Compressed Air System Energy Efficiency Upgrades

Implemented vs. Underutilized Measures

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ABSTRACT

Since 2010, National Grid has been incentivizing customers in Upstate New York to become more energy efficient to fulfill mandated energy use reductions through the Energy Efficiency Portfolio Standard (EEPS). A significant portion of the customer applications in the industrial sector have been compressed air system capital equipment upgrades. For the most part these upgrades have focused on air compressor replacements with some effort to install additional receiver tank capacity and flow controllers, and improve desiccant dryer efficiency. The projects have been brought to National Grid for the most part by the trade ally network of air compressor vendors serving Upstate New York. This paper will provide the reader with the following key information:

- Results of 23 technical reviews[1] of compressed air system upgrades brought into the National Grid Custom Program through trade allies, as well as post inspection results for several larger applications with significant savings (> 500,000 kWh per year).
- Results of 18 scoping studies[2] at industrial facilities in the National Grid Upstate New York service territory that contained a cursory review of the facilities' compressed air systems for potential energy conservation measures.
- Opportunities that are and are not commonly pursued by facilities to optimize system performance based on a sample of technical reviews and scoping studies in Upstate New York.
- Opportunities for facilities to improve system performance and for National Grid to improve customer relations through higher incentives and lower energy bills.
- Conclusions and future steps to address missed opportunities.

Introduction

Compressed air systems are commonly used by many different industries for a variety of purposes, including pneumatic pumps and mixers, controls, process equipment, etc. To meet the needs of so many industries, a variety of compressor plant equipment is used. Compressors may be rotary screw, reciprocating, or centrifugal units with or without oil injection; dryers, if

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[1] In this study, a technical review consists of evaluating an application from a customer for project implementation co-funding through National Grid's Custom Incentive Program. The review is a third party evaluation of the customer's estimated savings for a project, typically provided by the compressed air equipment vendor. More information will be provided on the following page.

[2] A scoping study is a walkthrough energy assessment where the technical assistance contractor to National Grid spent part of a day identifying capital and O&M based energy conservation measures that could be eligible for custom or prescriptive incentives through National Grid. More information will be provided on the following page.

present, may be desiccant-based or refrigerated. Receivers vary in storage capacity and may be "wet" or "dry." With many different options and configurations, particularly in distribution piping, every compressed air system is different from the next. This variety results in many options for improving efficiency.

Some of the most common opportunities for compressed air systems include leak maintenance, replacing fixed speed compressors with variable speed compressors, adding additional receivers to increase storage capacity, reducing operating and discharge pressures, reconfiguring the system to eliminate unused equipment, and utilizing pressure and flow valves. (Such opportunities are discussed in more detail in the next section.) While not every system will have equal opportunity for improvement, it is likely that several of these options can result in increased efficiency and energy savings.

This paper will focus on the possible opportunities for compressed air improvements versus the opportunities actually implemented in the marketplace. The focus is based on two levels of technical analyses that were conducted at facilities eligible for incentives through National Grid's Custom Energy Efficiency Programs in Upstate New York, Massachusetts, and Rhode Island. These levels of analyses included:

1. **"Scoping" studies.** Through the Custom Program, industrial customers can receive high-level (similar to ASHRAE Level 1), facility-wide energy assessments. These studies are meant to help customers who have not yet selected or prioritized energy efficiency projects to pursue. The auditing engineer (not a customer or a vendor) identifies opportunities, and the scoping studies are performed across a broad range of industrial settings; accordingly, these studies are expected to be an unbiased, representative sample of the kinds of opportunities present in industrial compressed air systems. This paper considers scoping studies performed by 6 different engineering firms with no compressed air vendor affiliations.
2. **"Technical review" studies**. When a customer with a defined energy project applies for an incentive from National Grid, a third-party engineer is assigned to perform metering and data collection to establish the energy savings that are expected from the project. The efficiency measures considered in these studies were selected by the customer, often in consultation with a compressed air equipment vendor. These projects are at the implementation stage and accordingly are representative of the kinds of compressed air efficiency projects that are actually being completed.

The scoping studies and technical review studies were not performed for the same customers. (No site's compressed air system appears in both pools of data.) However, both pools are expected to be representative of typical industrial compressed air systems, and all sites share some degree of "energy-mindedness" in that they have engaged with National Grid to identify and/or implement efficiency projects.

By comparing the types of opportunities identified in the scoping studies (the potential projects) with the opportunities considered in the technical review studies (the projects actually implemented), it is possible to understand at a high level whether the most frequent opportunities are also the most frequently implemented projects – or if customers on average seem to be passing over beneficial efficiency projects. This suggests opportunities that could result in additional improvements if targeted by incentive programs.

Observed Industrial Compressed Air Systems

Compressed air systems are used throughout a wide cross section of industries. This study observed systems from many of these different industries including food and beverage processing, pharmaceutical manufacturing, electronics manufacturing, machining, textile processing, and many others. The projects considered in this review involved rotary screw compressor plants operating at medium pressures (90-125 psig), generally with dryers and without pressure/flow controllers. Forty-one (41) systems from the National Grid's service areas in Upstate New York and Massachusetts were considered. Of the observed systems, 18 were reviewed through scoping studies for possible opportunities for improvement, while the remaining 23 systems were reviewed through the technical review process to review savings and remaining opportunities for the compressed air system. Most of the observed systems ranged between 100 – 200 hp in total compressor capacity and had multiple compressors and receivers, but lacked sufficient storage. The compressors that were in use were often near the end of their useful lives and in some cases ineffective. There was also a lack of systems controls, specifically pressure/flow controllers, whose purpose is to match system supply with demand.

Potential Compressed Air Opportunities (Scoping Studies)

There are many opportunities that can improve the efficiency of a compressed air system, ranging from a simple leak detection and repair project to a capital based upgrade, such as installing a new variable speed drive compressor. In 18 scoping studies[3] to determine possible opportunities, 8 updates and repairs (Table 1) were most frequently identified as beneficial (i.e., with a simple payback less than the project lifetime) for the customer to reduce compressed air system energy requirements. These opportunities in general are discussed exhaustively in the literature cited at the end of the paper and will not be detailed here, but a basic technical overview will be provided later in this section for reference.

Table 1 displays how often each individual measure was recommended in the scoping studies, highlighting the most common and universal opportunities. Within the data set there were two sites for which no opportunities were presented, reducing the frequency of all measures.[4]

[3] The studies were performed by six different firms and the combination of opportunities identified may reflect the firms' engineering judgment. Also, seven of the studies were "focused" scoping studies, meaning that they concentrated on the compressed air system, not the facility as a whole, meaning that a greater number of measures were likely to be identified. However, all firms performing the scoping assessments were experienced with compressed air systems and not vendor-affiliated.

[4] In these two cases, the customer's compressed air system was well maintained, with modern, high-efficiency equipment operating with sufficient air storage. Any potential upgrades would have small efficiency gains, and minimal compressed air leaks were believed to be present.

Table 1. Occurrence and Frequency of Compressed Air Opportunities[5]

Opportunity	Occurrence (%)	Frequency (no.)
Leak Maintenance	61%	11
Install Variable Speed Drive Compressor	61%	11
Install New Dryer	28%	5
Install Receivers/Increase Storage	33%	6
Utilize System Controls	22%	4
Reduce Operating and Discharge Pressures	33%	6
Reconfigure System Piping	33%	6
Reduce Inappropriate Use of Equipment	50%	9

Leak Maintenance

Leaks within a compressed air system (typically at pressure regulators, open condensate traps, shut-off valves and couplings/fittings) are inevitable, and can at times result in a 20%-30% reduction in output flow (Best Practices for Compressed Air Systems, 2014). However with proper maintenance, losses due to leaks can be significantly reduced. A practical way to identify the impact of leaks in a compressed air system is to complete a leak test as outlined in Improving Compressed Air System Performance: A Sourcebook for Industry (2003). Another useful resource is Compressed Air Challenge with their Best Practices Manual. If the amount of air being lost to leaks is of concern, an ultrasonic leak survey can be completed to identify where throughout the system leaks are located. In order to ensure that leaks never cause extreme inefficiency, a leak test and survey should be completed on a regular basis. In most of the 18 scoping studies, a leak test was suggested even when no obvious system deficits were present. In almost all cases, the facilities lacked regular leak detection and repair programs or other leak-related preventive maintenance practices, making it likely that their leak rates were excessive.

Install Variable Speed Drive Compressors

Variable speed drive (VSD) compressors have the ability to precisely match the output (cfm) of the compressor to the demand of the system even when minimal air storage is present. VSD compressors perform more efficiently at partial loads than do load/unload or inlet modulating rotary screw compressors, making them an appealing replacement for fixed-speed units. While a VSD is more efficient for partial loads, fixed speed compressors are more efficient for full load operation. It is recommended that a fixed speed compressor be the base load unit in the system and run at full capacity, while a VSD unit be used to meet the remainder of the load and provide trim control to meet plant demand. This prevents a secondary fixed speed unit from continuously running at part load or turning on and off repeatedly (cycling).

In the scoping studies, installation of VSD compressors was recommended relatively frequently, usually as a replacement for an aging or unreliable fixed speed machine.

[5] This table is based upon the 18 scoping studies and states the percentage of the time a common compressed air system opportunity was identified along with the number of times the opportunity was identified. Some studies didn't identify any compressed air measures while most identified multiple compressed air system measures.

Install Receivers/Increase Storage

Adding receivers to a compressed air system helps reduce energy consumption by minimizing the spikes in air demand the compressor must quickly increase air flow to meet. When receivers are present and there is a large spike in demand, the system can use the receiver as a reservoir to pull air from, instead of the compressor rapidly increasing production. In many systems with multiple compressors, when demand spikes and temporarily exceeds the capacity of the primary compressor(s), the secondary compressor will turn on and very quickly (depending on how long the demand lasts) begin to idle. This idling could occur for several minutes before the secondary compressor eventually shuts off. When sufficient storage is present, the fluctuation of the system is minimized, as is the unnecessary use of a secondary compressor. While this was the most uncommon opportunity observed, it still has the potential to improve certain systems, particularly those with loads just short of the capacity of the primary compressor(s).

Utilize System Controls

System controls, such as master compressor plant controllers and pressure/flow control valves, are used to closely match the supply of air from the compressors with the demand of the system while optimizing some aspect of plant operation (e.g., compressor sequencing). When looking at updates to existing systems the most frequently appropriate control is a pressure/flow control valve combined with adequately sized storage. This control allows compressors to produce air at a high pressure that maximizes primary receiver effectiveness, regardless of the desired end use pressure. The control valve draws air from primary storage and reduces it to the proper pressure for end use. Utilizing a pressure/flow controller to decouple discharge and distribution pressures balances enhanced storage capacity with reduced demand from unregulated sources such as leaks and artificial demand.

Reduce Operating and Discharge Pressures

Reducing pressures within the system can help increase efficiency in several ways. By reducing operating pressure, the pressure at which the compressor runs, the compressor's specific power is reduced. While operating pressure does need to be larger than end use pressure, due to losses throughout the system, the closer the operating and end use pressures can become the more efficient the system will become. A reduction in pressure by 2 psig can result in a 1% decrease in electrical consumption output (Improving Compressed Air System Performance: A Sourcebook for Industry, 2003). A strategy to address this objective would be to monitor pressures at key locations of the piping system with the objective to minimize pressure differential across system delivery. As air moves through the system at a higher pressure, it is forced out through leaks with more pressure as well. By reducing the distribution pressure of unregulated sources the amount of air lost to leaks throughout the system is reduced, reducing the overall load on the compressors. This measure was typically recommended in concert with leak remediation, as leak reduction may also reduce pressure differentials, allowing greater pressure reductions than could otherwise be achieved.

Reconfigure System Piping

As compressed air systems are updated and additional equipment is added, the layout of a system can become inefficient. By rearranging the system to reduce the length air has to travel, pressure drops can be reduced. Increasing pipe size can also decrease pressure losses. With a smaller pressure differential there is the opportunity to more closely match operating and discharge pressures, resulting in the benefits previously discussed. Equipment that is no longer in use should also be removed from the system, or completely sealed off. High-pressure or especially low-dew point loads should be considered for isolation with dedicated compressed air equipment. This may require some piping reconfiguration in some cases.

Reduce Inappropriate Use of Equipment

Compressed air systems require large amounts of energy relative to lower-pressure fans that can in many cases perform the same task. Applications that can be satisfied in a more efficient way, without the use of compressed air, should make the transition away from compressed air. Where feasible compressed air driven devices can be replaced with electric motor driven systems such as air motors, air hoists, air wrenches, etc.

Implemented Projects – Technical Review Studies

As noted previously, the technical review studies represent the measures that customers tend to actually install. A matrix displaying the installed updates for each of the 23 observed systems is seen in Table 3 on the following page. The matrix is intended to allow the reader to observe the types of upgrades that tended to be implemented together in a single project and the settings in which the upgrades took place. A summary of these results can be seen in Table 2. 70% of the time, the existing equipment was retained in service as a backup or redundant unit, while the remaining 30% of the time the existing equipment was removed and disposed. Table 4 displays the occurrence (%) and frequency of multiple updates installed concurrently. The savings from the 23 projects varied depending on the size of the system and the scale of the implemented upgrades (Table 3).

Table 2. Occurrence and Frequency of Installed Updates[6]

Opportunity	Occurrence (%)	Frequency (no.)
Install Variable Speed Drive Compressor	96%	22
Install Receivers/Increase Storage	57%	13
Install New Dryer	57%	13
Utilize System Controls[7]	26%	6
Reconfigure System Piping	17%	4
Reduced System Size[8]	57%	13

[6] The sum of the occurrences will not equal to 100% as multiple measures were installed in many projects.
[7] This measure included the addition of pressure / flow controllers.
[8] A reduction in the total horsepower of the system's compressors (not including back-up units) was classified as a reduction in system size.

Table 3. Matrix of Installed Updates

Facility Type	Install New Equipment	Replace Existing Equipment	Install VSD Compressor	Increase Storage	Install Dryers	Utilize System Controls	Reconfigure System Piping	Reduce System Size	Total Energy Savings (kWh/year)
Textile Processing	X		X	X	X	X		X	171,000
Plastics Mfg.	X		X					X	652,000
Electronics Mfg.	X		X	X	X				209,000
Glass Mfg.		X	X		X				1,174,000
Paper and Packaging Mfg.	X		X	X	X		X	X	201,000
Food/Beverage		X	X	X	X		X	X	596,000
Food/Beverage	X		X	X	X	X			420,000
Appliances Mfg.		X			X			X	136,000
Machining		X	X	X	X	X		X	93,000
Food/Beverage		X	X						245,000
Food/Beverage	X		X	X	X	X		X	273,000
Gasket Sealing	X		X	X	X			X	359,000
Gasket Sealing	X		X					X	267,000
Machine Mfg.	X		X					X	147,000
Amenities Mfg.	X		X	X	X				144,000
Paper Mfg.	X		X	X	X	X			563,000
Abrasives Mfg.		X	X					X	531,000
Amenities and Paper Mfg.	X		X					X	689,000
Pharmaceutical Mfg.	X		X				X	X	66,000
Asphalt Mfg.	X		X	X			X		15,000
Turbine Mfg.	X		X						899,000
Glass and Metal Mfg.	X		X	X		X			30,000
Medical Mfg.		X	X	X	X				348,000

Table 4. Occurrence and Frequency of Multiple Installed Updates[9]

Multiple Opportunities Installed	Occurrence (%)	Frequency (no.)
Install VSD Compressor and Reduced System Size	55%	12
Install VSD Compressor and Flow Control	50%	11
Install VSD Compressor, Dryers and Increased Storage	23%	5
Install VSD Compressor, Dryers, Increased Storage, and Flow Control	27%	6

Opportunities Left on the Table

Despite the sites' clear efforts to improve the efficiency of their compressed air systems, a comparison of the surveyed opportunities list with the surveyed implementation list suggests that there are still likely many opportunities available that could improve the efficiency of existing systems. Of the 23 compressed air systems reviewed, 70% installed new equipment and retained the existing equipment. While installing new, more efficient equipment is helpful in decreasing energy consumption, it is also important that the previous, less efficient equipment is, for the most part, no longer operational. If backup equipment is frequently being used or left to idle, the installation of new equipment is redundant. Backup equipment is necessary, in the case of a system failure, but operations should be limited. When possible, unnecessary equipment should be removed from the system, to avoid the unnecessary stacking of equipment.

Leak maintenance is a reasonably cost-effective solution to system inefficiency. Leak tests and surveys should be completed frequently on all systems. More than half (61%) of the studied systems had the opportunity to reduce losses due to leaks through a test/survey, but none elected to address leaks during project implementation, or stated any intention to implement preventive maintenance practices related to leaks. While almost all updates (96%) included installing a new VSD compressor, roughly half installed new receivers and replaced dryers (57% and 57%, respectively). While having an efficient compressor does reduce a system's energy consumption, receivers with inadequate capacity and an inefficient dryer can neutralize any savings from an installed compressor.

Table 5 displays which opportunities were installed at or above the frequency of the initial recommendations and which opportunities seem to be under-implemented. The potential opportunities and the implemented projects were assessed via separate sets of data with a limited sample size, leading to a low level of statistical significance for any individual opportunity. However, the gross differences in identification and implementation rates of demand side measures (e.g., leak remediation) contrasted with the relative agreement in the case of supply-

[9] Frequencies were calculated by determining of the number of systems that implemented the primary update, how many also implemented the secondary update. For example, of the 96% of systems that installed VSD compressors, 55% reduced the size of the system, etc.

side measures (e.g., installation of VSD compressors) suggest that demand-side measures are under-used while capital measures are being more readily adopted.

Table 5. Comparison of Potential versus Installed Opportunities

Opportunity	Potential Opportunities (based on Scoping Studies)	Installed Opportunities (based on Technical Reviews)
Install Variable Speed Drive Compressor	61%	96%
Install Receivers/Increase Storage	28%	57%
Install Dryers	33%	57%
Utilize System Controls (Pressure/Flow)	22%	26%
Reconfigure System Piping	33%	17%
Leak Maintenance	61%	0%[10]
Reduce Operating and Discharge Pressures	33%	Not Determined
Reduce Inappropriate Use of Equipment	50%	Not Determined
Reduced System Size	Not Determined[11]	57%

The green cells represent opportunities where there was a larger installed percentage than the potential percentage. The orange cells represent opportunities where a clear correlation could not be drawn. The red cells represent areas where the installed opportunities were less frequent than the potential. However, these values do stem from different sets of data and some variation is inherent.

Conclusion

Compressed air systems, if left unmaintained, can become a large source of inefficiency. Ideally, a systems approach should be implemented with demand side opportunities evaluated first, then followed by supply side opportunities (Taranto, 2012). Through the interpretation of the 43 National Grid technical reviews and scoping studies involving compressed air systems, predominantly capital based opportunities on the supply side are being implemented in the facilities (i.e. installing VSD compressors, increasing storage through the addition of receivers, and replacing dryers). A number of improvements are rarely utilized, which are on the demand side. Adding system controls, reconfiguring system piping, and performing comprehensive leak maintenance are the three most commonly available demand side improvements, but simultaneously the least implemented. While reducing operating and discharge pressures, reducing inappropriate use of equipment, and reducing the size of a system were all also feasible

[10] The compressed air systems analyzed in the study are industrial systems applying for capital-based incentives. It is plausible that the low percentage of projects which implemented leak maintenance is due to the nature of the sample of systems, and not an actual lack of leak maintenance.

[11] While it can be recommended for systems to be "right sized," during the studies conducted there was not enough information to recommend downsizing systems. Customers tend to be on cautious side to have a cushion of additional capacity to account for growth in business.

improvements, due to a lack of information it is unknown what percentages of projects utilize them. These under-implemented opportunities leave room for continued improvement within facilities having compressed air systems.

Future Steps

A larger sample of projects across a larger geographic region would be useful to bolster the found conclusions and suggest other trends in compressed air system improvement. Also, a survey of industrial compressed air projects in states with more lucrative incentive programs for operations and maintenance based improvements would also be another way to compare against the findings in this analysis as the National Grid programs in Upstate New York and Massachusetts are for the most part, a capital project based incentive programs.

While the above narrative is a summary of findings from some compressed air projects completed in the National Grid service areas of Upstate New York and Massachusetts, National Grid has started to take steps to embrace systems optimization approach on current and future projects. The challenge has always been and remains today that trade allies are more focused on equipment sales and as such their business model does not facilitate a total systems optimization approach. While trade allies can bring projects for review, in depth investigation of more complex systems will be reviewed by specialists who can provide objective recommendations. Through its participation in national organizations such as Compressed Air Challenge (CAC), Consortium for Energy Efficiency (CEE), etc., National Grid has concluded that this is a problem nationally. National Grid is collaborating with other program administrators and utilities to address these issues. Outcomes from this effort could be topic for a future paper.

Another opportunity in the works is to facilitate the systems engineering approach for compressed air systems. ASME EA-4 has incorporated two matrices of Objectives, Action Items, and Methodologies that are considered when designing a compressed air system assessment (ASME, 2010). National Grid is working on a document to match customer priorities, cost effectiveness of system assessment and potential savings available in a given facility to determine scope and effort needed for a study. Once the document is completed and publicized by National Grid, the results of that effort can be used to develop a future paper and augment the results reported here.

References

American Society of Mechanical Engineers (ASME). Energy Assessment for Compressed Air Systems. ASME EA-4-2010.

Scales, W. and D. McCulloch. Best Practices for Compressed Air Systems. New York: Compressed Air Challenge; 2014.

Taranto, T. and R. Kondapi. "International Wire Trims Compressed Air Costs Using the "Systems Approach"." *Compressed Air Best Practices*, March 2012, 39-44.

U.S. Department of Energy. Improving Compressed Air System Performance: A Sourcebook for Industry. Washington: Lawrence Berkeley National Laboratory; 2003.