Identifying Energy Inefficiencies in Compressed Air Systems: A Systematic Approach with the Compressed Air Scoping Tool[1]

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Abstract

Compressed air systems in industrial facilities often incur exorbitant electricity costs and require systematic improvements. To address this, the Compressed Air (CA) Scoping Tool was developed as an initial step for system analysis and optimization. This tool incorporates up-to-date best practices and serves as a valuable resource for facility personnel, offering insights into compressed air systems from production to end use. By utilizing the CA Scoping Tool, plant managers, energy engineers, and maintenance personnel can enhance system efficiency, reduce energy consumption, and achieve cost savings. This paper highlights the importance of improving compressed air systems, outlines the tool's development and features, and underscores its value as a nonbiased resource for system evaluation and optimization. Additionally, the paper presents a case study based on a food manufacturing facility to demonstrate the practical application of the tool. Furthermore, the paper discusses potential future opportunities for enhancing the CA Scoping Tool.

Keywords

compressed air benchmarking, compressed air operations, compressed air optimization, compressed air systems, compressor specific energy, energy efficiency, manufacturing energy savings, scoping tool

1. Introduction

Over 70% of manufacturing facilities are equipped with compressed air systems [1]. Compressed air has a wide array of applications within the manufacturing sector, including conveyance, pneumatic tools, paint booth operations, and actuation of robotic arms. Compared with electrical means of operation, compressed air provides smoother, more reliable power and better torque control on machinery and can eliminate the potential shock hazards of mechanical equipment. Compressed air systems are often considered mandatory for modern manufacturing; however, a compressed air system can also be the most inefficient system in a facility [2]. Compressors lose a significant amount of energy, with roughly 80% of the energy consumed being lost to heat of compression [3]. After factoring in losses due to drive efficiency and leaks in the system, the point of use receives only 5%–10% of the power that was originally fed to the compressor (Figure 1).

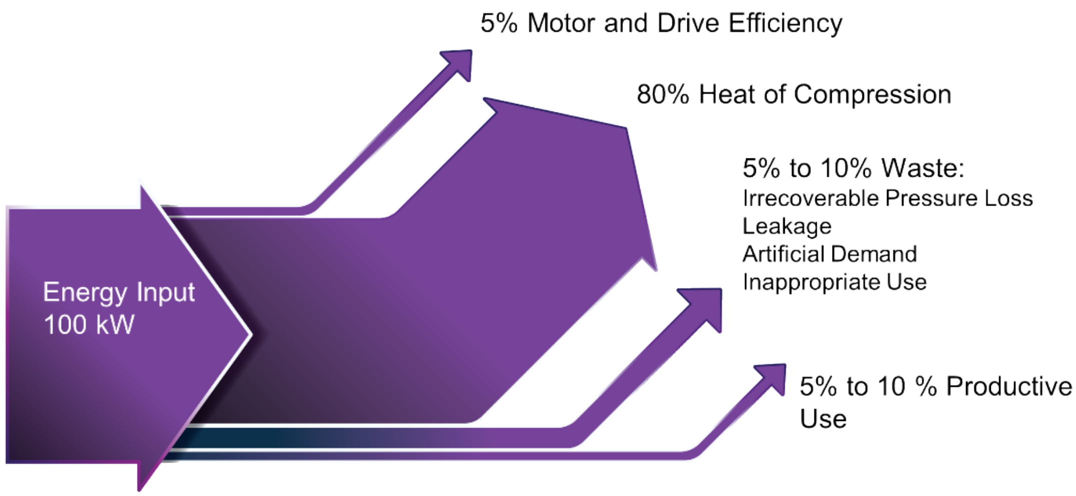

Figure 1. Typical Compressed Air Power Sankey. **Error! Bookmark not defined.**

For some facilities, compressed air systems can consume 30% of the total plant energy cost [1] [4]. In large facilities, compressed air is often treated as a fourth utility because of its high cost of production. The cost of compressed air can be anywhere from 1.8 to 3.0 cents per 100 cubic feet depending on the type and controls of a compressor. Figure 2 highlights that over a 10-year period, electricity is the single most expensive cost [4]. As the cost of electricity continues to rise, so will the cost to produce compressed air. These reasons have led industry to take a more methodical look into their compressed air usage and operation practices.

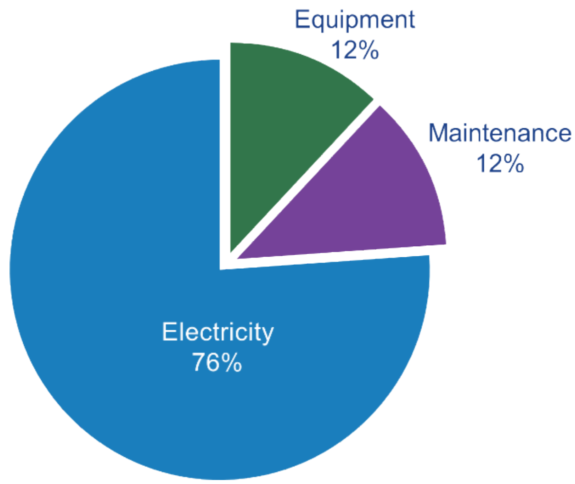

Figure 2. Life Cycle Cost over 10 years to Operate a Compressor.

Given the exorbitant electricity costs associated with compressed air, many facilities are starting to take a systematic approach to improving their compressed air systems and operating procedures. To provide manufacturers with a starting point for reducing the electricity consumption of their systems, the Compressed Air (CA) Scoping Tool was developed as a first step toward conducting an overall system analysis.

Optimizing compressed air systems has traditionally taken a back seat within manufacturing because air usage is often considered a necessary evil. Many compressed air systems were implemented without much consideration or plans for continuous improvements. Even today, 60-year-old systems in dire need of attention are common throughout industry. More recently, compressed air has been recognized as a key large energy user with extremely poor performance. As of 2018, compressed air systems are the third most retrofitted systems in manufacturing, behind HVAC and lighting systems [5]. This recognition has led to advances in compressor controls and best practices that are continually evaluated and updated.

Standards and practices around compressed air systems are also evolving as previous golden rules become outdated for the current energy-conscious manufacturing society. For example, the previous rule of thumb for compressed air storage of 1–3 gal/cfm [6] [7] is now accepted to be 3–5 gal/cfm, reflecting a need for greater storage to optimize overall system performance [7] [8]. This change in recommended storage is only one of many in the industry, leaving many manufacturers lost in a sea of contradicting best practices to sift through. The new CA Scoping Tool was created with the most up-to-date best practices in the industry (as of 2023) and can be used as a nonbiased, one-stop shop for best practice recommendations.

To help encourage energy efficiency among US manufacturers, the US Department of Energy (DOE) developed the Better Plants (BP) program. Through this program, manufacturing companies (partners) establish specific energy reduction goals over a defined period, typically a 25% reduction in energy intensity over 10 years. Partners gain access to a wide range of technical resources to help achieve their goals, including quick-start guides that teach how to build an energy management program from the ground up [9], workforce development programs such as in-plant or virtual system trainings, and free energy and carbon assessment software [10] [11]. Many partners have also found resources available through other entities external to the BP program such as third-party assessors or their local utilities. By leveraging such resource networks, partners have been able to excel in their energy goals. Some of the tools and resources offered by the BP program specifically for compressed air include the Manufacturing Energy Assessment Software for Utility Reduction (MEASUR) software suite assessment module and calculators, virtual trainings [12], in-plant trainings, energy boot camp trainings, compressed air tip sheets, diagnostic equipment loans, and much more. Each of these resources vary in their approach and information type, ranging from general system information to interactive resources that would require a more in-depth analysis. Figure 3 shows the network of compressed air specific resources that are available to program partners and how they intertwine with one another.

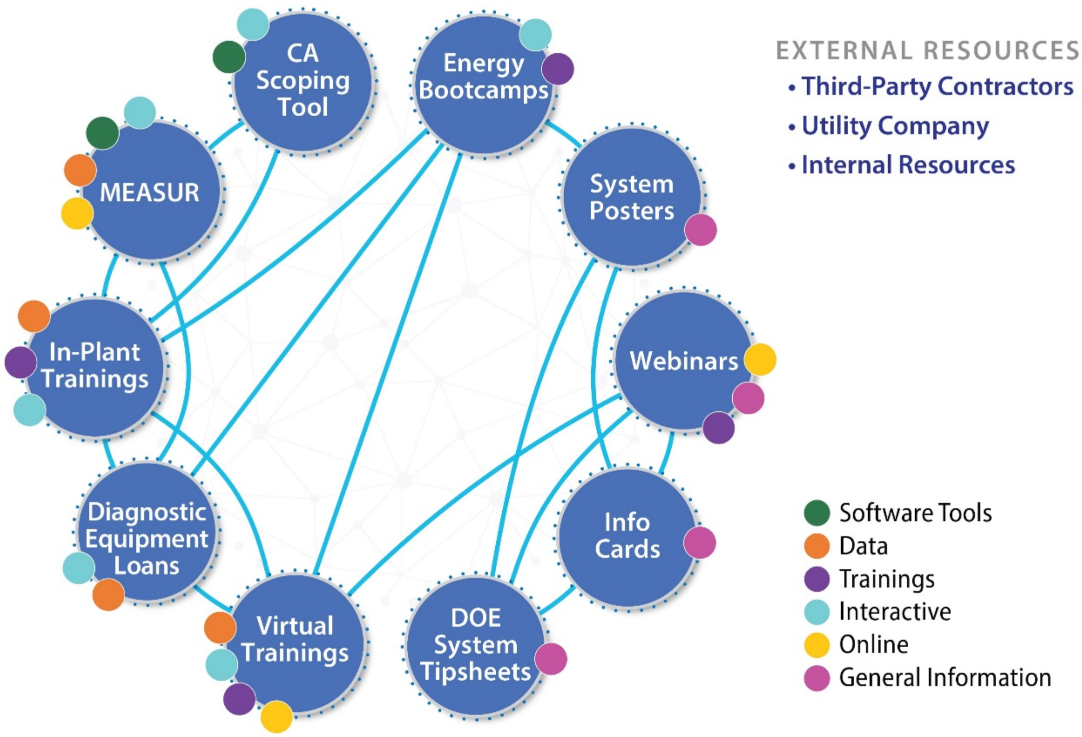

Figure 3. Compressed Air Resource Network.

The CA Scoping Tool was developed as an additional resource for BP partners. The tool is designed for facility personnel interested in improving their compressed air systems, including plant managers, energy engineers, or maintenance personnel. The tool serves as an initial step in understanding a facility's compressed air system and the common practices that are currently standard operating procedures. Ideally, the tool should be used before DOE's MEASUR [13] assessment tool. The CA Scoping Tool acts as an operational baselining tool, enabling users to comprehend various aspects of a facility's system, from the production of compressed air to its utilization at the end users.

2. Development of the Compressed Air Scoping Tool

The CA Scoping Tool was developed through a partnership between Oak Ridge National Laboratory (ORNL) and an industrial partner from the BP program. The partner was inspired by the DOE's Steam System Scoping Tool (SSST), applying the same principles to compressed air. DOE and ORNL always encourage opportunities to develop tools and resources that are useful for their industry partners. As a result, ORNL and the partner collaborated to create the CA Scoping Tool as the compressed air equivalent of the SSST.

3. Overview of the Tool

The CA Scoping Tool is an Excel-based software tool that is used to evaluate compressed air systems comprehensively. It was developed without the use of macros to increase longevity, reducing the risk of future Excel updates disrupting the tool's functionality. Excel is a widely used software, enabling easy access for users. The premise of the tool is that users answer a series of questions pertaining to specific aspects of their compressed air systems, and then those answers are compared with industry-accepted best practices. Users simply select their responses from drop-down menus, which range from yes/no options to time ranges or frequencies. Each question receives a score based on the provided answer, contributing to the overall system evaluation. Some of the questions offer multiple answer options, with higher scores assigned to answers representing better operational practices. These scores are tallied at the end to produce a report card, and recommendations are suggested. Hence, the CA Scoping Tool serves as the initial step for industrial manufacturing plants to comprehend and enhance their compressed air systems.

As shown in Table 1, the tool consists of nine tabs, six of which are part of the graded portion. The table displays the types of data collected, the corresponding results, and the identified energy-savings opportunities.

Table 1. CA Tool Outline

Tab Title	Content
1. Instructions	Instructions on how to fill out the data collection sheets
2. Plant Information	Equipment description
	Resource consumption (compressor inputs)
	Facility set points (compressor outputs)
	Production uses
	Annual costs
3. System Profiler	System measurements
	System cost analysis
	Compressed air intensity
	Heat recovery
4. Compressed Air System Operating Practices	Air leak management
	Pressure control
	Maintaining effective system operations
5. Air Compressor Operating Practices	Compressor efficiency
	Compressor performance
6. Compressed Air Quality ISO 8573.1	Particulate content
	Moisture content
	Oil content
7. Compressed Air System Operating Practices - Distribution, End Use, Recovery	Inappropriate uses
	Artificial demand
8. Results	The final scores for each section
9. Energy Saving Opportunities	Possible recommendations based on the user's inputs

The tool breaks down the scoping process into three distinctive steps: benchmarking the current system, comparing operating procedures against current best practices, and identifying possible energy efficiency opportunities based on user responses (Figure 4).

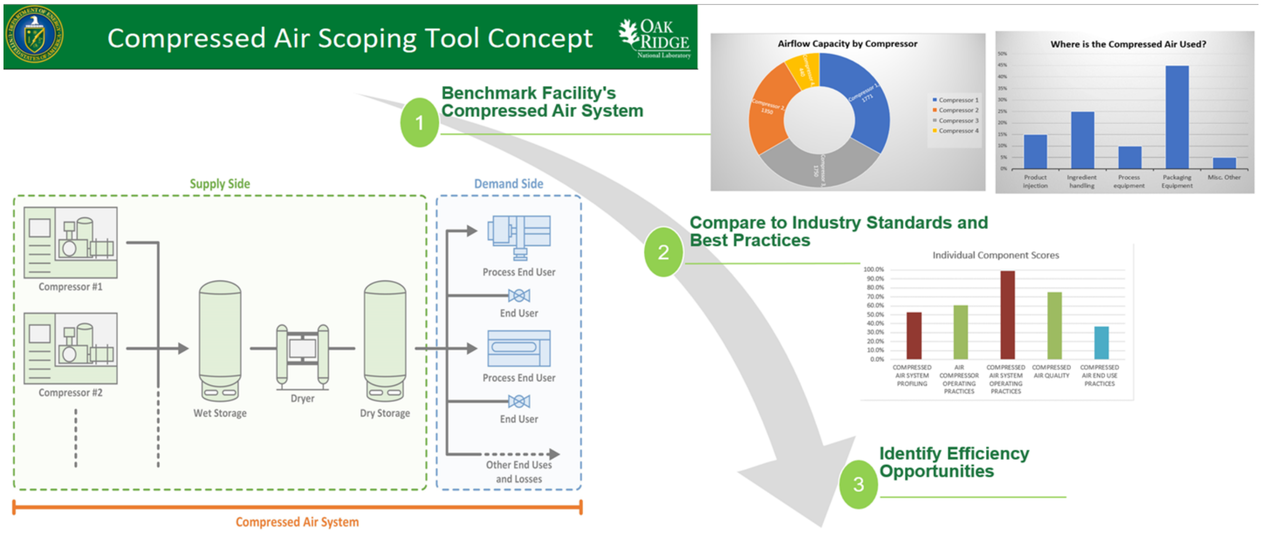

Figure 4. Compressed Air Scoping Tool Concept.

3.1 Benchmarking the System

The first step in the CA Scoping Tool is to benchmark the facility's compressed air system. The tool asks various compressed air system parameters and produces graphs based on the user's inputs. The questions are basic operational parameters the facility should know prior to considering best practice upgrades. This step is not used in producing the report card at the end of the tool but is an exercise in understanding the operation and cost of the system. Additionally, this step is critical if a company intends to compare two facilities within the company. The questions in this section include the system basics, such as the number and size of compressors in the facility, and gradually progress to more challenging questions such as the annual operating costs for the auxiliary equipment. These questions are the building blocks to comprehend the size, capability, and cost of the system.

3.2 Compare Facility with Industry Standards and Best Practices

The second step in the CA Scoping Tool is to compare the facility's operational characteristics with industry-accepted standards and best practices, which can be found in tabs 3 through 7. These 97 questions comprise best practices that are widely accepted in academia and the compressed air auditing industry and have been reviewed by members of both communities. The questions range from rules of thumb to International Organization for Standardization (ISO) standards for compressed air systems.

Compressed air systems are typically divided into two halves: the demand side and the supply side (Figure 5). The demand side encompasses equipment or end uses such as leaks, tools, and pneumatic machinery, whereas the supply side comprises receiver tanks, compressors, dryers, and supporting auxiliary equipment. The CA Scoping Tool approaches the comparison in a similar manner, dividing questions into three groupings: supply side, demand side, and then a system-wide focus.

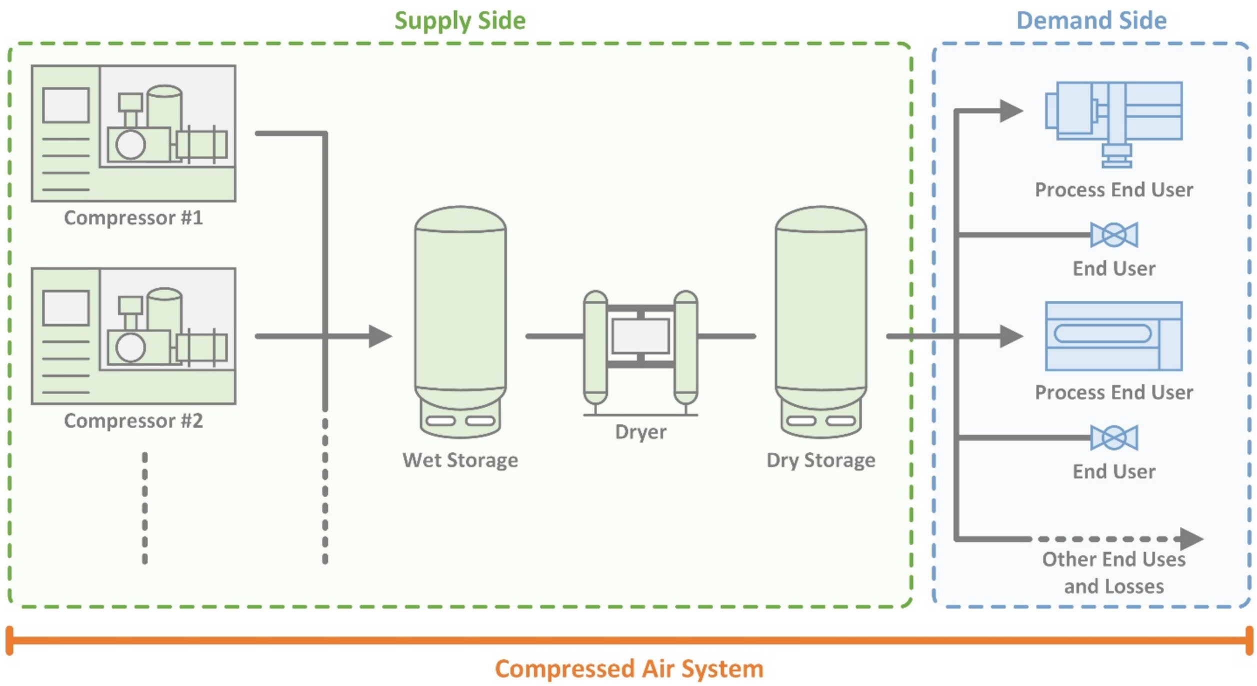

Figure 5. A Typical Compressed Air System in Manufacturing Plants.

Within the tool, tabs 2 through 4 include the system-wide questions and pertain to aspects that that affect the entire compressed air system. The best practice questions cover system profiling, system measurements, compressed air costs, heat recovery, etc. System-wide questions focus on system practices, pressure control, leak management, etc. Tabs 5 and 6 concentrate on the supply side of the compressed air system, focusing on compressor practices including compressor efficiency and overall performance as well as air quality aspects like particulate content and moisture content. Finally, tab 7 focuses on the system's end users, encompassing issues such as inappropriate uses and artificial demand. Figure 6 summarizes categories for the questions and their respective parts of the compressed air system.

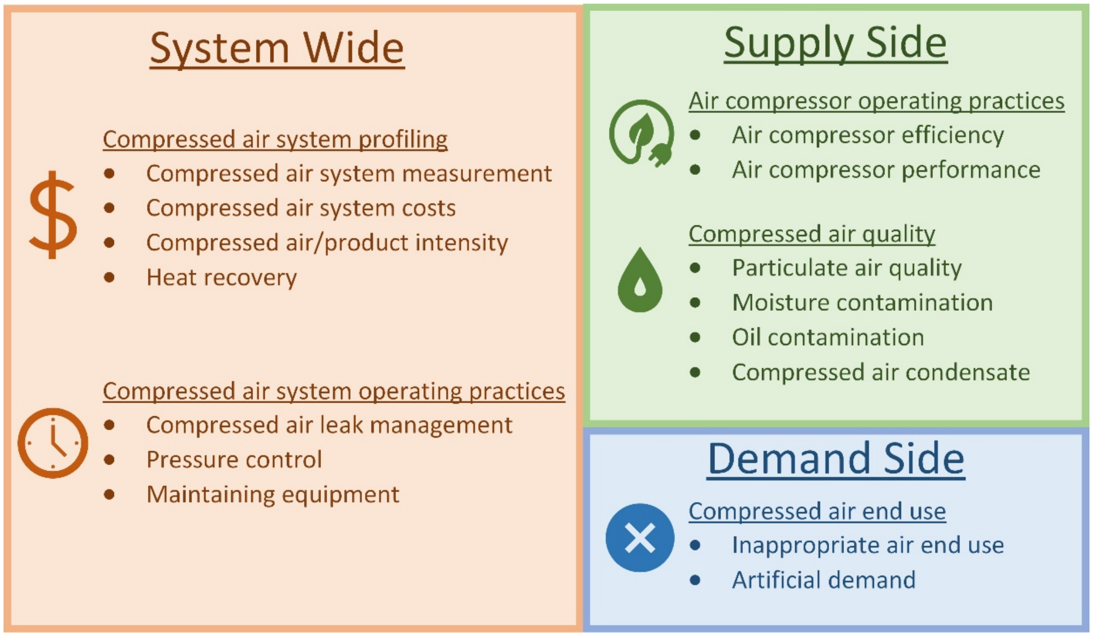

Figure 6. Groupings of Questions within the CA Tool.

3.3 Results and Identified Efficiency Opportunities

After completing the questionnaire, the user is prompted to move to tabs 8 and 9 for the results and identified opportunities. Tab 8, the results page, gathers the scores from the comparison step and summarizes the results. This tab displays each topic, the user's score, and the maximum possible score for each question. At the bottom of the page, the scores are summarized and graded based on the total possible score, providing a percentage. Finally, the results are displayed in a bar chart to reflect the grade from each tab. Once the facility receives its report card, the next tab shows the possible energy-savings opportunities based on the user's scores. These opportunities are directly linked to the answers given in the comparison steps of the tool and should be seen as steppingstones to start investigating plausible recommendations for the facility. A full list of possible recommendations can be found in the appendix.

3.4 Benefits to the Manufacturing Industry

In recent years, compressed air systems have moved the forefront of the energy efficiency efforts within the manufacturing sector. Major manufacturers and large companies are even hiring their own in-house compressed air experts who can travel from site to site. Other facilities, however, are left to their own devices to learn best practices for their systems. Whether the user is a large company with multiple facilities or a smaller manufacturer trying to wade through the sea of best practices, this CA Scoping Tool can serve as a steppingstone to understanding the strengths and weaknesses of their compressed air systems. For multifacility companies, the CA Scoping Tool can be used to compare operations across several facilities and their respective compressed air systems. This comparison may help identify facilities that require additional attention or those with exemplary practices that should be replicated throughout the company.

4. Implementation of the Compressed Air Scoping Tool

4.1 Case Study

Through DOE's BP program, manufacturing companies (partners) establish specific energy reduction goals over a defined period, typically aiming for a 25% energy intensity reduction over 10 years. As part of the testing of the CA Scoping Tool, a food manufacturer in the BP program was asked to review and use the tool. The partner used the tool at one of their sites and based on the tool's results generated a list of recommendations to improve their compressed air system. The following sections provide an overview of their experience and usage of the tool.

Plant Information

The partner began by entering data on the plant information tab. This prompted them to examine the basics of their compressed air system operations. This involved physically accessing the compressor room, gathering data, and performing basic calculations about the system. The system comprised four compressors: two 400 hp, one 300 hp, and one 100 hp compressor, for a total system rated power of 1,200 hp. Through discussions with plant personnel, the partner discovered that the operating times for each compressor differed slightly and that none of them ran 24/7 for the whole year. Finally, using the nameplate values, the partner defined the total potential airflow for the compressors. A summary of the compressors is shown in Table 2, and Figure 7 reflects the proportional rated flows for the compressors in the system.

Table 2. Summary of Plant's Compressed Air System

Compressor Name	Rated Power (hp)	Annual Operating Hours (Hrs/year)	Rated Flow Capacity (acfm)
Compressor A	400	6,000	1,771
Compressor B	300	3,744	1,350
Compressor C	400	8,400	1,750
Compressor D	100	6,000	460
System Total	**1,200**	**—**	**5,331**

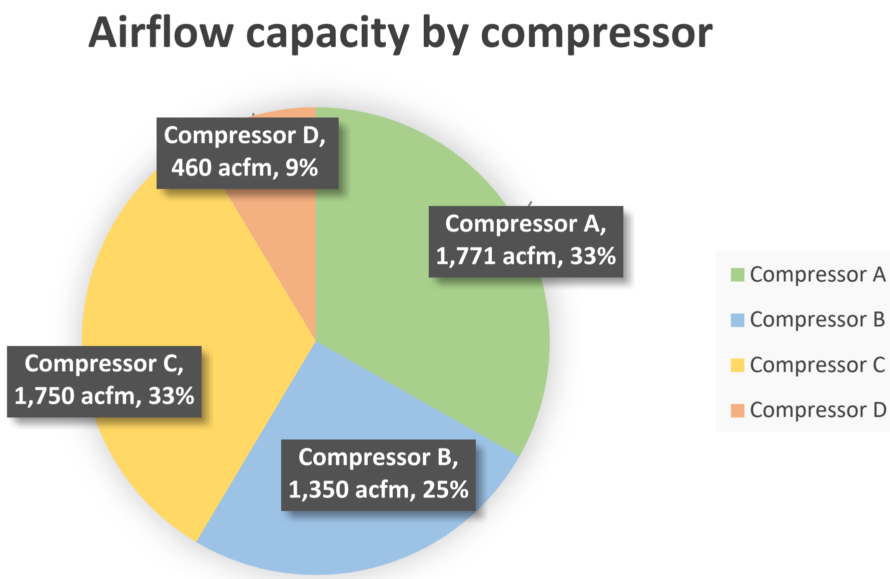

Figure 7. Summary of Airflow Capacity by Compressor.

In the next section, the partner reported an annual electrical consumption of 4,454,218 kWh/year to operate the system, with no cooling water consumed and no compressed air purchased off-site. After reviewing air production data, the partner reported an average air production of 1,720 acfm during production hours, with a peak air demand of 2,315 acfm and with a pressure set point of 104 psig. Based on results from the plant information tab using a marginal cost of $0.04/kWh, the facility found that the estimated cost of the compressed air system was $338,168/year, roughly equivalent to $0.343/100 cubic feet of compressed air.

System Profiler

After completing the plant information tab, the partner proceeded to complete the graded portion, the questionnaire. The graded portion starts with tab 3 and 4, the system-wide questions. The partner answered the 24 questions (14 topics) on tab 3 relating to the system profile, including questions regarding measurement practices, compressed air–related costs, compressed air intensity, and heat recovery. Of the possible 268 points for the section, the partner scored 102 points, a 28% score; this was the partner's lowest-scoring section. The results of the section are shown in Table 3.

Table 3. Summary of the Partner's Score for the System Profile Section

Scoping Tool Questions	Possible score	Plant score
3. Compressed Air System Profiling		
Compressed Air System Measurements		
MS1: Measure and record critical compressed air system parameters	78	52
MS2: Supply-side compressed air measurement intensity	20	15
MS3: Demand-side compressed air measurement intensity	30	10
Compressed Air System Costs		
CAC1: Review volume of compressed air generated	15	5

CAC2: Review frequency of electricity cost to generate compressed air	15	5
CAC3: Review cooling water costs to generate compressed air	15	0
CAC4: Review maintenance costs to generate compressed air	15	0
CAC5: Review capital costs and depreciated value of compressed air system	10	0
CAC6: Review fully loaded compressed air costs	15	5
CAC7: Usage of fully loaded cost data to make improvement decisions	10	0
Compressed Air/Product Intensity (Compressed Air/Product Volume)		
CAI1: Measure compressed air/product volume	15	0
CAI2: Usage of compressed air/product volume to make improvement decisions	10	10
Heat Recovery		
HR2: Heat recovered for room conditioning (air cooled)	10	0
HR2: Heat recovered for process hot water (water cooled)	10	0
Compressed Air System Profiling Score	**268**	**102**

System Practices

The partner then addressed the system practices in tab 4. The system practices section of the questionnaire focuses on leak management, pressure controls, and maintaining effective compressed air system operations. After answering the 25 questions (14 topics) in this section, the partner scored 108 points of the possible 253 points for a grade of 42%. The results of the section are shown in Table 4.

Table 4. Summary of the Partner's Score for the System Practices Section

Scoping Tool Questions	Possible Score	Plant Score
4. Compressed Air System Operating Practices		
Compressed Air Leak Management		
LK1: Leak rate baselining	10	0
LK2: Leak detection and repair program effectiveness	38	0
Pressure Control		
PS1: Pressure measurement locations	60	30
PS2: Pressure drop across the compressed air system	10	10
PS3: Pressure fluctuations at main header	10	8
PS4: Pressure drop across dryer	10	0
PS5: Pressure control methods	35	35
PS6: Compressed air storage	10	5
Maintaining Compressed Air Equipment		
MN1: Adherence to recommended maintenance tasks and schedule	15	5
MN2: Equipment service provider	15	15
MN3: Timely follow-up on equipment issues	10	0
MN4: Root cause analysis performed	10	0
MN5: Rental equipment installation potential	10	0
MN6: Air compressor/dryer redundancy for maintenance during production	10	0
Compressed Air System Operating Practices Score	**253**	**108**

Compressor Practices

In the supply-side portion of the tool, tabs 5 and 6, the tool focuses on specific compressor practices, including air compressor efficiency and air compressor performance. Tab 5 includes 17 questions (7 topics). The partner scored 44% on this section, receiving 73 of 165 points for their answers. A summary of the section points can be seen in Table 5.

Table 5. Summary of the Partner's Score for the Compressor Practices Section

Scoping Tool Questions	Possible Score	Plant Score
5. Air Compressor Operating Practices		
Air Compressor Efficiency		
CE1: Air compressor efficiency measurement frequency	20	0
CE2: Air compressor efficiency measurement data usage	40	0
Air Compressor Performance		
CP1: Air compressor performance parameters	50	35
CP2: Air compressor performance data usage	25	10
CP3: Unplanned downtime hours	10	8
CP4: Air compressor faults/stoppages	10	10
CP5: Air compressor high-temperature alarms	10	10
Air Compressor Operating Practices Score	**165**	**73**

Air Quality

The second section of supply-side questions, tab 6, focuses on the air quality. The questions in this tab concentrate on compressed air particulate content, compressed air moisture content, compressed air oil content, and compressed air condensate. The partner answered the 27 questions (17 topics) and received a 46% for the section, gaining 138 of the possible 295 points. A summary of the section is shown in Table 6.

Table 6. Summary of the Partner's Score for the Air Quality Section

Scoping Tool Questions	Possible Score	Plant Score
6. Compressed Air Quality		
Particulate Contamination		
PA1: Particulate size filtering	10	10
PA2: Compressed air particulate contamination sampling	10	10
PA3: Particulate filter checks	15	5
Water/Condensate/Moisture Contamination		
MO1: Dew-point measurement	20	15
MO2: Dew-point check frequency	15	15
MO3: Dew-point measurement usage	25	15
MO4: Methods of removing condensate from compressed air	15	15
MO5: Detection controls for water/condensate in compressed air discharge	25	15
MO6: Occurrence frequency of water/condensate in compressed air discharge	10	0
MO7: Prevention controls or water/condensate compressed air discharge	50	0

Oil Contamination		
OL1: Oil contamination level	15	15
OL2: Compressed air oil contamination sampling	10	5
OL3: Oil contamination measurement usage	30	0
OL4: Coalescing filter checks	15	0
Compressed Air Condensate		
CD1: Condensate removal management	10	5
CD2: Condensate drain locations	10	10
CD3: Condensate drain verification	10	3
Compressed Air Quality Score	**295**	**138**

End Users

The partner then completed the section for the demand side of the compressed air system, the end users—tab 7. The questions in this section focus mainly on inappropriate uses and artificial demand. The partner answered 14 questions and received 108 of 145 points, or 74%. This was the partner's highest-scoring section. A summary of the end-user scores can be seen in Table 7.

Table 7. Summary of the Partner's Score for the End-User Section

Scoping Tool Questions	Possible Score	Plant Score
7. Compressed Air End Use		
Inappropriate Uses		
IU1: Compressed air usage for vacuum venturis/generators	10	10
IU2: Compressed air usage for keeping instrumentation clean	10	0
IU3: Usage of zero-loss condensate drains	10	10
IU4: Compressed air usage for cooling electrical panels, motor, etc.	10	10
IU5: Compressed air usage for injection, sparging, agitation	10	10
IU6: Compressed air usage for personnel cooling	10	10
IU7: Amplifying air wand usage	10	10
IU8: Compressed air usage for product transport/transfer	10	10
IU9: Usage of compressed air diaphragm pumps	10	10
IU10: Compressed air usage for drying equipment after sanitation	10	10
IU11: Zero-loss condensate drains	10	0
Artificial Demand		
AD1: Pressure gauges installed on end-use equipment	10	10
AD2: Equipment target pressure check frequency	15	8
AD3: Equipment pressure adjustments for poor performance	10	0
Compressed Air End-Use Practices Score	**145**	**108**

Results

After completing the questionnaire portion of the tool, the partner's score was summarized in the results tab. Overall, the partner received a 47% scoring (529 of the available 1,126 points). The scores indicate room for improvement across the entire compressed air system, with the lowest score in the compressed air system profiling section. The results also showed the strongest aspect of their system is their end users. Table 8 and Figure 8 reflect the partner's score for each section. The partner intends to reassess this system at a later date and compare results after improvements are made. The partner would also like to compare similar facilities to gather and replicate best practices within their own company.

Table 8. Summary of Partner's Overall Score

	Possible Score	Plant Score	%
Compressed air system profiling	268	102	38.1%
Air compressor operating practices	253	108	42.7%
Compressed air system operating practices	165	73	44.2%
Compressed air quality	295	138	46.8%
Compressed air end-use practices	145	108	74.5%
Total scoping tool questionnaire score	**1,126**	**529**	**47.0%**

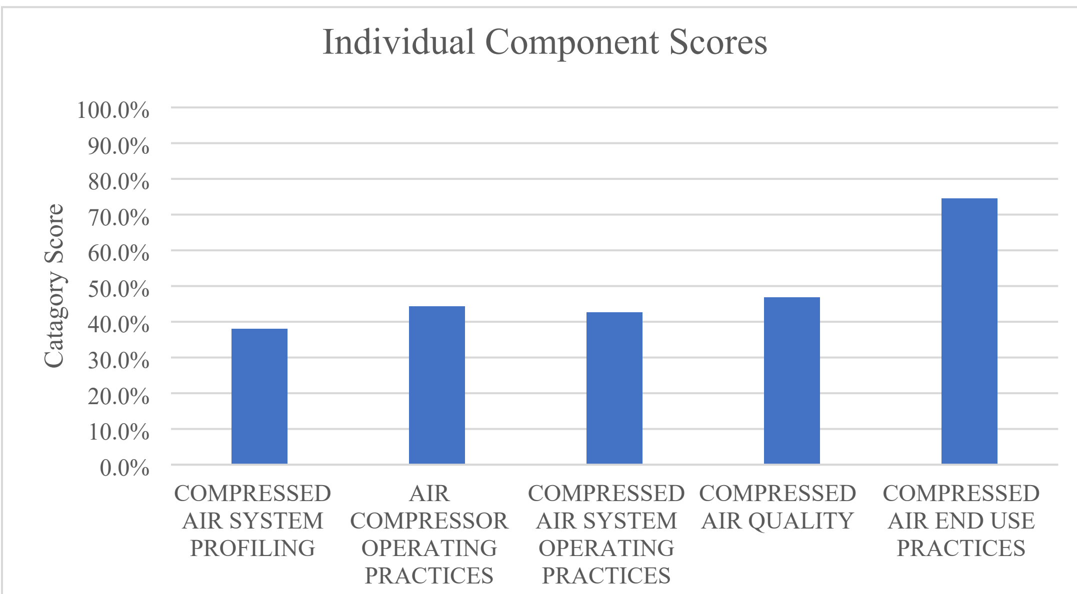

Figure 8. Summary of Compressed Air Scoping Tool Results.

Energy-Saving Opportunities

Based on the partner's answers, the CA Scoping Tool curated a list of 44 possible recommendations that should be further investigated. A full list of the partner's recommendations can be found in the appendix. For their lowest-scoring section, compressed air system profiling, the possible energy-saving opportunities are as follows:

- **Compressed Air System Profiling**
    - Compressed air system measurements

1. Improve data measuring, recording, and trending for critical compressed air system parameters.
2. Improve metering for supply-side compressed airflows.
3. Increase metering for demand-side compressed airflows.

- Compressed air system costs

1. Increase the frequency the volume of compressed air is calculated and reviewed.
2. Increase the frequency the electricity cost for the air compressors and dryers is calculated and reviewed.
3. Increase the frequency the cost to generate and provide cooling water to the compressed air system is calculated and reviewed.
4. Increase the frequency the maintenance costs (parts, labor, outside services) for the compressed air system are tracked and reviewed.
5. Increase the frequency the capital costs and the depreciated value of the compressed air system are tracked and reviewed.
6. Increase the frequency the fully loaded cost to generate compressed air is calculated and reviewed.
7. Use the fully loaded cost data to determine where to make improvements to the compressed air system.

- Compressed air/product intensity (compressed air divided by product volume)

1. Increase the frequency the air intensity (compressed air divided by product volume) is measured and trended in terms of cubic feet of compressed air needed per unit of product produced.

- Heat recovery

1. Recover heat for room conditioning.
2. Recover heat for hot process water.

5. Discussion

The CA Scoping Tool is a first step in analyzing and understanding a compressed air system. Once they complete the questions, users should gain a better understanding of their systems and possible recommendations that will save energy and money. The tool serves as a training instrument, guiding a workforce in the comprehension of their system's operational practices. It is designed to identify the areas in need of improvement but can also be used to identify best practices to be replicated. Results should be used to brainstorm feasible improvements or indicate when an external expert should be consulted. After the analysis is complete and the system is improved, a user should revisit the tool periodically to conduct a comparison to their baseline and continue the improvement cycle.

5.1 Opportunities for Future Work

The current version of the tool is an Excel-based spreadsheet, and though this does have its benefits, it has also proven to be an opportunity for improvement. The development team is actively receiving user reports, comments, and feedback to further enhance and refine the tool. As part of DOE's BP program, the CA Scoping Tool will be utilized during compressed air in-plant trainings to analyze additional real-world cases and gather user feedback. Ultimately, the tool will become part of DOE's MEASUR tool suite. MEASUR currently comprises a collection of enhanced software tools designed to assist manufacturing facilities in analyzing the energy efficiency of their systems and equipment, including compressed air, pumps, fans, steam, and process heating. The integration into MEASUR will provide the CA Scoping Tool a wider audience, a more cohesive operating format that matches existing DOE tools, and a more seamless and usable user interface.

The Beta version of the tool and sample data can be found on DOE's Industrial Efficiency & Decarbonization Office's resources website for the CA Scoping Tool. [14]

Funding Statement
This work was supported by the US Department of Energy's Better Plants Program.

Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions
Alex Botts – Tool creation, conception, writing, review; Leslie Marshall – Tool creation, Review, Case Study Recruitment; Frank Moskowitz – Tool Review, Tool testing, paper review; Sachin Nimbalkar – Case study recruitment, drafting, and review; Thomas Wenning – Case study recruitment, funding, review, guidance, and project management.

Acknowledgment
The authors acknowledge the support from the US Department of Energy's Better Plants program in recruiting a case study partner facility.

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Author Biographies

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Leslie Marshall is a national accounts sales manager at Atlas Copco Compressors. She has nearly 30 years of manufacturing experience in various industries primarily with food processing. She has optimized compressed air systems and other industrial utilities over the past 8 years saving companies millions of dollars. She holds a Bachelor's degree from Cornell University.

Frank Moskowitz has been an associate of Draw Professional Services for the last 25 years providing auditing, consulting, and training. He has over 45 years' experience of in-plant engineering. He has a degree in mechanical engineering from Stony Brook University. He is the primary compressed air challenge instructor and certified CAGI compressed air specialist. He is Vice-Chair for ASME Standard EA-4-2010; and is a member of International Standards Organization (ISO) technical committee for Air Compressors and compressed air systems energy management.

Dr. Sachin Nimbalkar is the group leader of Oak Ridge National Laboratory's Manufacturing Energy Efficiency Research and Analysis Group. He is a technical account manager for the U.S. DOE's Better Plants Program. Dr. Nimbalkar has more than 15 years of experience in process heating systems and energy efficiency research. He received his PhD and master's degrees in mechanical engineering from Rutgers University.

Thomas Wenning is a program manager at the U.S. DOE's Oak Ridge National Laboratory. He supports the DOE's Better Plants and Better Climate Challenge programs, providing industrial sites with technical assistance activities, energy assessments, and energy management guidance. He also leads the DOE's technical assistance software tools efforts. He completed his Bachelor's and Master of Science degrees in mechanical engineering from the University of Dayton.

Appendix

List of all possible recommendations

- **Compressed Air System Profiling**
  - Compressed air system measurements
    1. Improve data measuring, recording, and trending for critical compressed air system parameters.
    2. Improve metering for supply-side compressed airflows.
    3. Increase metering for demand-side compressed airflows.
  - Compressed air system costs
    1. Increase the frequency the volume of compressed air is calculated and reviewed.
    2. Increase the frequency the electricity cost for the air compressors and dryers is calculated and reviewed.
    3. Increase the frequency the cost to generate and provide cooling water to the compressed air system is calculated and reviewed.
    4. Increase the frequency the maintenance costs (parts, labor, outside services) for the compressed air system are tracked and reviewed.
    5. Increase the frequency the capital costs and the depreciated value of the compressed air system are tracked and reviewed.
    6. Increase the frequency the fully loaded cost to generate compressed air is calculated and reviewed.
    7. Use the fully loaded cost data to determine where to make improvements to the compressed air system.
  - Compressed air/product intensity (compressed air divided by product volume)
    1. Increase the frequency the air intensity (compressed air divided by product volume) is measured and trended in terms of cubic feet of compressed air needed per unit of product produced.
    2. Use the compressed air/product intensity data to determine where to focus on cost reductions and make improvements to the compressed air system.
  - Heat recovery
    1. Recover heat for room conditioning.
    2. Recover heat for hot process water.
- **Compressed Air System Operating Practices**
  - Compressed air leak management
    1. Reduce the compressed air leak rate.
    2. Improve the procedure for the leak detection/repair maintenance program.
  - Pressure control
    1. Improve pressure measuring at key locations throughout the compressed air system.
    2. Reduce the pressure drop from the dryer discharge to the end of the compressed air system.
    3. Reduce pressure fluctuations at the main header.
    4. Improve the pressure drop across the dryer.
    5. Implement best practices to reduce pressure fluctuations.
    6. Increase the compressed air storage.
  - Maintaining compressed air equipment

1. Improve the completion rate of original equipment manufacturer (OEM)–recommended (per equipment manual) maintenance checks on all compressed air system equipment and components.
2. Reevaluate who conducts major service and rebuilds on air compressors and dryers.
3. Follow up on corrective actions after OEM service within 1 week of discovery.
4. Regularly conduct root cause failure analysis on compressed air system equipment and components.
5. Install electrical connections and compressed air tie-ins to have the ability to install a temporary rental air compressor to the system.
6. Improve system capacity (number of compressors) to be able to conduct maintenance on air compressors/dryers during production uptime without affecting operations.

- **Air Compressor Operating Practices**
  - Air compressor efficiency
    1. Increase the frequency the individual compressor efficiency (scfm/1,000 kW) is measured.
    2. Use compressor efficiency data to make decisions about compressor procedures.
  - Air compressor performance
    1. Measure more compressed air parameters for better performance indication.
    2. Use compressor performance data to make informed decisions about the system.
    3. Reduce unplanned downtime hours on the air compressors.
    4. Reduce faults that cause air compressor shutdown.
    5. Reduce the frequency of high-temperature alarms on the air compressors.
- **Compressed Air Quality**
  - Particulate contamination
    1. Be aware of what size particulate is filtered.
    2. Improve the particulate contamination check procedure.
    3. Improve the particulate filter check procedure.
  - Water/condensate/moisture contamination
    1. Improve dryer dew-point controls.
    2. Improve the dryer dew-point check procedure.
    3. Include dew-point readings in system analysis.
    4. Improve the condensate removal process.
    5. Improve condensate detection in the system.
    6. Reduce condensate presences in the system.
    7. Improve controls that are in place to prevent water/condensate from getting into compressed air.
  - Oil contamination
    1. Improve the oil contamination checking procedure.
    2. Include the use of oil contamination data for maintenance purposes.
    3. Improve the coalescing filter element maintenance process.
  - Compressed air condensate
    1. Improve the condensate management program.
    2. Install condensate drains at key locations in the system.
    3. Increase the frequency at which condensate drains are verified for proper function.
- **Compressed Air End Use**

- Inappropriate uses
    1. Remove compressed air venturis in vacuum packaging.
    2. Eliminate the use of compressed air to keep instrumentation (infrared, level probes, etc.) from getting dusty.
    3. Consider adding drains on timers (on compressors, dryers, or headers).
    4. Eliminate the use of compressed air to cool electrical panels or equipment prone to overheating (e.g., motors).
    5. Eliminate the use of compressed air injection into tanks, vessels, vats, or baths to agitate ingredients or liquid or for sparging application.
    6. Eliminate the use of compressed air to provide personnel cooling.
    7. Use amplifying compressed air wands where applicable.
    8. Eliminate the use of compressed air to move product or to prevent it from sticking, accumulating, etc.
    9. Eliminate the use of pneumatic diaphragm pumps.
    10. Eliminate the use of compressed air for drying belts/equipment after sanitation.
    11. Use zero-loss condensate drains when possible.
- Artificial demand
    1. Install pressure regulators and gauges on the inlet compressed air lines of production equipment.
    2. Increase the frequency the set pressure of production equipment is checked against its designed target pressure.
    3. Eliminate adjusting the set pressure of production equipment to compensate for performance issues as a standard practice.

<u>Partner's list of recommendations</u>

Based on the partner's answers in the CA Scoping Tool, a list of 44 possible recommendations was created. The full list of recommendation for the partner is as follows:

- **Compressed Air System Profiling**
    - Compressed air system measurements
        1. Improve data measuring, recording, and trending for critical compressed air system parameters.
        2. Improve metering for supply-side compressed airflows.
        3. Increase metering for demand-side compressed airflows.
    - Compressed air system costs
        1. Increase the frequency the volume of compressed air is calculated and reviewed.
        2. Increase the frequency the electricity cost for the air compressors and dryers is calculated and reviewed.
        3. Increase the frequency the cost to generate and provide cooling water to the compressed air system is calculated and reviewed.
        4. Increase the frequency the maintenance costs (parts, labor, outside services) for the compressed air system are tracked and reviewed.
        5. Increase the frequency the capital costs and the depreciated value of the compressed air system are tracked and reviewed.
        6. Increase the frequency the fully loaded cost to generate compressed air is calculated and reviewed.

7. Use the fully loaded cost data to determine where to make improvements to the compressed air system.
- Compressed air/product intensity (compressed air divided by product volume)
  1. Increase the frequency the air intensity (compressed air divided by product volume) is measured and trended in terms of cubic feet of compressed air needed per unit of product produced.
- Heat recovery
  1. Recover heat for room conditioning.
  2. Recover heat for hot process water.

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  - Compressed air leak management
    1. Reduce the compressed air leak rate.
    2. Improve the procedure for the leak detection/repair maintenance program.
  - Pressure control
    1. Improve pressure measuring at key locations throughout the compressed air system.
    2. Reduce pressure fluctuations at the main header.
    3. Improve the pressure drop across the dryer.
    4. Increase the compressed air storage.
  - Maintaining compressed air equipment
    1. Improve the completion rate of OEM-recommended (per equipment manual) maintenance checks on all compressed air system equipment and components.
    2. Follow up on corrective actions after OEM service within 1 week of discovery.
    3. Regularly conduct root cause failure analysis on compressed air system equipment and components.
    4. Install electrical connections and compressed air tie-ins to have the ability to install a temporary rental air compressor to the system.
    5. Improve system capacity (number of compressors) to be able to conduct maintenance on air compressors/dryers during production uptime without affecting operations.
- **Air Compressor Operating Practices**
  - Air compressor efficiency
    1. Increase the frequency individual compressor efficiency (scfm/1,000 kW) is measured.
    2. Use compressor efficiency data to make decisions about compressor procedures.
  - Air compressor performance
    1. Measure more compressed air parameters for better performance indication.
    2. Use compressor performance data to make informed decisions about the system.
    3. Reduce unplanned downtime hours on the air compressors.
- **Compressed Air Quality**
  - Particulate contamination
    1. Improve the particulate filter check procedure.
  - Water/condensate/moisture contamination
    1. Improve dryer dew-point controls.
    2. Include dew-point readings in system analysis.
    3. Improve condensate detection in the system.

4. Reduce condensate presences in the system.
5. Improve controls that are in place to prevent water/condensate from getting into compressed air.

- Oil contamination

1. Improve the oil contamination checking procedure.
2. Include the use of oil contamination data for maintenance purposes.
3. Improve the coalescing filter element maintenance process.

- Compressed air condensate

1. Improve the condensate management program.
2. Increase the frequency at which condensate drains are verified for proper function.

- **Compressed Air End Use**

  - Inappropriate uses

    1. Eliminate the use of compressed air to keep instrumentation (i.e., level probes, etc.) from getting dusty.
    2. Use zero-loss condensate drains when possible.

  - Artificial demand

    1. Increase the frequency the set pressure of production equipment is checked against its designed target pressure.
    2. Eliminate adjusting the set pressure of production equipment to compensate for performance issues as a standard practice.