GAS COMPRESSION

Reducing Unplanned Downtime & Hidden Costs

RESONANCE SYSTEMS, INC.
TRUST YOUR MACHINE

Introduction

The natural gas compression industry is essential for maintaining reliable gas transportation across vast pipeline networks. With over 3 million miles of pipelines and thousands of compressor stations in the U.S., ensuring efficiency, reliability, and cost-effectiveness is critical.
This document covers key aspects of gas compression, including:

- Pipeline Infrastructure & Gas Pricing: Overview of network capacity and pricing at various supply chain points.
- Maintenance Strategies & KPIs: Discussion of corrective, preventive, predictive, and RCM approaches, and their impact on availability, MTBF, MTTR, and OEE.
- Failure Detection & Performance Monitoring: Common engines and reciprocating compressor failures, diagnostic tools like ultrasonic testing and PV curves, and their role in predictive maintenance.
- Economic & Operational Impact: Cost implications of failures, efficiency losses, and how predictive maintenance improves profitability.
- Training & AI Integration: Addressing the industry's skills gap and the role of AI-driven diagnostics and expert training programs.

This document is a resource for engineers, maintenance teams, and industry leaders focused on optimizing compressor performance, reducing downtime, and improving long-term efficiency.

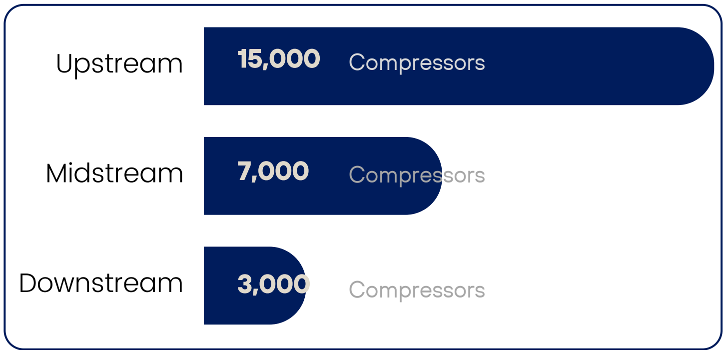
United States natural gas pipeline network

The U.S. natural gas pipeline network is a highly integrated system that transported 89,000 Mmscfd of natural gas in 2023, representing 36% of the country's total primary energy consumption [6].

The United States pipeline network has about 3 million miles of mainline and other pipelines that link natural gas production areas and storage facilities with consumers [3].

Note: U.S. Energy Information Administration, U.S. Energy Atlas, January 29, 2024. Light-Blue lines are intrastate pipelines, dark-blue lines are interstate pipelines, and + are border crossings. Source: [3]

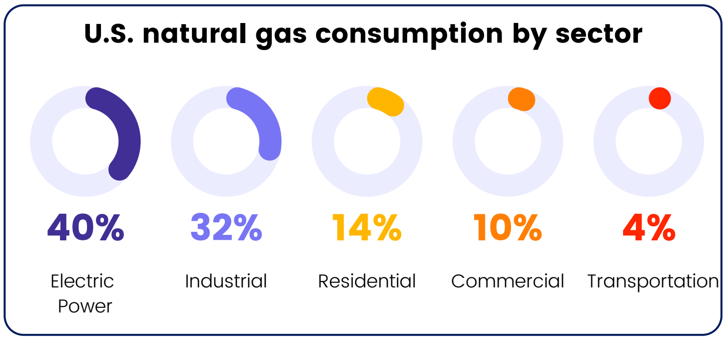
With approximately 1,700 natural gas compressor stations on midstream pipelines, housing between 5,000 to 7,000 compressors. Additionally, there are about 13,000 to 15,000 smaller compressors in upstream operations and 2,000 to 3,000 compressors in downstream oil and gas applications. These stations are strategically located along the extensive natural gas pipeline network, typically spaced every 40 to 100 miles, to maintain the necessary pressure for efficient gas transportation [5].



Note: These values are estimates based on available data -Oct 2024- and may be subject to revision as more comprehensive information becomes available. Source: [5]

U.S. natural gas flow

Consumption has grown significantly, led by the electric power and industrial sectors, while residential and commercial usage remains steady. The transportation sector has seen modest growth, highlighting natural gas's critical role in power generation, industry, and heating.

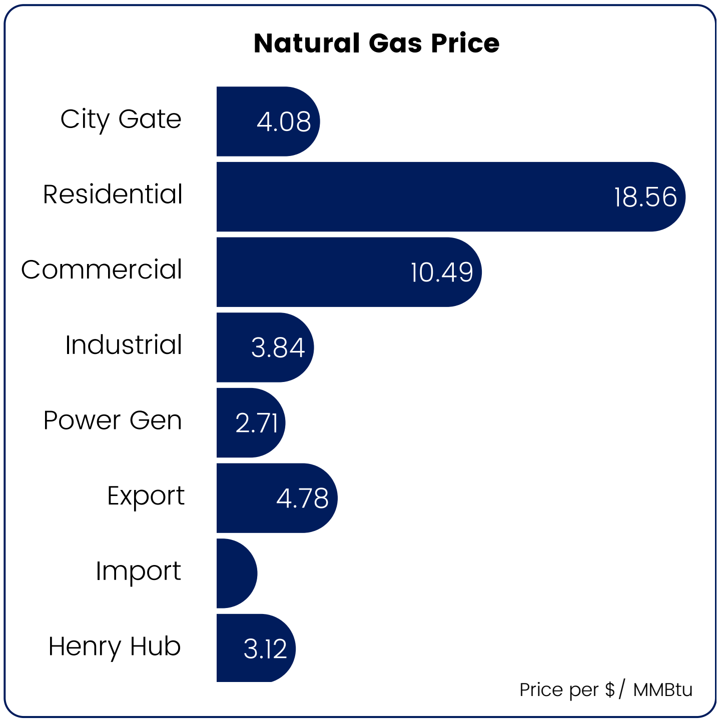


Note: These values are estimates based on available data -Oct 2024- and may be subject to revision as more comprehensive information becomes available. Source:[4]

Natural Gas Price

Natural gas prices vary across the supply chain based on delivery points, associated costs, and market dynamics. Here is a breakdown of key price points with recent values:

- Wellhead Price: This is the price of natural gas at the point of production, before any processing or transportation.
- City Gate Price: This price includes the cost of transporting natural gas from the main pipelines to local distribution companies
- Residential Price: Represents the final cost paid by end-users, incorporating all supply chain expenses, taxes, and local distribution charges.
- Commercial Price: The rate that is paid by businesses for heating, cooling, and operations.
- Industrial Price: The cost for industrial users. Used by manufacturers for processes like heating and as a feedstock, it often consumes large volumes of natural gas.
- Electric Power Price: The price paid by power plants for electricity generation.
- Export Price: The price at which natural gas is exported, primarily as liquified natural gas (LNG)or via pipelines to Mexico and Canada.
- Import Price: Reflects the cost of natural gas imported into the U.S., often via pipelines or LNG.
- Futures Price: Reflects the market's expectations of natural gas prices, traded on NYMEX, with Henry Hub as the delivery point.



Note: These values are estimates average prices in U.S. based on available data -Oct 2024- and may be subject to revision as more comprehensive information becomes available. Source:[7] & [8]

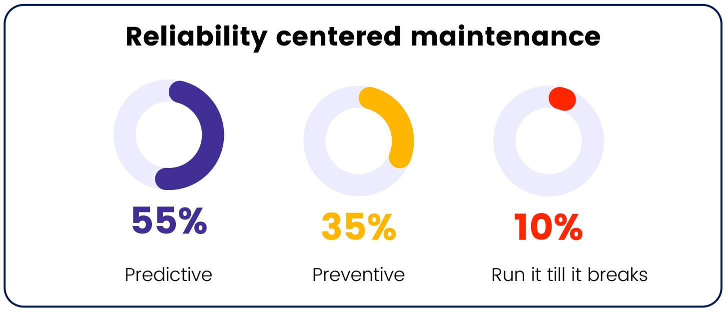
The Maintenance of gas compressors units

The maintenance of natural gas compressors is critical to ensuring their reliability, efficiency, and safety within the broader natural gas supply chain. Often located in remote areas, these machines operate under high-pressure and high-temperature conditions, making them susceptible to wear and tear over time.

An effective maintenance program is essential to minimize downtime. Maintaining these compressors includes corrective, preventive, predictive, and proactive strategies.

Corrective maintenance: Reactive maintenance is basically the “run it till it breaks” maintenance mode.

- Preventive maintenance: Involves scheduled inspections, replacements, and servicing to prevent potential issues before they arise.
- Predictive maintenance: Uses real-time data and advanced technologies such as vibration analysis to predict failures and plan interventions effectively.
- Reliability centered maintenance (RCM): This methodology recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. Is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a reactive maintenance approach. [9]



Note: RCM methodology utilize all available maintenance approaches with the predominant methodology being predictive. [9]

In the oil and gas industry, preventive maintenance is the most commonly implemented strategy. This approach involves scheduled inspections, servicing, and part replacements to prevent equipment failures and ensure operational reliability. Regular tasks such as replacing filters, spark plugs, lubrication oil, and inspecting critical components are standard practices. [10]

In recent years, there has been a growing adoption of predictive maintenance strategies within the industry. Leveraging advancements in data analytics and real-time monitoring, predictive maintenance allows companies to forecast equipment issues before they lead to failures. [11]

While Reliability-Centered Maintenance (RCM) offers a comprehensive framework for ensuring that systems continue to perform their intended functions, its implementation can be resource-intensive. Consequently, many organizations opt for preventive and predictive maintenance strategies, which are more straightforward to implement and manage. [12]

Management indicators

Regardless of the strategy adopted by management or maintenance leaders, there are key performance indicators (KPIs) that allow for the evaluation and measurement of how effective the maintenance strategy is. These indicators provide essential data for decision-making and optimizing maintenance processes. Among the most commonly used are:

- Availability: which measures the time equipment remains operational relative to total time.

$$Availability = \frac{MTBF}{MTBF + MTTR}$$ [22]

- MTBF (Mean Time Between Failures): It reflects the average time between failures.

$$MTBF = \frac{TotalOperatingTime}{NumberofFailures}$$ [22]

- MTTR (Mean Time to Repair): Which measures the average time required to restore equipment after a failure.

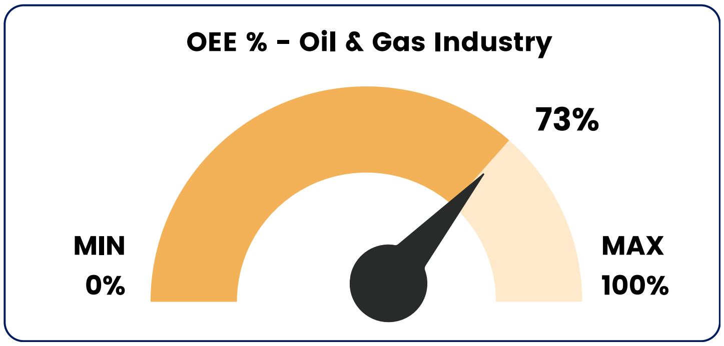
$$MTTR = \frac{DowntimeDuetoFailure}{NumberOfFailures}$$ [22]

- OEE (Overall Equipment Effectiveness): Which combines availability and performance to evaluate overall effectiveness. The standard OEE formula is:

$$\mathrm{OEE} = \mathrm{Availability} \times \mathrm{Performance\ Efficiency} \times \mathrm{Quality\ Rate}$$ [22]

    - Performance Efficiency: Assesses whether the compressor is operating at its optimal capacity.
    - Quality Rate: Quality takes into account manufactured parts that do not meet quality standards

...indicators provide essential data for decision-making...



Note: This value is based on available data -Oct 2024- and may be subject to revision as more comprehensive information becomes available. Source:[13]

In the gas compression industry, <u>Performance Efficiency</u> within the Overall Equipment Effectiveness (OEE) framework measures how efficiently a gas compressor operates relative to its designed capacity. [14]

Several key factors can lead to a reduction in the performance efficiency of a gas compressor:

- Operational Parameters: Variations in inlet and outlet pressures can impact the efficiency of compressor cylinder valves, leading to a decrease in compression capacity.
- Mechanical Wear and Damage: Worn or damaged piston rings, packing, and valve plates can cause gas leakage or internal recirculation within the cylinder, reducing overall compression efficiency.
- Obstructed Flow: Clogged valves and pipelines restrict gas movement, lowering the compressor's capacity and reducing performance.

Note: This damage to the compressor discharge valve plate has reduced the compressor capacity by 25%. [16]

The <u>quality rate</u>, a component of the OEE metric, is generally not impacted as natural gas passes through a compressor. However, in practice, the quality of the gas can be affected if excessive oil from the force-feed lubrication system enters the compressor cylinder and mixes with the gas flow.

Despite this possibility, the impact is typically negligible, as the volume of oil introduced is minimal compared to the vast amount of gas being compressed, making it an insignificant factor in overall gas quality assessment.

Likewise, in gas transmission systems, scrubbers and filters are commonly used to capture contaminants like oil, ensuring that the gas remains within quality standards before reaching its destination.

Note: This valve shows excess oil at the point where it is clogged. This was probably due to excess oil from forced lubrication systems. Source: [15]

<u>Availability</u>, that is part of the OEE calculation, is a critical performance indicator within the maintenance leaders, measuring the proportion of time a compressor is operational and ready for use compared to the total possible operational time.

Reaching 100% availability in gas compression systems is impossible unless the equipment never stops. In reality, both the driver (engine) and the driven unit (compressor) must undergo scheduled maintenance, as recommended by their manufacturers, to ensure operational reliability and longevity.

Benchmark - Availability Level

Level	Description	Availability
World-Class	Excellent performance with minimal downtime.	>99%
Industry Standard	Good availability, with occasional unplanned maintenance.	95%–99%
Needs Improvement	Higher downtime, requiring process optimization.	<95%

Note: These figures are commonly used as a rule of thumb and are considered aspirational goals for organizations.

Unplanned Downtime in Gas Compression Packages

Considering a typical gas compression package consisting of a Caterpillar 3500 series engine and an Ariel compressor:

- According to Caterpillar's maintenance guidelines, the engine requires scheduled maintenance every 2,000 hours.
- Ariel recommends compressor shutdowns every 4,000 hours for scheduled servicing.
- The maintenance duration for these tasks typically ranges between 6 to 12 hours, depending on the complexity and crew efficiency.

If we assume that the only downtime is for scheduled maintenance, the availability of the package would range between 99.4% and 99.7%. However, in real-world operations, reactive maintenance —unplanned interventions due to equipment failures—also occurs with varying frequency and severity.

The impact of these failures on availability depends on the maintenance strategy employed:

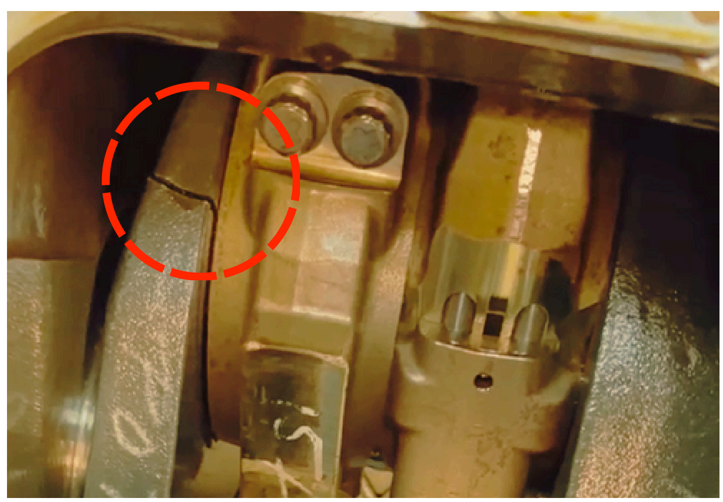
- Minor repairs may take only a few hours.
- Severe failures can lead to extensive downtime, or in extreme cases, a complete operational loss until major overhauls or replacements are performed.

While a high availability rate (>99%) is achievable with a robust preventive and predictive maintenance strategy, 100% availability remains unattainable due to the necessity of scheduled servicing and unplanned repairs. The key lies in minimizing unplanned downtime through condition-based monitoring, predictive maintenance, and efficient repair strategies.

Gas compression packages consist of multiple rotating and reciprocating components that are subject to mechanical fatigue and wear over time. These components have a finite lifespan, requiring periodic replacement and servicing as outlined in the manufacturer's scheduled or preventive maintenance recommendations.

However, even with the most robust preventive maintenance programs, unplanned failures can still occur. For example:

- Incorrect shaft alignment can lead to crankshaft failure.
- Spark plug fouling due to debris between the electrodes can cause misfiring, impacting engine performance.



Note: This image shows a crack in the unit's crankshaft, indicating a severe failure that may require anywhere from three days and several months to repair, depending on the availability of resources. Source: [16]

Predictive technologies add a layer of intelligence that helps operators anticipate failures

This is where predictive maintenance technologies play a crucial role. By monitoring components, these systems detect early signs of failure, providing sufficient time to schedule repairs during planned maintenance windows, thereby avoiding unexpected downtime.

In some cases, predictive technologies also serve as an immediate alert system, enabling operators to shut down equipment proactively before severe damage occurs. This intervention can prevent catastrophic failures, reducing repair costs and ensuring continuous operation with minimal disruptions.

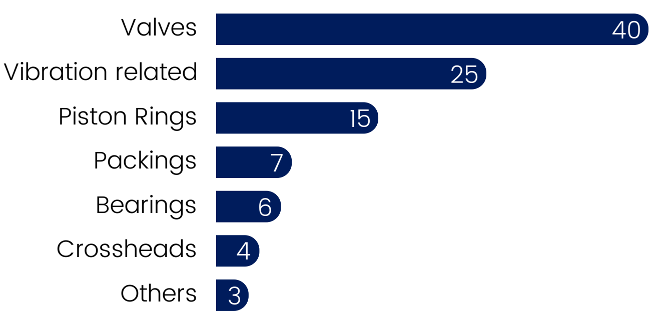
Note: This spark plug has a short circuit between the electrodes, leading to a cylinder misfire, reduced power, and increased torsional vibration. Source: [16]

Type of failures & detection

The majority of failures in gas compression packages occur in moving components. Here's what maintenance leaders need to know about the most common failures:

- Valve problems
- Rings
- Packing case
- Rocker bushing & bridge wear (Engines)
- Main bearing
- Rod & wrist pin knocks
- Piston slap (Engines)
- Detonation (Engines)
- Timing (Engines)
- Ignition problems (Engines)
- Compressor rod problems
- Rod load reversal event
- Looseness
- Pulsation
- Torsional Vibration

Most common failures in Reciprocating Compressors



Note: This is a hypothetical distribution of failures based on the author's experience and expertise in detecting such issues.

Resonance Systems Inc. offers a portable and online diagnostic kit that integrates multiple predictive technologies into a single system. This advanced solution can collect data at every 0.33 degrees of rotation, enabling the detection of most failures in reciprocating gas compressor packages.

Case: Engine Burnt valve

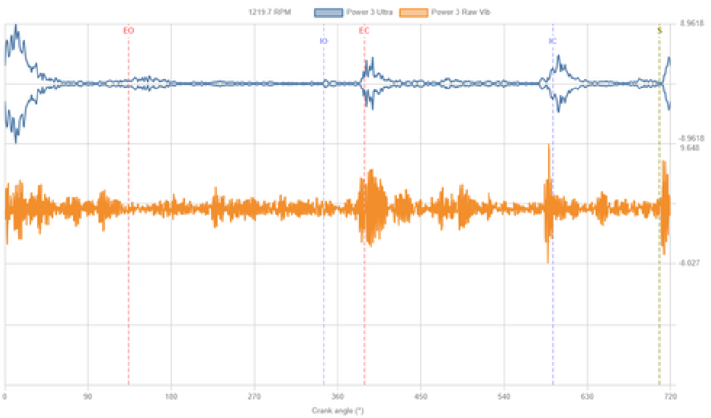
For example, exhaust valves in combustion engines can reach temperatures of up to 3,500ºF, while discharge valves in compressors typically operate at around 350ºF. The combination of elevated temperatures, mechanical impact forces, and continuous cycling significantly increases the likelihood of wear, fatigue, and leakage over time.

To mitigate these risks, ultrasonic testing can detect valve leakage in its early stages. By using ultrasonic diagnostics, technicians can accurately identify valve anomalies before they escalate into major failures.

Resonance Systems' software can generate detailed charts to identify various types of failures.

Note: This engine head exhibits an exhaust burnt valve, decreasing its ability to generate power. The issue was identified using ultrasonic diagnostics. Source: [16]

Using an ultrasonic sensor that collects data at every 0.33 degrees of rotation and synchronizes with the crankshaft reference, Resonance Systems' software can generate detailed charts that allow technicians to identify various types of failures.

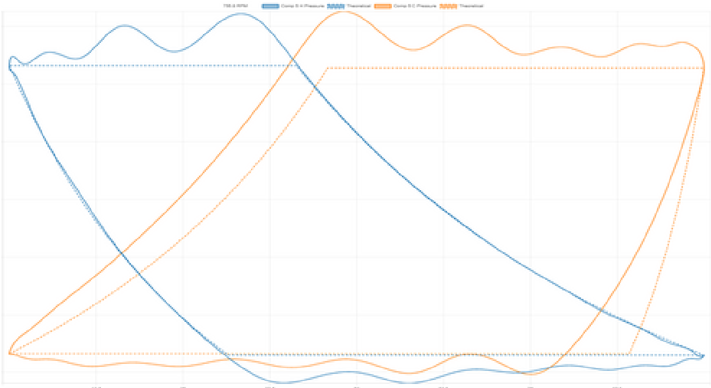


Note: This is an engine cylinder ultrasonic trace that shows a leakage when the piston is on power stroke, indicating a potential issue. Source: [16]

Case: Compressor Valve Leakage

In compressor valves, a similar failure pattern occurs. Ultrasonic traces, pressure traces, and numerical indicators help confirm if a valve is leaking.

To diagnose the issue, technicians rely on multiple data sources, with the most common being the pressure-volume (PV) curve, which serves as the primary indicator of leakage, whether due to internal recirculation or valve malfunction.



Note: This is a PV plot that exhibit that a compressor discharge valve is leaking. Source: [16]

Note: This picture shows a damaged discharge compressor valve following the recommendation of the technician to replace it. Source: [16]

Likewise, the pressure-volume (PV) curve helps to understand how much power the compressor needs to run. Similarly, collecting pressure data from an engine allows to determinate the power output. These measurements are a reliable way to check if an engine or compressor is overloaded or operating with reduced efficiency.

Whether it results in reduced efficiency or total equipment failure, the ultimate consequence of a compressor malfunction is financial loss.

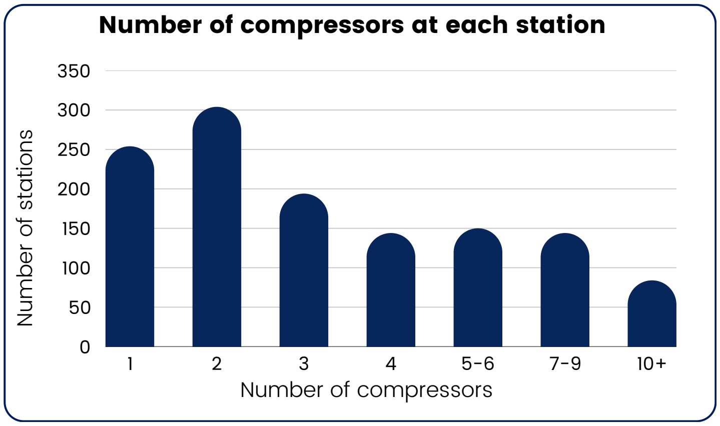
In the early stages of a valve failure, the compressor's capacity can decrease by 1–25%, directly impacting Performance Efficiency and, consequently, the OEE (Overall Equipment Effectiveness) indicator.

If the failure progresses to a complete valve malfunction, it can lead to a non-reversal of the crosshead pin, a critical compressor component. This type of failure can force an unscheduled shutdown of the unit, significantly disrupting operations. The repair time can range from 1–90 days or longer, negatively affecting the Availability Index and further reducing OEE scores.

Such extended downtimes can reflect poor maintenance management, reinforcing the importance of early detection and predictive maintenance strategies to prevent avoidable losses.

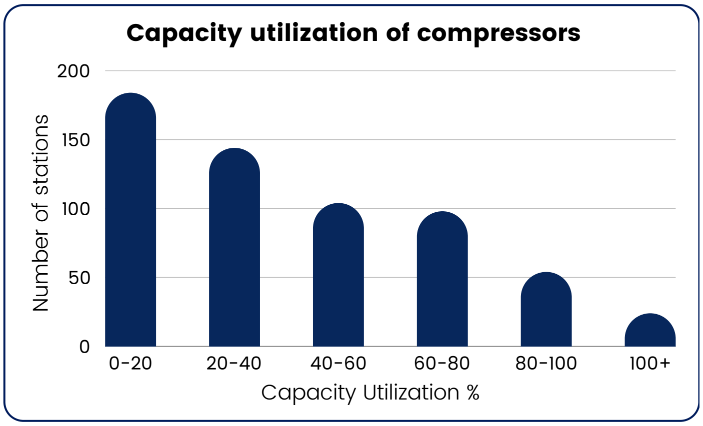
Redundancy and Compressor underutilization

The most areas of the U.S., the natural gas supply system is reliable and is designed with multiple redundant systems to ensure natural gas deliveries. [23]



Note: Compressor stations typically have more than one compressor with some stations having between 10 and 16 units. Source: [23]

The majority of compressor stations are equipped with two or more compressor units. However, most of these units operate below their maximum capacity, with a significant portion falling within the 0-20% capacity utilization range.



Note: Compressors operate at different levels of utilization. Source: [23]

This underutilization reflects the fact that compressor operation is not solely dependent on the compressors themselves but is largely influenced by the available gas flow. This flow is determined by upstream production rates, such as gas from wells, or by downstream pipeline transmission demands.

Any reduction in compressor capacity can often be compensated by increasing the compressor's speed or redistributing the load across additional units. While this ensures that production is not disrupted and the station continues to pump the required volume of gas, it comes with a significant drawback : increased fuel consumption. This adjustment can lead to higher costs, making fuel efficiency a critical consideration in such scenarios.

Economic Impact - Intro

Implementing predictive maintenance with specialized diagnostic tools for reciprocating machinery can generate significant financial savings by preventing unplanned failures, reducing downtime, and optimizing performance.

Consider an upstream gas compressor rated at 1,380 HP operating at 1,400 RPM, designed to increase pressure from 150 psig to 1,200 psig while transporting 10 Mmscfd of natural gas. Any undetected mechanical issues, such as valve leakage, piston ring wear, or bearing issues, could lead to efficiency losses, increased fuel consumption, or even complete shutdowns—resulting in substantial financial losses.

To determine the cost per million standard cubic feet per day (Mmscfd), we need the energy content of natural gas. On average, 1,000 cubic feet (Mcf) of natural gas contains approximately 1.037 MMBtu [17].

Therefore, 1 MMscf equates to:

$$1{,}000 \text{ Mcf/day} \times 1.037 \text{ MMBtu/Mcf} = 1{,}037 \text{ MMBtu/day}$$

Using the Henry Hub spot price:

$$1{,}037 \text{ MMBtu/day} \times \$3.12 \text{ per MMBtu} = \$3{,}235.44 \text{ per day}$$

Therefore, at the current Henry Hub price [7]&[8], 1 Mmscfd of natural gas would cost approximately $3,235.44 per day.

Economic impact

The economic impact of compressor inefficiencies primarily arises from reduced production capacity and increased fuel consumption. However, several additional factors influence the overall cost implications:

- Redundancy in Compressor Stations: Some facilities operate with multiple compressors or standby units, mitigating immediate production losses. Stations without redundant systems face more severe downtime and higher financial losses.
- Underutilized Compressor Stations: Facilities operating below full capacity may absorb efficiency losses differently than fully loaded systems.
- Time to Detection and Repair: The longer a failure or leakage remains unaddressed, the greater the cumulative economic impact.

A compressor valve leakage is one of the most frequent failures in gas compression units. To evaluate its impact, a study was conducted analyzing the progression of a valve failure in the absence of a predictive maintenance strategy.

To evaluate the financial repercussions of this failure across different scenarios or configurations of stations/compressors;

Initial Considerations:

- Compressor Package Evaluation: The assessment focuses on a typical setup involving a Caterpillar 3500 series paired with an Ariel compressor JGT or similar, with a capacity of 10 Mmscfd.
- Common Failure - Valve leakage: Initially minor, the compressor valve leakage gradually worsens, reducing the compressor's capacity by 25%. This degradation typically develops over an estimated period from 0 to 360 days, based on the author's experience.
- Risk of Catastrophic Failure: Once the compressor's capacity is reduced by 25%, there is a substantial risk of catastrophic failure. This usually manifests as a non-reversible lubrication event on the crosshead components, leading to a major breakdown.

Cost Considerations:

- <u>Opportunity in Production:</u> When a compressor valve leaks, it uses more fuel. This leakage also affects production, especially if the compressor has no residual capacity or is not underutilized. The cost is considered an opportunity cost, which means the money lost from the natural gas that couldn't be sold.
- <u>Direct Activities:</u> Implementing predictive maintenance strategy uses regular checks to prevent bigger problems, that requires extra work hours and parts. This cost is straightforward monetary cost.
- <u>Estimated Risk:</u> A situation where a valve leak isn't caught early enough and leads to a big, costly breakdown. This risk cost is what it might cost if such

a problem actually happens, showing the importance of catching issues early.

Estimated Risk can be calculated:

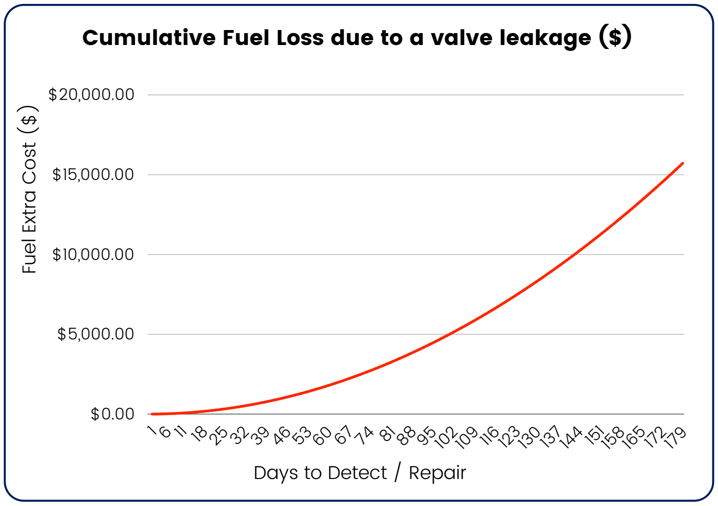
$$Risk = ProbabilityOfOccurrence \times ImpactOfOccurrence$$

This comparison evaluates the financial impact of the following scenarios:

- **Case 1 - Underutilized Compressor & <u>No</u> Predictive Maintenance Strategy**

At many stations, engine fuel is taken from the discharge pipeline, using up some of the natural gas intended for sale. For example, a Caterpillar 3500 series engine consumes about 0.217 Mmscfd at full load, operating most efficiently. Efficiency drops at lower loads, increasing fuel use per power unit.

Conversely, an Ariel compressor undergoes scheduled maintenance every 4,000 hours. If a valve failure starts halfway through this period, the leakage will continue for about 83 days until the next scheduled maintenance. The extra fuel cost over this period can be up to $3,317.90.



Note: The red curve shows fuel costs during a valve failure, initially rising slowly then accelerating as the failure worsens. It starts with a minor discharge valve leak (reducing compressor capacity by 1%) and worsens to 25% (1380 HP & 10 Mmscfd), assuming no production loss. Cost data is from October 2024. [7] & [8]

This calculation does not include labor costs or the expense of replacement parts, which are expected to be addressed during routine maintenance activities.

If the leakage worsens unexpectedly, could lead to a non-reversible load event on the crosshead pin - causing an unplanned shutdown and major repairs with extended downtime.

The Risk of not fixing this type of failure quickly could really bump up the costs, potentially adding more than $160,000 to the total, reaching an Estimated Potential Cost of **$163,317.90.**

It's important to clarify that this figure does not represent a real monetary loss, as the leaked natural gas remains within the system or piping. However, this situation does represent a significant opportunity cost associated with the inability to sell this amount of gas.

Additionally, the actual financial loss in this scenario arises from the extra fuel consumption required by the compressor package. The presence of a leakage component necessitates additional energy or extra power to maintain operational efficiency, which directly impacts fuel expenses.

The cost associated with this risk doesn't represent a direct monetary loss but rather a potential scenario that could occur.

Integrating a portable kit from Resonance Systems Inc. could significantly improve the facility's ability to implement predictive maintenance strategies effectively. These systems are designed to identify potential failures early in their development, allowing for timely interventions that prevent leakage, reduce unnecessary power consumption and major failures.

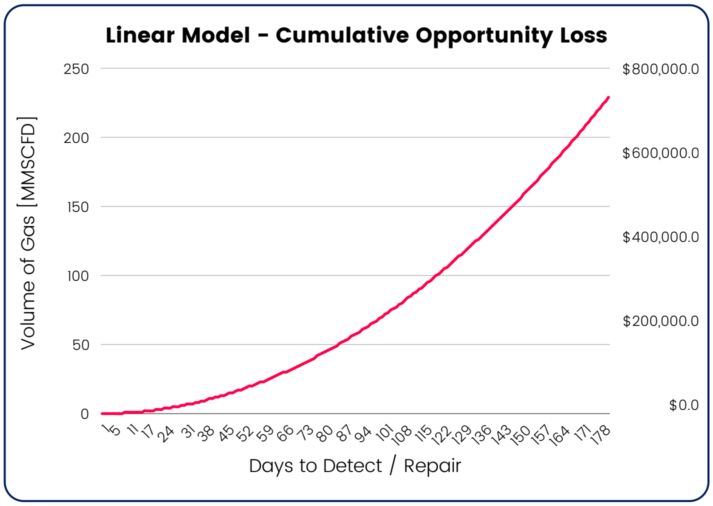
By incorporating such technologies, operations can move towards more sustainable practices, minimizing opportunity costs and direct financial losses associated with equipment malfunctions.

...this situation does represent a significant opportunity cost associated with the inability to sell this amount of gas.

- **Case 2 - ~100% Load Compressor & <u>No</u> Predictive Maintenance Strategy**

In scenarios where predictive maintenance strategies are absent, and a compression station operates with a single unit without alternatives to counteract production declines due to valve leakage, financial repercussions can be significantly magnified.

Consider a similar scenario where a maintenance schedule inspections occur every 4,000 operating hours. If a valve failure occurs at the midpoint of this cycle, the leakage would persist for an estimated 83 days before the next maintenance intervention.



Note: The red curve shows how much money and fuel are lost when a compressor valve starts to leak. It tracks the compressor's capacity dropping from 1% to 25% because of the leak, getting worse over time (this example uses 1380 HP engine & 10 Mmscfd compressor). Cost data is from October 2024. [7] & [8]

Assuming the compressor's capacity is 10 Mmscfd, and there is a gradual decrease in this capacity from 1% to 25% due to the leakage, the cumulative loss of gas would total:

48.28 Mmscfd × $3,235.44 = $156,237.83

Additional fuel cost over this period can be : $3,317.90.

The Risk of not fixing this type of failure quickly could really bump up the costs.

Given a 40% probability of valve failure and a potential maximum cost of $400,000.00 the risk could add more than $160,000 to the total. This leads to an Estimated Potential Cost of **$319,555.73.**

Costs Without a Predictive Maintenance Strategy

	Opportunity Cost in Production	Direct Activities Costs	Risk Related Costs
Underutilized Unit	▼	▼	▲
Fully Utilized Unit	▲	▼	▲

Note: The comparation table represents when No Predictive Maintenance Strategy is NOT applied, either the unit is fully or underutilized. Source: Author

- **Case 3 - Underutilized Compressor & Applying a Predictive Maintenance Strategy**

Assuming that the compressor is underutilized and valve leakage has been detected after 15 days started, and takes another 15 days to address the intervention or repair it -The repair time takes 2-4 hrs.-. The reduction in compressor capacity due to the leakage is 0 Mmscfd, but during this period the unit need extra power to compensate the loss or leakage.

So, the cumulative fuel consumption will be:

0.131 Mmscfd x $3,235.44 = $423.84

Cost of Field service technician with an expertise on Predictive Maintenance in Reciprocating machinery:

1 Service (Data Collection + Analysis) = $2,476.96

Time to repair, Impact on production (due to repair), Labor cost [20] and parts:

2 hours impact on Production = $2,685.42
2 hours x $34.13 x 2 people = $136.52
1 valve = $440.00 [21]

The risk cost is negligible since the valve failure is addressed promptly before it escalates into a major issue. Therefore, the total estimated cost is $5,586.22.

This scenario underscores the value of early detection and predictive maintenance in preventing efficiency losses, operational disruptions, and potential shutdowns.

- **Case 4 - 100% Load Compressor & Applying a Predictive Maintenance Strategy**

Assuming that the compressor is underutilized and valve leakage has been detected after 15 days started, and takes another 15 days to address the intervention or repair it -The repair time takes 2-4 hrs.-. The reduction in compressor capacity due to the leakage is 0 Mmscfd, but during this period the unit need extra power to compensate the loss or leakage.

Thus, the cumulative fuel consumption will be:

0.131 Mmscfd x $3235.44 = $423.84

Additionally, the cumulative loss on production will be:

6 Mmscfd x $3235.44 = $19,412.64

Cost of Field service technician with an expertise on Predictive Maintenance in Reciprocating machinery:

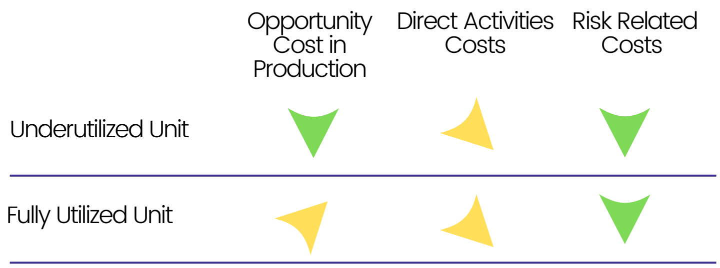
1 Service (Data Collection + Analysis) = $2476.96

Time to repair, Impact on production (due to repair), Labor cost [20] and parts:

2 hours impact on Production = $2685.42
2 hours x $34.13 x 2 people = $136.52
1 valve = $440.00 [21]

Given that the valve failure is addressed promptly before it becomes a major issue, the risk cost is considered negligible. Consequently, the total estimated cost is $24,575.38.

Costs Applying a Predictive Maintenance Strategy



Note: The comparation table represents when No Predictive Maintenance Strategy is applied, either the unit is fully or underutilized. Source: Author

Training Technicians

Becoming a world-class engine and compressor analyst can take up to 10,000 hours [18] of training and fieldwork, demanding strong commitment from both the employer and the technician to achieve this level of expertise.

Additionally, the oil and gas industry faces a growing skills gap due to the disruptions caused by COVID-19 and an aging workforce. More than 50% of industry professionals plan to retire within the next 5 to 10 years [1], making it increasingly difficult for companies to find highly trained analysts. This has led to a highly competitive labor market, where skilled personnel is becoming a significant challenge.

Resonance Systems addresses this issue through its expert-led training programs, designed to accelerate skills development with a user-centric approach. Additionally, its Rmonix software platform is designed to be user-friendly and intuitive, allowing users to stay globally connected in real-time while collecting data.

With immediate remote assistance available via a internet connection, technicians can receive guidance instantly, ensuring a top-tier support experience.

Having immediate access to technical support or a mentor can significantly reduce the time it takes for a technician to develop expertise. Quick guidance helps solve issues faster, improves diagnostic skills, and minimizes mistakes in the field.

Resonance Systems continuously works on developing new tools, hardware, and software to make diagnostics simpler for its users. A clear example is the release of its AI-assisted Demo Tool [19], designed to detect valve issues in engines and compressors by recognizing failure patterns. This tool helps technicians analyze problems more efficiently, reducing time and improving maintenance decision-making.

Artificial Intelligence

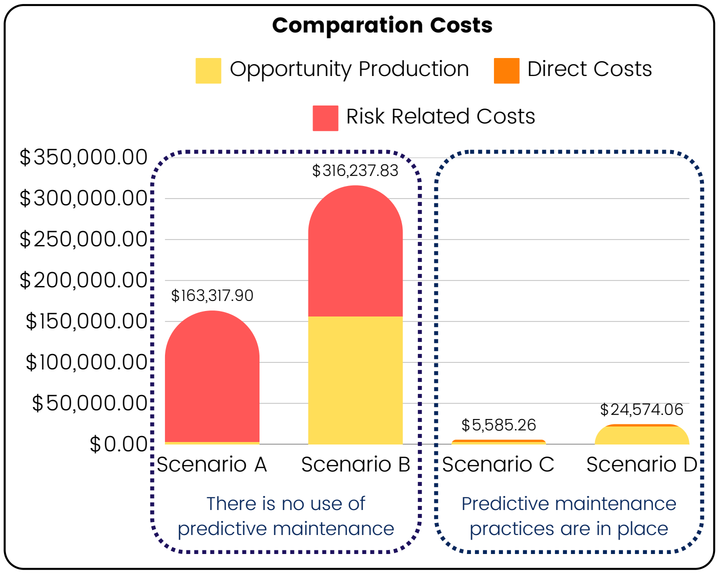
We are currently seeing AI being introduced into many industries, including mechanical diagnostics. Companies are starting to use AI to help improve their processes, but those that don't adapt might struggle to compete.

In mechanical diagnostics, AI is still in its early stages. While it can help analysts process more data and improve efficiency, it is not advanced enough to replace human expertise. Developing AI models for diagnostics takes a lot of historical data, sometimes years' worth of samples, just to create a model for diagnosing a single machine component failure.

Many AI diagnostic tools available today are limited—they mostly provide basic warnings, using standard statistics or calculations rather than full analysis like a human expert. Even though AI will continue to improve, it will take years before it can reliably diagnose failures like experienced technicians. Until then, human analysts remain essential for verifying and improving AI models.

Conclusions

Implementing predictive maintenance strategies not only significantly boosts the operational efficiency and safety of gas compression systems but also offers a competitive edge in the industry. Resonance Systems Inc. equips companies with advanced diagnostic tools that enable early detection of potential failures, thus reducing unplanned downtime and enhancing the overall reliability of the systems.



Note: This graph shows the Estimated Total Cost for each scenario. All scenarios use a setup that includes a Cat3500 series and an Ariel Compressor, each capable of handling 10 Mmscfd. Scenarios A and C involve units that are not at fully capacity, while Scenarios B and D use units that are running at full capacity. Source: Author

Adopting proactive maintenance strategies such as predictive maintenance is highly cost-effective. These practices minimize the costs associated with sudden equipment failures and extensive repairs. By maintaining equipment regularly and predicting potential failures, companies can manage their maintenance budget more effectively, avoiding the high costs of emergency fixes and lost production time.

The integration of AI and other advanced technologies into maintenance practices represents a significant advancement in the natural gas compression industry. These technologies provide detailed insights into equipment health and operational status, allowing for more informed decision-making and more precise maintenance interventions. This technological shift not only improves maintenance practices but also sets a new standard for operational excellence in the industry.

References

[1]https://www.maxgrip.com/resource/article-the-cost-of-unplanned-downtime/
[2]https://www.aogr.com/magazine/sneak-peek-preview/smart-maintenance-and-more-robust-parts-boost-compressor-uptime
[3]https://www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php
[4]https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php
[5] https://netl.doe.gov/sites/default/files/netl-file/Brun.pdf
[6] https://www.eia.gov/energyexplained/us-energy-facts/
[7]https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PM0_DMcf_m.htm
[8]https://www.cmegroup.com/markets/energy/natural-gas/natural-gas.html
[9]https://www.energy.gov/sites/prod/files/2020/04/f74/omguide_complete_w-eo-disclaimer.pdf
[10]https://www.dombor.com/oil-and-gas-maintenance-tips/
[11] https://akselos.com/predictive-maintenance-for-oil-and-gas-operations/
[12]https://www.emaint.com/blog-four-maintenance-strategies/
[13]https://literature.rockwellautomation.com/idc/groups/literature/documents/ap/oag-ap027_-en-e.pdf
[14]https://www.ogj.com/refining-processing/gas-processing/new-plants/article/17235988/oee-method-improves-condition-based-maintenance
[15]https://www.mes.co.jp/english/business/afterservice/industrial/mrv.html
[16] Resonance Systems client
[17]https://www.neighborhoodenergyne.com/market-insights/natural-gas-cost-per-therm-the-actual-numbers
[18] Malcolm Gladwell published his blockbuster book, Outliers, in 2008
[19] https://resonance.systems/eng-valve-analysis-tool
[20]https://www.ziprecruiter.com/Salaries/Oil-Gas-Technician-Salary
[21]Average price valve of multiples Ariel compressors, https://www.ebay.com/
[22]https://www.reliabilityconnect.com/how-to-measure-and-use-reliability-metrics/
[23]https://www.netl.doe.gov/projects/files/NGCompressorsandProcessors%E2%80%93OverviewandPotentialImpactonPowerSystemReliability_071817.pdf

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Ramiro Quiroga brings extensive experience as an engineer specializing in rotating equipment within the Oil & Gas industry. Over the past decade, he has applied his expertise to diagnosing failures and optimizing reciprocating machinery. His proactive maintenance strategies and careful life cycle cost analyses have significantly improved equipment performance and reliability.

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