CEE Industrial Compressed Air Systems Initiative

For information, contact:
Walker Larsen
Industrial Program Manager
Motors and Motor Systems Committee
wlarsen@cee1.org
617-337-9273
Consortium for Energy Efficiency
98 North Washington Street, Suite 101
Boston, MA 02114

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1 Introduction
Compressed air systems represent a major energy end use in the commercial and industrial sectors of the United States and Canada, consuming 91.56 TWh of electricity in the United States annually and representing 16.5 percent of motor-driven systems energy use in US manufacturing facilities. At the same time, the savings potential in compressed air systems is significant. According to a 2010 United Nations Industrial Development Organization (UNIDO) report, Motor Systems Efficiency Supply Curves, over 41,000 GWh of annual cost-effective energy savings exist in the United States and Canada, representing four percent of total annual industrial energy consumption in the United States and three percent of total annual industrial electricity consumption in Canada. Overall technical savings potential is more than 58,000 GWh in North America.

However, it is hard to achieve these savings because compressed air systems are complex, and generally no two systems are the same. As a result, energy savings opportunities are generally identified through compressed air system audits. These audits are performed by third-party vendors with varying levels of expertise and accreditation, resulting in inconsistent data collection, which in turn makes it difficult for program administrators and their customers to consistently identify all cost-effective energy saving opportunities in a given compressed air system.

In fact, Consortium for Energy Efficiency (CEE) analysis indicates that 43 percent of potential system savings are left unaddressed when compressed air system audits focus on the supply side of the system and ignore energy saving opportunities on the demand side. This Initiative addresses this problem by:

- Defining minimum data collection and reporting requirements for compressed air system audits
- Specifying that the supply and demand sides of the system be consistently assessed to allow customers and program administrators to identify and address all available energy efficiency opportunities.

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This Initiative helps customers and program administrators capture more compressed air system savings in two ways:

1. The Initiative’s accompanying CEE Compressed Air Audit Specification defines minimum data collection and reporting standards for compressed air system audits, in support of holistic audits that assess energy saving opportunities on both the supply and demand sides of systems. This definition, broadly adopted in the market, will align program administrator and industry support for holistic audits, resulting in binationally consistent program measures and a pool of auditors trained to provide holistic system audits.

2. The Initiative strategy positions CEE to define “high efficiency” packaged air compressor product specifications that can contribute to supply side energy savings. As envisioned, the specifications would include communicating equipment features that could allow for automated energy tracking and reporting and other connected benefits.

The CEESM Industrial Compressed Air Systems Initiative provides program administrators with a set of tools for addressing complex system energy savings and a framework for exploring new equipment specification opportunities. The Initiative takes into account multiple program approaches related to industrial compressed air systems, including customer and trade ally education and training, customer audits and engineering studies, and custom projects.

2 Initiative Objectives
The energy efficiency program industry has never adopted a uniform approach for achieving compressed air savings because compressed air systems are complex and lack consistent characteristics and design. Through this Initiative, program administrators have acted together to share their collective needs and expectations for compressed air system audits.

The specific Initiative objectives are to:

- Increase the availability of holistic compressed air system audits of consistently high quality, as defined in the CEE audit specification
- Broaden the focus of compressed air system audits beyond the compressor and increase customer demand for compressed air system efficiency, including leak management, improved operations and management practices, and evaluation of demand reduction opportunities

One challenge is that customers are often hesitant to consider or proceed with compressed air system efficiency projects because compressed air is integral to their production processes and they cannot afford to shut down production to address energy efficiency. Industrial customers are especially hesitant to consider energy efficiency opportunities on the demand side of their systems. One of the goals of this Initiative is for participating program administrators to educate their customers on the importance of considering a system holistically and properly understanding a
system’s performance over time. This will help customers to understand the energy and cost saving benefits that can be gained through a holistic compressed air system audit and actions to address identified inefficiencies.

2.1 Vision
The vision of the Initiative is that by accomplishing the objectives listed above, program administrators will support market demand for holistic compressed air audits of consistent quality, which will lead to industry support for trained auditors and ultimately drive down the cost of holistic compressed air system audits. This cycle should lead to more facilities requesting holistic audits, which will identify both supply- and demand-side system energy savings opportunities and allow more program administrators to support energy efficiency measures that address these savings opportunities. This, in turn, will increase the amount of system energy savings addressed by energy efficiency projects. Compressed air system operators will realize greater system energy savings, program administrators will capture more savings, and the cost of these savings will decrease as the market grows.

2.2 Compressed Air System Efficiency Strategies
The Initiative objectives and vision will be accomplished through the following strategies.

**Strategy One:** Specify data to be collected and reported during compressed air system audits that are completed as part of program supported energy efficiency projects. In addition, recommend best practices for data collection.

Energy efficiency opportunities are typically identified during a compressed system audit. In today’s market, wide variation in compressed air audit quality and comprehensiveness is a barrier to more efficient and productive compressed air systems and to more effective compressed air efficiency programs. The Initiative will address this challenge by specifying minimum practices for compressed air system audits and aligning support from program administrators and the compressed air industry.

**Strategy Two:** Specify CEE energy performance tiers for packaged air compressor products covered by DOE regulation.

Additional compressed air system energy savings can be achieved by the use of more efficient air compressors on the supply side of the system. The US Department of Energy (DOE) is currently developing a packaged rotary compressor energy performance standard.\(^4\) Program administrators have traditionally not specified packaged compressors for their energy efficiency performance, other than recommending a variable speed compressor to serve as a trim compressor. The DOE rule may offer a credible basis for customers to choose high efficiency compressors

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and for manufacturers to differentiate their products by energy performance. This Initiative supports program administrator exploration of a binational energy performance specification for packaged air compressors, including specification of integrated communicating equipment features.

3 Initiative Scope

This Initiative addresses three-phase, electrically-driven compressed air systems with air compressors greater than 1 hp, full-load operating pressures between 36 and 225 psig, and pressure-increase ratios exceeding 1.3. It recognizes that facilities might have multiple compressed air systems, and that individual compressed air systems might have multiple air compressors. In addition to air compressors themselves, this Initiative addresses system operations and maintenance and most other system components, including air receivers, controllers, dryers, and other auxiliary equipment.

The Initiative does not include a scope limitation based on compressor horsepower, recognizing the wide range in compressor size for different industrial applications.

4 Technology Background

4.1 Technology Definitions

A compressed air system is comprised of integrated sets of components, including air compressors, treatment equipment, controls, piping, pneumatic tools, pneumatically powered machinery, and process applications using compressed air. Because of their many components and end uses, no two compressed air systems are identical. Some facilities have multiple compressed air systems.

4.1.1 Air Compressors

Many air compressors are sold “packaged,” including a compressor, motor, control, and other accessories mounted on a single frame. There are two basic types of electrically-driven air compressors: positive displacement and dynamic (see Figure 1). Packaged air compressors are currently rated by their Specific Power, or the power (kW) used to generate 100 cubic feet per minute (SCFM) of air.\footnote{The Compressed Air and Gas Institute (CAGI) has developed data sheets to enable standardized reporting for rotary compressors, rotary variable frequency drive compressors, centrifugal compressors, and refrigerated compressed air dryers. For more information on the CAGI data sheets, visit the CAGI website at \url{cagi.org/performance-verification/data-sheets.aspx}.}

Positive displacement rotary compressors dominate the marketplace in the 1-500 hp size range, with other technologies serving niche roles and fitting well above or at the bottom of this compressor size range. According to 2013 shipment data provided to DOE, rotary and reciprocating compressors appear to represent the bulk of the air compressor market by units shipped. Dynamic compressors, which are typically larger in horsepower than positive displacement compressors and commonly...
engineered specifically for a unique customer or application, represent approximately one percent of the market.

Figure 1. Types of Air Compressors

<table>
<thead>
<tr>
<th>COMPRESSOR TYPES</th>
<th>POSITIVE DISPLACEMENT</th>
<th>DYNAMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RECIPROCATING</td>
<td>ROTARY</td>
</tr>
<tr>
<td></td>
<td>SINGLE ACTING</td>
<td>LOBE</td>
</tr>
<tr>
<td></td>
<td>DIA-PHRAGM</td>
<td>SCREW</td>
</tr>
<tr>
<td></td>
<td>DOUBLE ACTING</td>
<td>SCROLL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LIQUID RING</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VANE</td>
</tr>
</tbody>
</table>

Positive Displacement Compressors: The most popular type of positive displacement compressor in the marketplace is the rotary compressor, described by DOE as the “workhorse” of industry, making up 70 percent of all compressor sales annually. These compressors are commonly used in sizes ranging from 30 to 200 hp. In 2010, approximately 15,000 rotary compressors were sold. These units have a typical lifetime of 10–15 years. Rotary screw compressors are produced in lubricant-

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6 Defined by ISO/TR 12942: Positive-displacement compressor is a compressor machine in which the admission and compression of successive volumes of the gaseous medium are performed periodically by forced expansion and diminution of at least one closed space in at least one working chamber by means of displacement of at least one moving member or by the displacement and forced discharge of the gaseous medium into the high-pressure area. International Standards Organization, ISO/TR 12942:2012 Compressors -- Classification -- Complementary information to ISO 5590. September 2012. https://www.iso.org/standard/44633.html.


injected and lubricant-free varieties, and some also include a variable speed drive (VSD) to serve as a trim compressor.

Reciprocating compressors are the most common compressor type sold today for single-digit and fractional hp applications.\textsuperscript{10} Unlike other compressor types, CAGI does not currently offer data sheets for reciprocating compressors.\textsuperscript{11} According to CAGI, reciprocating compressors have a relatively low duty cycle and a small average capacity, resulting in a significantly lower energy savings potential than rotary screw packaged compressors. Additionally, CAGI commented to DOE that the market for reciprocating compressors is highly fragmented, with many assemblers purchasing parts from a variety of suppliers.\textsuperscript{12}

\textbf{Dynamic Compressors:}\textsuperscript{13} Centrifugal compressors, the most common variety of dynamic compressors, are primarily used for larger horsepower, general plant air applications. Because centrifugal compressors are inefficient at partial loads (less than 70\%), they are typically used for large baseload applications where a large constant demand exists, and are paired with rotary machines to meet variable load on top of that base demand. Shipment data is not available for this technology, and only four CAGI member manufacturers currently produce them. Centrifugal compressors are primarily sold in sizes greater than 400 hp.

Axial compressors are much less common than centrifugal; they also serve a baseload role but are designed for applications that demand more range in pressure.

\section{5 Market Actors and Delivery Channels}
Compressed air products and services, including system audits, are mainly provided by compressed air manufacturers, associated distributor groups, and independent engineering consultants.

\subsection{5.1 Manufacturers}
Compressed air manufacturers produce compressor packages, which typically consist of an electric motor, controls, compressor, filter, lubricant and air coolers,

\textsuperscript{11} CAGI data sheets are standardized forms for reporting air compressor performance. They are intended to help customers select appropriate air compressors. Additional information is available at cagi.org/performance-verification/data-sheets.aspx.
\textsuperscript{13} Defined by ISO/TR 12942: A dynamic compressor is a compressor machine in which the gas pressure increase is achieved in continuous flow essentially by increasing its kinetic energy in the flow path of the machine due to acceleration to the high velocities by mechanical action of blades placed on a rapid rotating wheel and further transformation of the kinetic energy into the potential energy of the elevated pressure by successive deceleration of the said flow. International Standards Organization, ISO/TR 12942:2012 Compressors -- Classification -- Complementary information to ISO 5390. September 2012. https://www.iso.org/standard/44633.html.
and lubricant air separator. According to the DOE, more than one million compressors are sold in the United States each year. Of these, 98 percent are less than 5 hp and are used in commercial and residential applications such as portable tools, air pumps, and pneumatic heating.

Figure 2. Compressed Air System Marketplace

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Larger compressors, typically 25 hp or greater, account for only one percent of sales but 80 percent of the annual energy consumption of compressed air systems, approximately 27–32 TWh per year, equivalent to six percent of all motor-driven electricity consumption in the industrial sector.16

Air compressor manufacturers have significant influence on the marketplace for compressed air system audits. They often offer low- or no-cost audits to interested customers through their associated distributors, and they maintain audit processes tailored to their own equipment.

In addition to compressor manufacturers, auxiliary equipment manufacturers also produce compressed air system components like dryers, filters, air receivers, and pneumatic tools, as well as distribution system components.

5.2 Distributors
Compressed air distributors offer a variety of services to customers, including sales and service of compressed air systems, service contracts, and system audits. Some prevalent distributor associations include:

- Association of Independent Compressor Distributors (AICD): Quincy, BOGE America, Mattei, Sullivan Palatek, Parker Hannifin, Jorc, Hankison, and CAS
- Association of Ingersoll-Rand Distributors (AIRD)
- Atlas Copco Industrial Compressor Association (ACIDA)
- North American Association of Compressor Distributors (NAACD)—CompAir
- Industrial Compressor Distributors Association (ICDA)—Gardner Denver
- Sullair North American Distributor Council
- Compressor Distributors Association—several associations coordinate their activities for CAC through this group

According to a 1999 DOE assessment of 94 compressed air distributors in 36 states, efficiency services, such as leak detection and compressed air audits, account for only four percent of distributor revenue. Sales (59 percent) and service (19 percent) made up the bulk of distributor revenue for the assessed firms.

5.3 Independent Engineering Firms
A variety of firms and contractors independent of manufacturer or distributor associations provide compressed air system audits and design and specify compressed air systems. These firms and contractors generally make recommendations that are brand neutral.

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5.4 Industry Stakeholders

5.4.1 Compressed Air and Gas Institute

The Compressed Air and Gas Institute (CAGI) is a nonprofit organization of companies that manufacture air and gas compressors, pneumatic machinery, and air and gas drying equipment.

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>CAGI Member Compressor Manufacturer Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Companies</td>
<td>Rotary Positive</td>
</tr>
<tr>
<td>Atlas Copco Compressors, LLC</td>
<td>✓</td>
</tr>
<tr>
<td>BOGE America</td>
<td>✓</td>
</tr>
<tr>
<td>Cameron</td>
<td></td>
</tr>
<tr>
<td>Chicago Pneumatic Tool Co.</td>
<td>✓</td>
</tr>
<tr>
<td>DV Systems Inc.</td>
<td>✓</td>
</tr>
<tr>
<td>Elgi Compressors USA, Inc.</td>
<td>✓</td>
</tr>
<tr>
<td>FS Elliott Co., LLC</td>
<td></td>
</tr>
<tr>
<td>FS-Curtis</td>
<td>✓</td>
</tr>
<tr>
<td>Gardner Denver</td>
<td>✓</td>
</tr>
<tr>
<td>Ingersoll Rand</td>
<td>✓</td>
</tr>
<tr>
<td>Kaeser Compressors</td>
<td>✓</td>
</tr>
<tr>
<td>Mattei Compressors</td>
<td>✓</td>
</tr>
<tr>
<td>Quincy Compressor</td>
<td>✓</td>
</tr>
<tr>
<td>Saylor Beall Manufacturing Co.</td>
<td></td>
</tr>
<tr>
<td>Sullair Corporation</td>
<td>✓</td>
</tr>
<tr>
<td>Sullivan-Paltek, Inc.</td>
<td>✓</td>
</tr>
</tbody>
</table>

CAGI influences the marketplace for audits through its data sheets for compressors and dryers, which allow auditors and customers to compare the performance of different products. The CAGI data sheets are a standardized reporting form used by CAGI members to report compressor performance to customers and other end users. Additionally, CAGI partners with the Compressed Air Challenge to help educate customers and other stakeholders about compressed air system best practices.

5.4.2 Compressed Air Challenge

The Compressed Air Challenge (CAC) is a nonprofit corporation, organized by utilities, energy service companies, national and local government agencies, and compressed air industry stakeholders in 2000 to foster, encourage, and improve the efficient generation and use of compressed air. The mission of CAC is to develop and provide resources that educate industry on the opportunities to increase net profits through compressed air system optimization. CAC influences the

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17 Information in this section was adapted from the CAGI website, see http://www.cagi.org/about
18 The information in this section was adapted from the Compressed Air Challenge website, compressedairchallenge.org/.
marketplace for audits by providing educational materials for customers, utility program managers, and other industry stakeholders.

CAC produces the printed manual *Best Practices for Compressed Air Systems*, as well as other resources that are available on its website. Additionally, the CAC, in conjunction with partner utilities and the DOE, regularly holds training courses across the United States and Canada.¹⁹

5.4.3 United States Department of Energy (DOE)
The Department of Energy²⁰ Office of Energy Efficiency and Renewable Energy (EERE) accelerates development and facilitates deployment of energy efficiency and renewable energy technologies and market solutions that strengthen US energy security, environmental quality, and economic vitality. Within EERE, the DOE Advanced Manufacturing Office (AMO) has developed tools and research to support utilities and industrial end users in taking advantage of compressed air efficiency opportunities. Some of these resources are listed in Appendix A.

6 Current Market and Potential Energy Savings

6.1 Compressed Air: The Fourth Utility
Compressed air is commonly used in manufacturing plants. According to DOE,²¹ 70 percent of all manufacturing facilities have some sort of compressed air system; compressed air is such an important resource for industrial manufacturers that it is often referred to as the “fourth utility.” One binational study²² estimated in 1994 that there were roughly 369,000 compressed air systems in the United States and Canada, with 280,000 in the United States alone.

As stated earlier, UNIDO estimates that more than 58,000 GWh per year of technical compressed air system energy savings exist in the United States and Canada. The breakdown of available savings by measure type is shown in Table 2. Note that US savings estimates shown in Table 2 exclude systems larger than 1000 hp, which is why the Table 2 estimates add up to 35,901 GWh/year. When systems larger than 1000 hp are included, the cumulative US technical savings estimate increases to 51,033 GWh per year. When combined with the almost 7,500 GWh/year in Canadian technical energy savings it yields a total of over 58,000.

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¹⁹ Courses include Fundamentals of Compressed Air Systems, Advanced Management of Compressed Air Systems, and AIRMaet+ Qualified Specialist. For more information, see <compressedairchallenge.org/calendar/>.

²⁰ The information in this section was adapted from the US DOE EERE website, <energy.gov/eere/about-office-energy-efficiency-and-renewable-energy>.


Table 2. Estimated Compressed Air System Energy Savings

<table>
<thead>
<tr>
<th>Energy Efficiency Measure</th>
<th>Cumulative Energy Savings (GWh/y)</th>
<th>Energy Savings (GWh/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>Canada</td>
</tr>
<tr>
<td>Fix leaks, adjust compressor controls, establish ongoing plan</td>
<td>7,073</td>
<td>1,867</td>
</tr>
<tr>
<td>Initiate predictive maintenance program</td>
<td>9,037</td>
<td>2,386</td>
</tr>
<tr>
<td>Install sequencer</td>
<td>11,862</td>
<td>3,131</td>
</tr>
<tr>
<td>Improve end use efficiency, shut off idle equipment, engineered nozzles, etc.</td>
<td>14,353</td>
<td>3,789</td>
</tr>
<tr>
<td>Eliminate inappropriate compressed air uses</td>
<td>17,832</td>
<td>4,707</td>
</tr>
<tr>
<td>Address restrictive end use drops and connections, faulty FRLs</td>
<td>18,783</td>
<td>4,958</td>
</tr>
<tr>
<td>Eliminate artificial demand with pressure optimization, control, and storage</td>
<td>20,334</td>
<td>5,368</td>
</tr>
<tr>
<td>Replace existing condensate drains with zero loss type</td>
<td>20,958</td>
<td>5,532</td>
</tr>
<tr>
<td>Correct compressor intake problems and replace filter</td>
<td>21,161</td>
<td>5,586</td>
</tr>
<tr>
<td>Correct excessive pressure drops in main line distribution piping</td>
<td>21,755</td>
<td>5,743</td>
</tr>
<tr>
<td>Install dedicated storage with metered recovery</td>
<td>22,328</td>
<td>5,894</td>
</tr>
<tr>
<td>Reconfigure branch header piping to reduce critical pressure loss</td>
<td>22,881</td>
<td>6,040</td>
</tr>
<tr>
<td>Correct excessive supply side pressure drop, i.e. treatment equipment</td>
<td>23,415</td>
<td>6,181</td>
</tr>
<tr>
<td>Match air treatment to demand side needs</td>
<td>24,431</td>
<td>6,449</td>
</tr>
<tr>
<td>Improve trim compressor part load efficiency, i.e. variable speed drive</td>
<td>26,699</td>
<td>7,048</td>
</tr>
<tr>
<td>Size replacement compressor to meet demand</td>
<td>28,403</td>
<td>7,498</td>
</tr>
</tbody>
</table>

The energy savings opportunities listed in Table 2 are on both the supply and demand sides of the compressed air system. As described in Appendix C, CEE analysis of existing member compressed air audits indicates inconsistency in
assessing the demand side of the system. The UNIDO data shows there are substantial savings on the demand side of the system, demonstrating that if the demand side of the system is not audited, substantial energy savings may go unaddressed. If program administrators support consistent, holistic system audits, per the CEE Audit Specification, more technical compressed air system savings can be identified and addressed through program measures.

6.2 Current and Emerging Program Activity
Compressed air projects are a popular source of energy savings for CEE member programs. According to the CEE 2016 Motors and Motor Systems Program Summary\textsuperscript{23}, 34 programs offer some type of compressed air incentive, with even more offering support for custom projects. After variable frequency drive (VFD) measures, compressed air measures were the second most popular area of support among industrial motor-driven system programs.

As shown in the chart below, the most popular area of support is prescriptive incentives for VFD compressors. About half of the 34 members offer prescriptive incentives for cycling refrigerated dryers, zero-loss drains, engineered nozzles, air receivers, and low-pressure drop filters. The predominant emphasis of current program activity is on compressed air supply, rather than distribution or end use, with prescriptive equipment incentives for compressors less than 75 hp. Leak assessments, air receivers, and system audits are under supported in comparison. This indicates an opportunity for growth of holistic compressed air efficiency projects.

6.3 Compressed Air Audits

Program Administrators use audits to identify energy efficiency opportunities in compressed air systems, and to support applications for custom incentive projects. Programs do not generally conduct their own audits; they rely on trade allies, typically an air compressor manufacturer or distributor or an independent compressed air specialist.

CEE identified the following market barriers that prevent customers from getting the benefits of holistic audits.

- **Cost**: Audits, especially those provided by independent auditors, are a significant investment. This high cost limits adoption of holistic audits and encourages the market for low- or no-cost audits.

- **Culture**: Many companies are reluctant to consider changes to their production processes, or in some cases even to allow auditors to examine end uses, serving as a barrier to demand-side audits.

- **Supply**: There are not always enough qualified auditors available to meet program demand. Some independent auditors are known to work nationally or binationally due to this scarcity.

- **Inconsistent Support**: Program administrator requirements for compressed air system audits vary significantly, with many programs having no specific requirements.

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The inconsistent quality and comprehensiveness of compressed air audit practice, specifically the inability to consistently quantify and compare potential savings opportunities, prevents more effective compressed air efficiency programs. The CEE Compressed Air Audit Specification: Minimum Elements for Compressed Air System Audits (Audit Specification) has been developed to provide program administrators with a means to specify minimum audit practices for consistent energy saving results (see Appendix B).

This Initiative, and the CEE Audit Specification, support holistic evaluation of the energy performance of a compressed air system, with the goal of identifying energy efficiency and performance improvement opportunities. This is distinct from audits that focus only or primarily on the supply side of the system. In Figure 4, the supply side is represented by the dotted box labeled "Compressor Package Enclosure." Adding the demand side of the system, for a truly holistic audit, requires auditing both the compressor package enclosure and the rest of the system all the way to the end uses, represented as pneumatic tools in Figure 4.

CEE analysis found that inconsistent audit practices result in 43 percent of available system energy savings being left unaddressed. This analysis is elaborated in Appendix C. Specifying minimum data and reporting for compressed air system audits will help ensure all available energy savings opportunities are consistently identified, and binational guidance will encourage individual program administrators to address all cost-effective energy efficiency improvements.
Figure 4. Diagram of a Typical Industrial Compressed Air System

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7 Initiative Activities and Program Resources

The tools and resources provided by this Initiative are designed to support program administrator education and training programs, dedicated compressed air programs, custom programs, and whole facility programs. When working with commercial and industrial customers, program administrators should use the CEE Audit Specification as the basis for programs that support targeted compressed air system energy savings.

The CEE role in accomplishing these activities is to:

- Facilitate increased member understanding of the energy efficiency opportunities in commercial and industrial compressed air systems
- Promote the adoption of the Initiative into voluntary programs as the basis for compressed air system energy efficiency offerings
- Provide to members and industry stakeholders information on member program efforts via annual program summaries and analysis that capture voluntary program measures addressing commercial and industrial compressed air systems
- Work closely with manufacturers and industry associations to track industry and government efforts related to compressed air systems and products and provide regular updates to CEE members

7.1 CEE Compressed Air Audit Specification: Minimum Elements for Compressed Air System Audits

The CEE Audit Specification defines minimum data collection, analysis, and reporting practices for compressed air system audits to ensure that efficiency programs have the data required to assess potential savings measures on the supply and demand sides of the compressed air system. See Appendix B.

Strategic Purpose:

- Increase the consistency of the measurement and reporting of compressed air system baseline performance data in order to improve the accuracy and comparability of baseline data and enhance confidence in the results of audits
- Increase the prevalence of holistic audits of compressed air systems of all sizes, including consideration of both the supply and demand sides of each system, in order to enable more accurate assessments of energy efficiency opportunities and increase the energy savings opportunities for customers and programs alike
- Shape the marketplace for compressed air system audits to better meet customer and program needs
7.2 CEE Compressed Air Program Summary
The Compressed Air Program Summary will consist of an annual member data collection effort intended to provide a landscape view of program support for compressed air system efficiency and detailed information regarding program adoption and support of the CEE Audit Specification.

Strategic Purpose:
- Demonstrate to compressed air technology and service providers the collective resources of programs supporting the CEE Audit Specification
- Inform compressed air program design by providing members with detailed descriptions of compressed air activities, considerations, and results
- Demonstrate and track the market impact of the CEE Initiative over time

7.3 Annual Audit Survey and Analysis
The Initiative will use the CEE staff analysis of 23 compressed air system audits provided by members as a baseline for market adoption of holistic audits as a means to assess Initiative progress over time. Annually, CEE staff will collect representative compressed air system audits from participating members and analyze the data collected using the same methodology that was used to analyze the original 23 (see Appendix C).

Strategic Purpose:
- Develop a dataset of compressed air system audit practices
- Demonstrate market adoption and availability of holistic compressed air system audits over time

7.4 Specification for Packaged Compressors Exploration
CEE will explore a potential voluntary energy performance specification for packaged air compressors, leveraging a DOE rulemaking defining energy conservation standards for them. Programs typically have not specified air compressors based on their efficiency levels, but CEE will examine industry data and data from the DOE rulemaking for compressor standards and assess whether a voluntary specification would create cost-effective savings opportunities for programs based on the rulemaking.

Strategic Purpose:
- Enhance compressed air program savings with a potential specification for packaged air compressors
- Support air compressor product differentiation by energy performance and integrated communicating product features
8 Initiative Participation

Participation in the Compressed Air System Initiative is voluntary. To be considered an initiative participant, a member program must meet a minimum set of participation requirements. Initiative participants are required to:

1. Incorporate the CEE Audit Specification into program design by explicitly referring to it in customer and trade ally outreach and education, RFPs for contracted services, requirements to qualify for program incentives, or other materials that demonstrate program support for holistic compressed air system audits

2. Communicate the scope, duration, and key aspects of program measures when requested by CEE staff for an annual Program Summary, and allow the use of the organization’s name and program information for the purpose of achieving the initiative objectives

3. Annually provide CEE staff with representative audit reports to gauge market penetration of holistic audits.

8.1 Benefits of Participation

Reporting member use of the CEE Audit Specification, by way of a CEE Compressed Air Program Summary, will enable members to demonstrate program support to industry, including the auditor and auditor training communities. Their support of holistic audit practices will encourage more auditors to perform holistic audits to the quality level required by energy efficiency program administrators, which should drive down the cost of holistic audits, making them cost-effective for more customers and reducing the need for program administrator financial incentives.

In addition to broad market transformation, this Initiative serves as a technical resource to help program administrators maximize energy savings from compressed air system measures, whether deemed or custom.

Program administrator adherence to the CEE Audit Specification will help ensure consistency in audit services, making it easier for more program administrators to support compressed air system energy efficiency projects. The CEE Compressed Air Program Summary and Committee will provide peer-to-peer information exchange about compressed air energy efficiency measures, encouraging binationally consistent program offerings.

By working together at the binational level through CEE, Initiative participants will leverage their collective resources and market coverage to transform the market more quickly and effectively than they could by acting individually.
Appendix A References and Resources

The following is a list of resources that informed the development of this Initiative.

- Clair Hessmer PE, James Olmsted PE, & Samantha Meserve, ANTARES Ram K. Kondapi, CPE, CEA, National Grid, ACEEE 2015 Summer Study. Compressed Air System Energy Efficiency Upgrades Implemented vs. Underutilized Measures
Appendix B  CEE Compressed Air Audit Specification: Minimum Elements for Compressed Air System Audits

The CEE Compressed Air Audit Specification is a resource for CEE program administrator members who support compressed air system energy efficiency measures.
Appendix C The Current Marketplace for Audits

To better understand the current marketplace for compressed air audits, CEE staff worked with program administrators to assess a set of 23 off-the-shelf compressed air system audit reports to see how thorough the audit process was, how market performance compares with the CEE Audit Specification, and what potential exists for saving energy through adopting CEE Audit Levels.

The audit database was designed to include geographic and situational diversity to better represent the marketplace. The audits came from five CEE member programs in five different states or provinces BC Hydro (British Columbia), Energy Trust of Oregon (Oregon), Puget Sound Energy (Washington), Tennessee Valley Authority (Tennessee), and Xcel Energy (Minnesota). 11 of the audits were of compressed air systems with greater than 100 hp (operational), while 12 were of systems less than 100 hp (operational). The customers that received the audits represent a variety of industrial vertical sectors, including food processing (two customers), paper and timber (five), plastics (two), metalwork and aluminum (two), waste management and wastewater treatment (two), fabrication and assembly (four), and high tech (one). Utility program administrators funded 19 of the audits to some degree. Vendors played a significant role in the audits in this dataset; 15 of the audits were provided by a vendor or distributor, and the remaining eight were provided by an independent auditor or third-party program manager.

Some audit quality issues are apparent in the dataset:

- Only eight audits included a block diagram of the system in question
- Data collection practices are very inconsistent: only four audits included direct power measurement, eight included direct flow measurement, and 15 included a pressure profile
- Only 11 audits included an evaluation of end use requirements
- Eight audits did not include adequate baseline data or graphs, and five did not include transparent methodologies

The 23 audits were assessed using a checklist designed to allow a comparison with industry best practices and the audit behaviors included in the CEE Audit Levels. To understand the potential benefit of adopting the CEE Audit Levels, the recommended audit actions were paired with energy savings projections from the 2010 UNIDO Motor Systems Efficiency Supply Curves. UNIDO estimated potential savings opportunities as a percent improvement above a base case. Percentages refer to the percent reduction in efficiency losses associated with each ECO. For example,

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https://www.unido.org/fileadmin/user_media/Services/Energy_and_Clim..
"if 30% of the compressed air is lost to leaks and the leak rate is reduced to 10%, then that is a 20% improvement over the base case."²⁷ The table below includes the savings estimates for the US and Canadian base case to help weigh the significance of each energy conservation opportunity (ECO) identified here. In other words, the table lists the ECOs in order of savings potential, with the highest potential opportunities at the top. The UNIDO estimates provide energy efficiency program administrators with a potential guide for which ECOs to focus on to maximize cost-effective energy savings in compressed air systems.

Table 3 summarizes the frequency of evaluation of specific energy conservation opportunities in the 23 audits assessed by the CEE Motors and Motor Systems Committee. The ECOs included in the CEE Audit Levels are listed along with the percentage of audits in which each was evaluated. Shaded cells indicate that less than fifty percent of the audits evaluated that particular ECO.

Table 3. Frequency of Evaluation of Energy Conservation Opportunities in Audits Assessed by CEE

<table>
<thead>
<tr>
<th>Energy Conservation Opportunity</th>
<th>% eval overall (23 audits)</th>
<th>% eval in systems &lt;100 hp (12 audits)</th>
<th>% eval in systems &gt;100 hp (11 audits)</th>
<th>% improvement over UNIDO base case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement/VSD compressor to meet variable loads/demand more efficiently&lt;sup&gt;28&lt;/sup&gt;</td>
<td>74%</td>
<td>83%</td>
<td>64%</td>
<td>28%</td>
</tr>
<tr>
<td>Assess leak load and develop recommendation for regular leak detection and repair if necessary</td>
<td>65%</td>
<td>67%</td>
<td>64%</td>
<td>15%</td>
</tr>
<tr>
<td>Evaluate opportunities eliminate inappropriate uses of compressed air</td>
<td>43%</td>
<td>25%</td>
<td>64%</td>
<td>13%</td>
</tr>
<tr>
<td>Reduce the supply side target pressure by reducing pressure drops across the system</td>
<td>43%</td>
<td>33%</td>
<td>64%</td>
<td>13%</td>
</tr>
<tr>
<td>Evaluate existing compressor control strategy and compressor staging for optimization opportunities</td>
<td>91%</td>
<td>91%</td>
<td>100%</td>
<td>8%</td>
</tr>
<tr>
<td>Engineered nozzles to improve end use efficiency</td>
<td>13%</td>
<td>8%</td>
<td>18%</td>
<td>8%</td>
</tr>
<tr>
<td>Eliminate artificial demand with pressure optimization, control, or storage</td>
<td>42%</td>
<td>33%</td>
<td>55%</td>
<td>7%</td>
</tr>
<tr>
<td>Evaluate end uses’ air quality requirements for opportunities to reduce pressure loss</td>
<td>26%</td>
<td>17%</td>
<td>36%</td>
<td>6%</td>
</tr>
<tr>
<td>Include recommendations for improving system O&amp;M practices</td>
<td>57%</td>
<td>42%</td>
<td>73%</td>
<td>5%</td>
</tr>
<tr>
<td>Replace condensate drains with zero-loss type</td>
<td>52%</td>
<td>42%</td>
<td>64%</td>
<td>3%</td>
</tr>
<tr>
<td>Evaluate added storage to isolate intermittent high pressure/volume uses</td>
<td>39%</td>
<td>42%</td>
<td>36%</td>
<td>3%</td>
</tr>
<tr>
<td>Outside air intake</td>
<td>9%</td>
<td>0%</td>
<td>18%</td>
<td>1%</td>
</tr>
<tr>
<td>Dryers (e.g. cycling, VSD refrigerated, thermal mass)</td>
<td>65%</td>
<td>58%</td>
<td>73%</td>
<td>N/A</td>
</tr>
<tr>
<td>Low pressure drop filters</td>
<td>35%</td>
<td>25%</td>
<td>45%</td>
<td>N/A</td>
</tr>
<tr>
<td>Waste heat applications</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<sup>28</sup>This figure is the sum of two separate ECOs, 1) a replacement compressor to meet demand more efficiently and 2) a VSD compressor to serve variable loads more efficiently. The replacement of a compressor may provide only a portion of this savings percentage, depending on which ECOs are being met with a particular application. They are combined here because, in theory, both would be evaluated at the same time.
In addition to the quality issues identified, the 23 audits show a great degree of inconsistency in terms of which ECOs were evaluated in each audit, with a substantial portion of potential savings left “on the table.” Most of the audits considered opportunities in the compressor room, such as replacement compressors or control strategies, but a majority missed common opportunities outside the compressor room, such as evaluating artificial demand, inappropriate uses, pressure drops, or end use air quality requirements. Even leak detection and repair, one of the most cost-effective and impactful opportunities with a potential 15 percent improvement over base case, was missed in 35 percent of the 23 audits. Using the savings improvement projections in the UNIDO report, the audits analyzed left an average of 43 percent of potential savings on the table through not evaluating specific ECOs.

Separately, in 2015 National Grid coauthored a paper for the ACEEE Summer Study entitled “Compressed Air System Energy Efficiency Upgrades: Implemented vs. Underutilized Measures” that provides additional weight to the conclusions above. The authors examined 43 compressed air studies brought to National Grid in New York and found that:

- More than half (61 percent) of the studied systems had the opportunity to reduce losses due to leaks through a test or survey, but none elected to address leaks.
- While almost all updates (96 percent) included installing a new VSD compressor, roughly half (57 percent) installed new receivers and replaced dryers. While having an efficient compressor can reduce a system’s energy consumption, receivers with inadequate capacity and an inefficient dryer can neutralize any savings achieved in the compressor upgrade.
- Gross indifferences in identification and implementation rates of demand-side measures (e.g. leak remediation) contrast with the relative prevalence of supply-side measures (e.g. installation of VSD compressor), suggesting that demand-side measures are underused while capital measures are more readily adopted.

Overall, the audits represented in these datasets support the Committee’s observations, representing a marketplace that often concentrates on supply-side capital projects and ignores demand-side opportunities.

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