time to Economic Resolution – (MTeR)** – Time until error growth stops, not just when equipment is touched
 - **Measurement Confidence Index (MCI)** – A probabilistic confidence score for station accuracy today
 - **Remaining Accurate Operating Time (RAOT)** – How long a station can continue operating within acceptable financial error
 - **Action Effectiveness Scoring** – Expected risk reduction per action
 - **Engineer Leverage Factor (ELF)** – Stations effectively managed per engineer
 - **Exception Coverage Ratio** – Percentage of system throughout under continuous economic verification

The background of the slide is a dark, blue-tinted photograph of an industrial facility, showing various pipes, valves, and structural elements. Overlaid on the upper left portion of this background is a graphic consisting of several yellow diamonds arranged in a larger, symmetrical diamond shape.

The Impact

The Impact – Eliminating “Decision Latency”

- “Decision Latency – the gap between when an anomaly/alert/problem is detected and when an action is taken “ – Jag Gattu, CEO of UptimeAI
 - ▶ Activities in the gap
 - Anomaly detected => Expert receives anomaly => Expert assesses validity => Expert compiles personal experience, relevant data sources, tools => Expert applies domain skills to analyze all info => Expert decides on best course of action => expert routes actions to right team => action taken
- Current expert decision capacity means workflow executed for less than 5% of anomalies detected
 - ▶ From C-SMART’s VCM Database:
 - 70 - 80% of stations are OK at any given time
 - 20-30% have anomalies detected
 - 6% have anomalies that contribute error now
 - ▶ If the expert guesses correctly, 1-1.5 anomalies per hundred meters are actioned today, while 6 anomalies per hundred are producing errors
 - Consistent with blind statistical trial results previously reported at CEESI Conferences

Status Quo vs. CBM & PdM driven by Automated MAHM

	With Virtual Check Meter™ or equal	Without Virtual Check Meter™ or equal
PPA exposure	↓ 60–90%	Reactive
O&M cost	↓ 30–80%	Linear with stations
Measurement error duration	↓ 70–90%	Weeks–months
Analyst headcount	Flat	Must grow with assets
Risk transparency	Quantified	Assumed



Time for Action

The Time is Now

- Leveraging your existing data to implement CBM and PdM creates positive ROI immediately
 - ▶ Costs less to implement and sustain than maintaining the Time-based Maintenance status quo
- Perfectly aligned with corporate strategies addressing today's financial pressures
- An automated Measurement Asset Health Management System is the essential piece
 - ▶ Alert thresholds alone lack
 - economic/measurement risk data necessary to distinguish between alerts and predict error
 - ability to eliminate “Decision Latency” problem



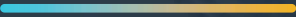
Conclusions

Conclusions

- Condition-Based Maintenance (CBM) and Predictive Maintenance (PdM) Paradigms are within the reach for Natural Gas Measurement teams today and can be implemented immediately
 - ▶ Assets exist
 - ▶ Secure data pipeline options exist
 - ▶ Powerful data analysis and verification platforms like the Virtual Check Meter exist
- CBM and PdM support contractual, regulatory, and standards guidance – no conflict
- CBM and PdM are aligned with corporate strategies - net immediate ROI by producing savings exceeding their cost of implementation



Thank You for your attention!



Contact Information

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