Guidelines

001
January 2012

Analyzing and Optimizing Compressed Air Systems

Background/Rationale: Compressed air systems often operate inefficiently, using an unnecessary and expensive amount of energy. Any business seeking to make operations more sustainable should take steps to fully understand the compressed air system, calculate its true cost, and implement strategies to make the system more energy efficient. Optimizing the operation of a compressed air system and reducing energy consumption will, in turn, indirectly help reduce greenhouse gas emissions and any adverse environmental impact associated with excess emissions.

Some improvements may be relatively simple and inexpensive to implement, while others may be more complex and require assistance from experienced professionals. The material contained in these guidelines is intended for use by persons who have a basic level of technical training/competence and familiarity with source reduction concepts and strategies.

Step 1: Assess the Current Situation/Define the Scope of the Situation

1.a. Collect and analyze information about current operations, including but not limited to:

- identify key/relevant sources of information (see Appendix 1, Examples 1 and 2):
  - the environmental cause champion,
  - maintenance and/or facility supervisor(s),
  - purchasing or accounts payable personnel,
  - key suppliers/vendors,
  - business representative at local electric utility
- collect pertinent documents and information (see Appendix 1, all examples):
  - policies/procedures related to compressed air system operation:
    - formal/informal guidelines/expectations regarding proper/improper use
    - employee training/supervision regarding proper/improper use
    - formal/informal guidelines/expectations for routine maintenance/quality assurance/leak prevention
  - maintenance records, equipment specifications and guides, manufacturer's user manuals and nameplate information
  - utility bills identifying billing rates and energy usage
- keep track of, document and distinguish between key assumptions, known or reported values, and information which is calculated (see Appendix 1, all examples)
- identify location/design of system network (see Appendix 1, all examples)
  - develop system map using existing blueprints or new diagram
  - include compressors, line layout, regulators, nozzles, storage capacity, filters, drains, intake air
  - may require expert consultation for some aspects (e.g. system lines, pump type, etc.)
- conduct use analysis (see Appendix 1, all examples)
  - identify hours of operation

- identify system pressure needs for routine and special uses through interviews, direct observation or using testing equipment:
    - per area/unit/end use
    - identify current and optimal pressure taking into account maximum draw or demand (include an extra or "safety" factor to ensure adequate pressure for all operations)
- develop diagram or map to represent system being analyzed so that everyone involved understands the scope and details of the system being analyzed
- identify "unregulated" uses of air (e.g. personal cooling, open blowing, open drains, etc.) by direct observation or interviews with key personnel
- identify maintenance schedule
    - does a formal preventative maintenance program exist?
    - identify tasks performed, frequency
    - identify reporting protocol

➢ calculate amount/cost of electricity for entire facility and amount/cost associated with operating the compressed air system to compare the impact of the system on the overall energy use at the facility (see Appendix 1, all examples)

- verify utility rate per kWh (focus on kWh cost for peak loading) from evaluation of the electric bills
- estimate the annual hours of operation for compressor(s) at full load and partial load
    - use the following formula to calculate amount/cost of compressed air with compressor fully loaded and partially loaded (reference Compressed Air Challenge, Fact Sheet #9, U.S. Department of Energy, April 1998):
        - $$\frac{\textbf{(bhp) x (0.746) x (\# operating hrs/yr) x (\$/kWh) x (\% time) x (\% full load bhp)}}{\textbf{motor efficiency}}$$
            - **bhp=compressor shaft horsepower per equipment specs**
            - **0.746= kW/hp**
            - **$/kWh=rate/cost per kWh**
            - **% time=percentage time running at this operating level**
            - **% full load bhp=percentage of full load bhp at this operating level**
            - **motor efficiency=motor efficiency per nameplate at this operating level**

➢ conduct leak analysis (see Appendix 1, Examples 1, and 2):

- use Ultrasonic leak detector to detect location and size of leaks
    - to calibrate leak detector, obtain a flexible hose with a crimped end and attach it to compressed air system at the target air pressure. Use a tool to incrementally create holes of various sizes (e.g., 1/16", 1/8") and calibrate the leak detector response for each size of hole.
- tag and possibly photograph leaks, and plot on diagram or map of facility.
- prioritize leaks for repair—fixing largest leaks first
- calculate amount/cost of electricity associated with leaks:
    - use leakage rates table and formula for calculating costs of leaks as outlined in reference #5 below; or
    - rule of thumb: 1/16" leak=$500/yr; 1/8" leak= $2000/yr; ¼" leak=$8000/yr assuming 100 psi constant pressure and $.05/kWh cost; or
    - use the following formula to calculate the cost of leaks:
        - **Cost of leaks = # of leaks x leakage rate (cfm) x kW/cfm x # of hours x $/kWh**

➢ calculate life cycle impact on greenhouse gas emissions from the energy consumed by the compressed air system using reference #6 below (see Appendix 3 for examples)

1.b. Conduct necessary research and calculations using the following references:

The following references are used to help calculate energy waste and to identify potential strategies for improving compressed air systems:

1. *Compressed Air Systems*, pp. 21-34, Industrial Audit Guidebook: A Guidebook for Performance Walk-through Energy Audits of Industrial Facilities, 2004, Bonneville Power Administration, U.S. Department of Energy, accessed online at:
   http://www.bpa.gov/energy/n/industrial/pdf/audit_guide.pdf
2. *Compressed Air Basics* fact sheet and related links, Minnesota Technical Assistance Program, University of Minnesota, updated 5/2011, accessed online at:
   http://www.mntap.umn.edu/greenbusiness/energy/compair.htm
3. *Compressed Air Best Practices* fact sheet and related links, Office of Industrial Technologies, Energy Efficiency and Renewable Energy, U.S. Department of Energy, updated 7/2011, accessed online at:
   http://www1.eere.energy.gov/industry/bestpractices/compressed_air.html
4. *Improving Compressed Air System Performance: A Sourcebook for Industry*, November 2003, Best Practices and Compressed Air Challenge, U.S. Department of Energy Efficiency and Renewable Energy, accessed online at:
   http://www1.eere.energy.gov/industry/bestpractices/pdfs/compressed_air_sourcebook.pdf
5. *Compressed Air Systems: Fix Leaks*, a University of Dayton Industrial Assessment Center document explaining the use of the S.A. Moss Equation available online at:
   academic.udayton.edu/kissock/http/IAC/.../CompAir_FixLeaks.doc
6. *Compressed Air Tip Sheet #3*, Office of Industrial Technologies, Energy Efficiency and Renewable Energy, U.S Department of Energy, December 2000, accessed online at:
   http://www.energystar.gov/ia/business/industry/compressed_air3.pdf

The following references are used to calculate life cycle impact on greenhouse gas emissions:

7. *Economic Input-Output Life Cycle Assessment (EIO-LCA)*, US 1997 Industry Benchmark model, Green Design Institute, Carnegie Mellon University, 2008, available online at:
   http://www.eiolca.net
8. *Waste Reduction Model (WARM)*, U.S. Environmental Protection Agency, available online at:
   http://epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

Step 2: Identify Feasible P2 Opportunities

2.1. In general:

- research a full range of possible operational improvements/modifications/suggestions relevant for the situation at hand (several commonly applicable suggestions are listed below)
- be specific about the "unit" for application, i.e. which air lines, compressors, leaks, etc. to modify
- keep track of, document and distinguish between key assumptions, known or reported values, and information which is calculated (see examples throughout appendices)
- include a thorough cost analysis: use a chart to compare current to proposed costs and calculate payback period
- include relevant vendor information (the vendor information included in these guidelines is for example only)
- identify how to monitor/measure impact for each suggestion if implemented, e.g. install gauge or electric meter, compare bills, monitor use

2.2. Selected strategies to consider, including techniques and calculations to perform:

- train/supervise employees:
  - see Appendix 2, Examples 1.a-c
    - implement leak management system
    - train employees in proper use of system
    - eliminate use for personal cooling
    - close shut off valves when not in use
    - inform employees about cost of compressed air
- fix leaks and implement leak management system:
  - see Appendix 2, Examples 2.a-c
    - use high-pressure sealant, Teflon tape around threaded connections, replacing leaking/damaged equipment
    - stop leaks at joints and attachments to tools, filters, drains, and machinery
    - maintenance staff should perform regular leak detection using ultrasonic leak detector
    - involve employees to identify, tag and fix leaks
  - use table listing type/quantity of leaks, volume air loss/costs per year and totals
  - calculate costs for repair: labor=hourly wage times total hours plus parts
  - calculate payback period: cost of implementation (e.g. repair costs for leaks) divided by annual savings X 365 days per year
- reduce system pressure:
  - see Appendix 2, Examples 3. a-c
    - reduce system pressure and test to assure demand met
    - reduce system pressure as a result of repairing leaks
    - reduce line pressure as a result of smaller nozzles
  - use table reflecting current practice psi energy use and cost per year vs. suggested psi energy use and cost
    - rule of thumb: every 2 psi increase, energy use increases 1-2% at full load
  - change system on a trial or test basis to assure capacity is not impacted negatively
- modify structural components of compressed air system:
  - see Appendix 2, Examples 4.a-g

        - install foot pedals
        - install solenoid valves to close drains/equipment in the system
        - replace large air nozzles with smaller one
        - modify or change location of air intake
        - hire expert consultant to evaluate system design
        - replace rather than rebuild main compressor
        - relocate compressor to reduce heat/noise for employee health/safety
        - use mechanical agitation for tank mixing
    - calculate expected life of equipment
    - use the Moss Equation (Ingersoll-Rand Condensed Air Power Data, 1998) to help calculate savings from reducing nozzle size (see Appendix 4c)
        - $W(lb/s) = 0.5303 \times A\ (in^2) \times C \times P\ (psia)\ /\ \sqrt{T(R)}$
- calculate life cycle impact on greenhouse gas emissions compared to current processes
    - see Appendix 3 for examples

Examples of additional strategies which may require more complex analysis include:

- heat and/or water recovery from compressors
- mechanical agitators in lieu of compressed air
- increased compressed air accumulation tank storage
- renovate air line design: length, bends, rises, etc.
- compressors with VFD motors

Step 3: Identify Barriers to and Benefits of Implementation for Each Opportunity

After analyzing the compressed air system and identifying feasible opportunities for realizing savings, you will want to make as strong a business case as possible for making changes to the compressed air system. Be proactive and identify key barriers to and benefits of implementing the opportunities you want to recommend. To help you do this, the P3 program offers the following information.

Based on experiences over the past 15 years, the P3 program has found that simple projects with thorough documentation and short pay back periods or projects with compelling cost and environmental savings have a high likelihood of being implemented. For example, suggestions for fixing large leaks, replacing nozzles, and reducing system pressure are often implemented. Companies are typically receptive to opportunities which reduce risk or increase safety and comfort for employees. Steps to reduce environmental impact often simultaneously have a positive impact on the health and safety of the working environment.

On the other hand, suggestions which are high cost, with long payback periods, or which have complex implementation logistics, or are not adequately researched or quantified are typically not implemented. For example, suggestions for using a mechanical agitator for tank mixing in lieu of compressed air or relocating the air intake or compressor locations may be complex and costly projects which are not favorably considered, at least in the short run. Interestingly, some low cost, quick payback suggestions which involve changing employee behavior may not be implemented due to the common human tendency of resistance to change. For example, eliminating improper use of compressed air such as blowing for personal cooling or for cleaning work stations via policy changes or employee education campaigns may not be strategic priorities.

See Appendix 2 for examples of implemented P2 compressed air suggestions from the Nebraska intern program. These are annotated to make it clear what information is needed to perform these calculations for a different facility and to explain why some suggestions were implemented and others were not.

Common Barriers:

Beliefs & Attitudes

- resistance to change—employees set in ways and enjoy convenience of using compressed air for self cooling or cleaning work area
- skepticism—employees skeptical about impact of reduced airline pressure on tool performance
- other/higher strategic priorities—the company may have other issues is sees as more important to address in the short run
- misinformation or lack of understanding about the full costs of using compressed air:
  - that small fixes can yield measurable results
  - how using unnecessary energy can affect the environment
  - lack of technical understanding that certain tools and/or processes can function with lower air pressure

Costs and Investments

- cost (time, effort and money) of implementing more complex suggestions
  - capital investment-“up-front costs”
  - space constraints
  - time/costs of re-training employees
- timeline for return on investment (ROI)—length of payback period

- perception of cheap and available "air"
- overall low cost of air relative to entire bottom line

Technical Issues: What to Do and How

- lack of knowledge/skills re: what needs to be done/how to implement strategies
  - access to equipment for detecting leaks
  - access to plumber for system modifications
- concern re: managing logistics and process changes, including down time

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Common Direct and Indirect Benefits:

Cost Savings

- reduces costs and improves efficiency of operations by using less energy to accomplish same work/product
- increased efficiency for compressor and pneumatic machines
- reduces maintenance and wear and tear on equipment from high airline pressure

Environmental Impact

- reduces impact of operational processes on the environment:
  - reduces use of natural resources/raw materials to produce energy
  - reduces greenhouse gas emissions related to energy production
  - conserves/preserves/provides clean environment/quality of life for future generations

Education

- educates employees and general public in efficiency and responsibility when information is posted about the change and why it was made

Health and Safety

- improves health and safety of work environment for employees from the risk of exposure to high pressure air, noise or excessive heat
- reduced pressure reduces need for air pressure regulators
- reduces noise

Company Image

- demonstrates social responsibility and best management practices

Step 4: Make the Business Case for Change

4.1. Develop a written report for submission to decision makers.

- include a thorough assessment of the system, with process descriptions, flow charts and air use/cost information.
- outline specific P2 Opportunities/Suggestions with the following information:
  - recommended action
  - brief summary of current operations
  - cost of implementing recommendation
    - include labor costs/savings in your economic analyses.
  - summary of benefits (acknowledge barriers but discuss how benefits outweigh):
    - potential cost savings ($)
    - air/electricity use reduction(s)
    - simple payback
    - indirect benefits: safety, risk/liability reduction, GHG reductions, etc.
- always identify how to monitor/measure impact for future analysis: e.g. install electric meter, monitor use on the plant floor
- incentives to change: conclude the report with a summary of the benefits to be realized from implementing the recommendations made. Stress environmental stewardship. Call for action!
  - you may want to reference previous successes in similar businesses as a selling point
  - see Appendix 2 for example projects implemented and their results

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4.2. Make an oral presentation to summarize your findings and call to action:

- focus on pertinent details of system assessment and P2 opportunities
- make it interesting yet include sufficient technical detail to be convincing and make the business case for change— include a picture of the product/change in action
- develop a final "impact" slide with table of metrics—call for action/change
- allow time for question/answer period

4.3. Advocate for change based on metrics/facts and environmental ethic:

- use informal interactions to establish trust in your abilities and to build a foundation for change
- use written report and formal presentation to communicate your findings and provide the formal information/rationale for implementing recommendations
- emphasize sustainability (triple bottom line) and preserving resources for future generations
  - energy conservation and the relationship to greenhouse gas emissions is particularly important for compressed air system operations
- use examples of implemented suggestions from past projects (see Appendix 2)

4.4. Report potential Greenhouse Gas (GHG) emission reductions as an important indirect benefit:

- include in written report and oral presentation
- include explanation of why GHG emissions are relevant/of concern to all businesses
- calculate potential carbon dioxide equivalent (CO2e) emission reductions for each recommendation
- include an appendix in written report documenting calculations (see Appendix 3 for details and example calculations for compressed air systems)
- see Appendix 4 for additional tips for making the business case for change.

Appendix 1
Example Assessments of Compressed Air Systems

Note: *Several examples of compressed air system assessments are included below. Each of these addresses one or more of the steps needed to accomplish a thorough assessment. In these examples, we have attempted to clarify for the reader what information is known or reported, what is logically assumed, and what has been calculated. This is embodied within the narrative for easy reference. In an actual report, these details would likely be in attached appendices so as not to interrupt the flow of the report.*

Example #1: Comprehensive Assessment of Compressed Air System (adapted from report by Caleb Peterson, 2011)

To complete assessment work for this project, the intern worked closely with the company's Environmental, Health, & Safety Coordinator who was familiar with the design and use of the system and several key vendors of compressed air equipment. The assessment was completed in several steps:

- Studying usage in blending, blow molding packaging, and maintenance departments (collecting equipment nameplate and utility bill information, interviewing employees who use the system to assess capacity need, direct observation of time compressor is operated)
- Developing a comprehensive diagram of the plant's airlines
- Calculating cost of compressed air use
- Conducting leak analysis

Compressed Air Usage

The blow molding department is the primary consumer of compressed air. This department has six blow molding machines to create a variety of plastic containers. They use a stretch blow molding process, where melted plastic is molded into its "preform", and then is placed inside a metal mold, where air is blown in to stretch the container into the shape desired. Other minor uses of compressed air come from pneumatic devices that test the bottles to see if there are leaks or if they meet the tensile strength and thickness desired.

The blending department uses compressed air to mix the oil and lubricants. The process of mixing/blending is achieved using a bubbling method, where the air is released at the bottom of the tank aerating the liquid causing it to mix. Compressed air is also used for tank blow back or to cut off the flow in the pipes and to then clean out the pipe by "blowing back".

The packaging department uses compressed air to run approximately 70 pneumatic machines, consuming between 1 and 10 CFM per machine. Additionally, there are many duplicate devices for the different packaging lines. Each line includes one: palletizer/depalletizer; bottle filler; bottle labeler; glue melting system; case erector; and case packager.

The maintenance department is likely the smallest consumer of compressed air. Probable consumption comes from maintenance on the forklifts like filling up tires and using pneumatic tools. There is also one digital case printer and a 50-ton shop press located in this department that utilizes compressed air.

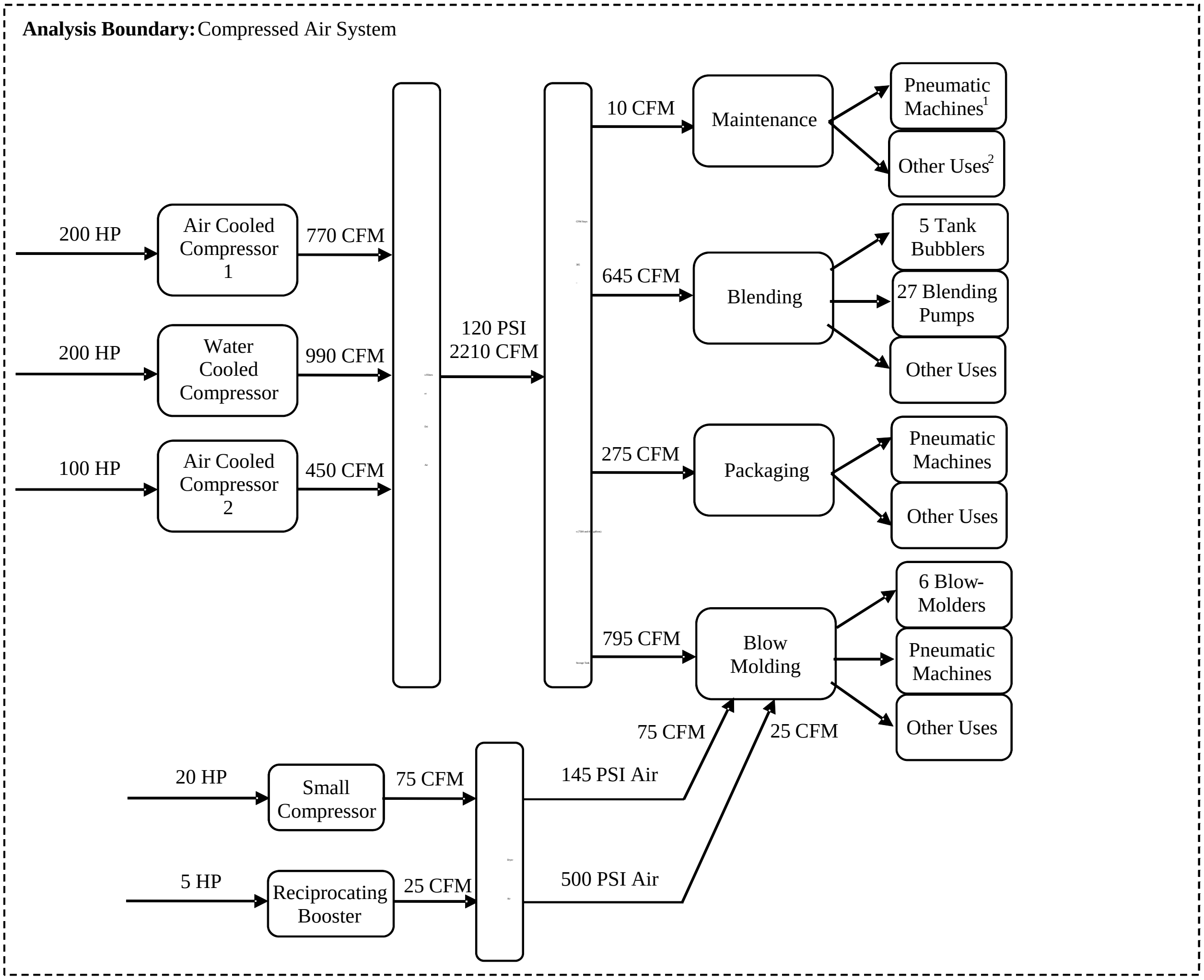
Other wastes can add up from the miscellaneous unnecessary use of compressed air. These include:

- Minor cleanups
- Blowing off dust and dirt
- Cleaning/cooling employees
- Cleaning filters

Even though they are hard to quantify, over time these practices can lead to financial and energy losses, and are deemed as unsafe. Though employees use pneumatic tools for cleanups that blow air at a lower pressure of 30 PSI, according to an article on State Fund Insurance's website entitled "Take Care with Compressed Air", even this pressure can cause bubbles of air to enter the blood stream, through layers of clothing, and damage body organs.

System Design

As depicted in Figure 1 below, the compressed air system is currently supplied by one 200 HP air cooled compressor which runs continuously; one 100 HP air cooled compressor which runs continuously; and one 200 HP water cooled compressor which runs infrequently. The compressors supply air to air filters and dryers, then to two large storage tanks, which feed into the entire airline system. There is also a 20 HP compressor and a 5 HP reciprocating booster used to supply one blow molder with 145 and 500 PSI. Figure 1 below shows the maximum CFM production and consumption in the plant, and how it is divided between the 4 departments based on nameplate ratings.



1. Complete list of pneumatic machines found in an Appendix
2. Other uses include:
    a. Cleaning filters
    b. Blowing dust and dirt
    c. Minor cleanups
    d. Cooling employees

Figure 1 – Process Flow Diagram of Compressed Air

An AutoCAD drawing detailing the layout of the airline system follows on a separate page.

Cost of Compressed Air System

These five compressors consume around 1,800,000 kWh/year, which costs approximately $90,000/yr. This accounts for about 20% of the company's energy bills, which is twice the national average for energy consumption. The details of these calculations, based on energy consumption and costs are shown below.

Compressed Air Cost Calculations

Known or reported values:

-- Two air cooled compressors
-- One water cooled compressor
-- One small compressor and one reciprocating booster
-- Electric rate is \$0.05/kWh
-- 0.746 = kW/HP

Assumptions:

Air Cooled #1:
- motor full-load horsepower (BHP)=200 HP
- runs year round: 8760 hrs/yr
- motor runs at 95% efficiency

Air Cooled #2:
-motor full-load horsepower=100 HP
- runs 24 hrs/5 days: 6240 hrs/yr
-motor runs at 95% efficiency

Water Cooled #1:
- motor full-load horsepower (BHP)=200 HP
- runs 1 hr/6 days: 312 hrs/yr
- motor runs at 95.0% efficiency

Small Compressor and Booster:
- compressor motor full-load BHP=20 HP
- booster motor full-load BHP=5 HP
- both run year round: 8760 hrs/yr
- motor runs at 95% efficiency

Calculations for Compressor Energy Use:

$$\frac{(Bhp)(0.746)(hours)(rate)}{efficiency} = \textbf{cost/yr}$$

Air Cooled #1:

$$\frac{(200hp)\left(\frac{.746kW}{hp}\right)\left(\frac{8760hr}{yr}\right)\left(\frac{\$0.05}{kW\text{-}hr}\right)}{0.95} = \frac{\$33{,}031.24}{year}$$

Air Cooled #2:

$$\frac{(100hp)\left(\frac{.746kW}{hp}\right)\left(\frac{6240hr}{yr}\right)\left(\frac{\$0.05}{kW\text{-}hr}\right)}{0.95} = \frac{\$23{,}275.20}{year}$$

Water Cooled #1:

$$\frac{(20hp)(\frac{.746kW}{hp})(\frac{8760hr}{yr})(\frac{\$0.05}{kW-hr})}{0.95} = \frac{\$6,878.91}{year}$$

Small Compressor:

$$\frac{(200hp)(\frac{.746kW}{hp})(\frac{312hr}{yr})(\frac{\$0.05}{kW-hr})}{0.95} = \frac{\$2,327.52}{year}$$

Reciprocating Booster:

$$\frac{(5hp)(\frac{.746kW}{hp})(\frac{8760hr}{yr})(\frac{\$0.05}{kW-hr})}{0.95} = \frac{\$1,719.73}{year}$$

Totals:

-- One year of operation = $55,031.24 + $23,275.20 + $2,327.52 + $6,878.91 + $1,719.73

-- One year of operation = $89,232.60 = **$90,000/yr**

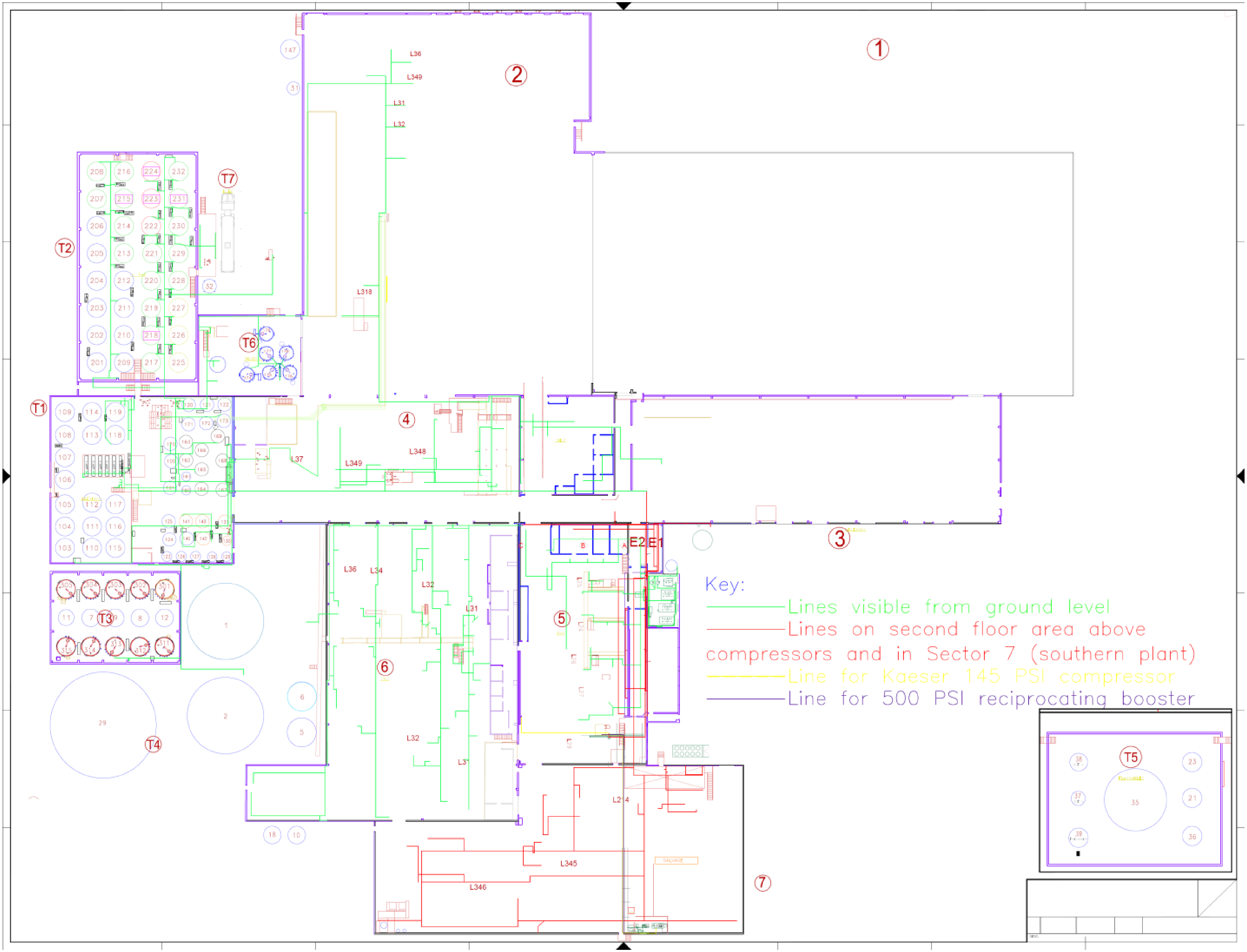
-- ($90,000/yr)(1 kWh/$0.05) = **1,800,000 kWh/yr** consumed

-- Average monthly electric bill for the entire facility : **$37,000**

-- Average yearly electric bill for the entire facility: **$444,000**

-- Average consumed by compressors: $^{\$90,000}/_{\$444,000}$ = **20% of total electric bills**

-- National average for contribution of compressed air to total electricity bill: **10% of total electric bills**



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T2
T3
T4
T5
T6
T7
E2
E1
L36
L349
L31
L32
L318
L37
L348
L34
L214
L345
L346
Key:
Lines visible from ground level
Lines on second floor area above compressors and in Sector 7 (southern plant)
Line for Kaeser 145 PSI compressor
Line for 500 PSI reciprocating booster

Leak Analysis

Additional wastes of energy and money come from leaks in the piping system. Every time an air compressor runs it uses energy. Leaks in an air compressor system require the compressors to run more frequently, using more energy. These problems are inevitable with compressed air systems and must be maintained properly. Using an Amprobe ultrasonic leak detector, the intern scanned the airline system at all reachable areas. This tool detects the sound of leaking air at volumes below what is detectable by the human ear. The assessment focused on points where hoses and tools were fastened to the main system and where splits and joints sent air to different places in the plant. Tags were placed at each leak for easy identification and repair. A total of 69 leaks were found and tagged throughout the facility. Based on the calculations shown below, these leaks cost up to $10,000, waste 200,000 kWh annually, and account for 11% of the company's compressed air expenses.

Air Leak Costs

Known or Reported Values:

Sizes of leaks are based relatively and not necessarily on measured size, as many leaks were found in seals and joints, not measurable holes.

-- 3 Very Significant – 1/8" diameter
-- 13 Significant – 1/16" diameter
-- 20 Moderately Significant – 1/32" diameter
-- 33 Slightly Significant – 1/64" diameter

Assumptions:

-- Follow US Department of Energy (DOE) equations/examples
-- Leakage rates using DOE tables
-- 8760 hours of operation
-- Electric rate is $0.05/kWh
-- Compressed air generation requirement is 18kW/100cfm
-- Pressure in leaks between 80-100 (90 PSI average)
-- All leaks have sharp edged orifices (multiplication factor of 0.61)
-- Cost of energy for compressed air system is $90,000/year as calculated previously

Calculations for leak costs:

Cost of leaks = (# of leaks)(leakage rate (CFM))(kW/CFM)(# of hours)($/kWh)(orifice factor)

Very Significant: (3 leak)(23.8 CFM)(0.18 kW/CFM)(8760 hours)($0.05/kWh)(0.61) = **$3,433.80**
Significant: (13 leaks)(5.9 CFM)(0.18 kW/CFM)(8760 hours)($0.05/kWh)(0.61) = **$3,688.69**
Moderately Significant: (20 leaks)(1.5 CFM)(0.18 kW/CFM)(8760 hours)($0.05/kWh)(0.61) = **$1,442.77**
Slightly Significant: (33 leaks)(0.37 CFM)(0.18 kW/CFM)(8760 hours)($0.05/kWh)(0.61) = **$587.21**
Additional Wastes: $500 and $500 from Blowmolding and Blending Departments = **$1,000**

Total Costs and Wastes

Leak Costs = $3,433.80 + $3,688.69 + $1,442.77 + $587.21 + $1,000 = $10,152.47 = **$10,000/yr**
Energy Wasted = ($10,000/yr)(1 kWh/$0.05) = **200,000 kWh/yr**
Percent Waste = Leak Costs/Total Costs = $10,000/$90,000 = 1/9 = **11%**

Example #2: Comprehensive Assessment of Compressed Air System (adapted from report by Benjamin Stewart, 2008)

The assessment focused on identifying uses within the system and finding leaks to be repaired. The compressor network was first analyzed during business and non-business hours. Next, the uses of the system were assessed. Lastly, the system was given a thorough inspection with an Ultrasonic Leak Detector. These steps were all aimed at reducing energy use and related costs.

Air Compressor Network

The air compressor system is made up of three air compressors. The plant's primary compressor unit is a Gardner Denver model EDE-99K. This 50 hp compressor only runs during the work day, maintaining a minimum pressure of 100 psi and cutting out at a maximum of 135 psi. This compressor is backed by two 20 hp back-up compressor units; one being an Ingersoll-Rand model 30T and the other a Champion model HRA 20-12. These back up compressors support the primary unit during the workday when pressure drops below 100 psi. After hours and on the weekends these compressors work alone to maintain a pressure of 100 psi in all lines in the plant.

Compressed Air Use

Compressed air is used in a variety of ways throughout the plant. The following describes how compressed air is used in two representative sections of the plant:

Assembly Lines and Engineering Technology

On the assembly lines and in the engineering technology department, compressed air is used for handheld instruments and nozzles at individual work stations. The following is a breakdown of the uses on the assembly line:

- 35 Nozzles used to clear dust or debris from parts
- 7 Drills
- 2 Vacuums
- 2 Rivet guns
- 1 Crimper
- 1 Caulk gun
- 1 Fume hood

Nozzles are required to maintain a maximum pressure of 30 psi according to OSHA regulations. This requires the use of a regulator at each nozzle joint.

Painting

The painting department of the plant uses compressed air in two paint guns, two nozzles and a paint gun/equipment cleaning machine.

Currently, the compressor system maintains air pressure in the range of 100-135 psi during the workday. In examining pressure use at different machines and tools in the plant, it was discovered that the two highest pressure uses were for water agitation in rinse tanks and to power the paint gun cleaner. The pressure gauges for these two pieces of equipment read 130 and 125 psi respectively. The spec plate on the paint gun and equipment cleaner indicated the machine could be operated between 85 and 125 psi, and still perform its function. Most of the other high use machines and tools operate at around 90 psi.

Leak Assessment

To perform the leak assessment, an Ultrasonic Leak detector was used. According to maintenance employees, the likelihood of leaks in the system pipes was very low as copper pipes were used to transport the air and soldering attached the pipes. This allowed the assessment to focus on air use on the plant floor. Tags were placed at each leak for easy identification and repair. A breakdown of the number of leaks detected in specific departments can be seen in Table 2 below.

Table 2. List of Compressed Air Leaks

Area	No. of Inaudible Leaks	No. of Audible Leaks
Compressor Room	4	0
Assembly Lines	5	2
Machining	21	8
Molding	0	2
Shipping & Receiving	3	0
Workshop	1	0
Total	**34**	**12**

Example #3: **Assessment of Compressed Air System** (adapted from report by Blair Debban, 2008)

The compressed air system in this manufacturing company contains numerous leaks and misuses of air. A few misuses that were noted include personal cooling, open blowing, and drains being left open. A simplified process flow diagram (Figure 1, below) was constructed which shows the maximum possible compressed air production based on compressor nameplate ratings. The unregulated air use of each of the four main compressed air lines shown below was determined during a test of the system.

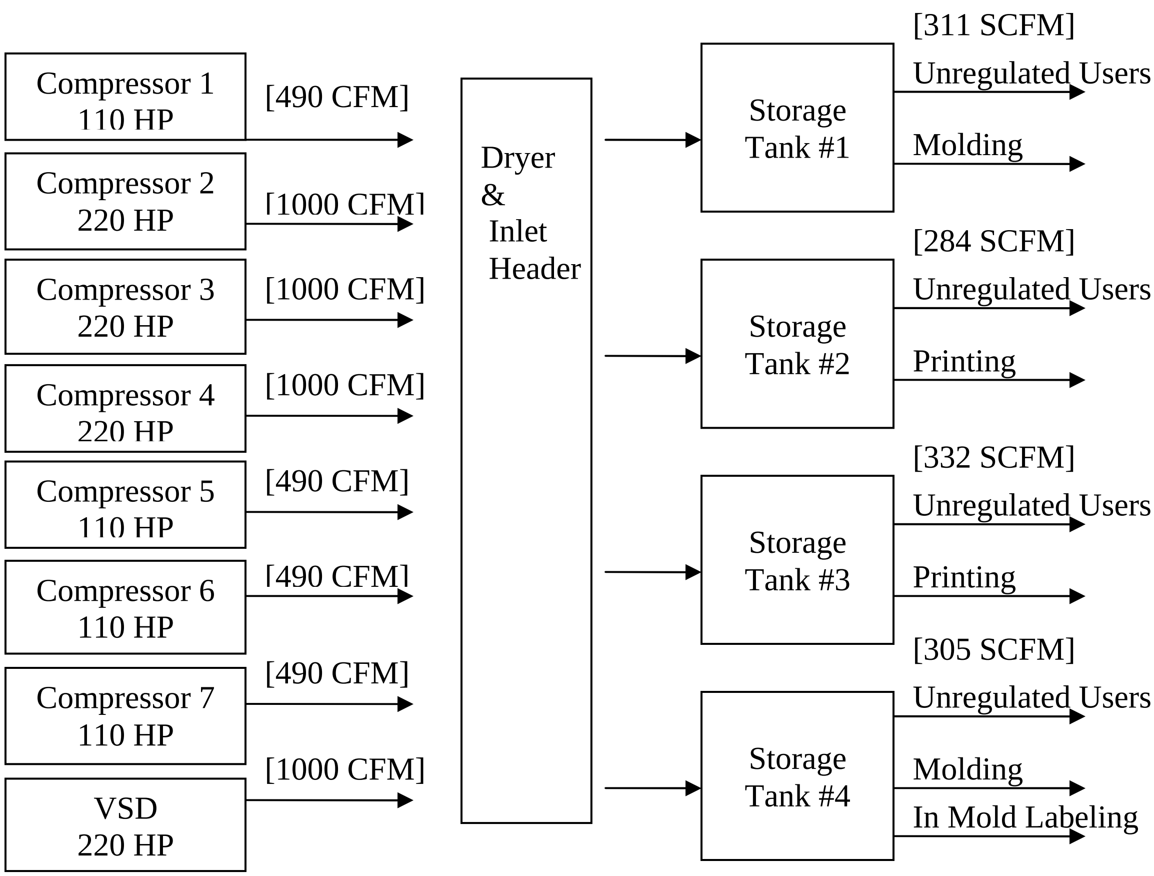

Figure 1 – Process Flow Diagram of Compressed Air System

The current cost of compressed air use at the company was calculated and is summarized in Table 1 below. The "All Air" use and "Unregulated Use" in SCFM were totaled from Figure 1 above. The "All Air" kWh usage was estimated from the input power (kW) of the compressors and dryers. The "Unregulated Use" kWh usage was estimated from a base load test of the system (performed by an outside professional) when no normal uses were occurring. The SCFM/kWh ratio varies depending upon compressor capacity and efficiency. For each "Unregulated Use" in Figure 1, the SCFM data was multiplied by the compressor specific kWh-to-CF ratio to estimate the electricity use. The associated cost was calculated from the electricity rate of $ 0.0385/kWh.

Table 1. Cost of Compressed Air Use

	Air Usage (SCFM)	Total Air Produced/Yr (CF)	Annual kWh Usage	Cost of Air/Yr
All Air	5960	1,128,463,200	4,809.240	$185,280
Unregulated Use	1232	647,639,200	2,330,160	$71,817

Appendix 2
Example P2 Opportunities for Compressed Air Systems

***Note:** Several examples of compressed air system opportunities are included below. Each of these addresses a different way to improve practices and achieve direct and/or indirect savings and each uses different techniques for encouraging implementation. In these examples, calculations are embodied within the narrative for easy reference, although in an actual report, these would likely be in appendices at the end so as not to interrupt the flow of the report.*

Area #1: Train Employees in Proper Use of Compressed Air

Example #1a: Implement leak management system (adapted from report by Caleb Peterson, 2011)

Justification: Although the company currently has an informal leak management system, where employees report noticeable leaks to their supervisors, it is not working efficiently. A high number of audible leaks were found during the assessment.

Recommendation: Use a formal leak management system to investigate future issues with leaks. To do this, employees should be trained to regularly check the airlines in their area of work for leaks, and not just stumble upon them. These job responsibilities can be rotated, or one specific employee can be responsible for this task. It is also recommended that the company purchase at least three Amprobe leak detectors and give one to the blow molding, blending, and packaging departments each to aid with the job. These detectors cost around $320 making the investment $960. Based on average sizes of leaks found in the plant, it can be assumed that that every year **$1,000** and **20,000 kWh** are wasted from new leaks generated (these values are assumed based upon trends in leaks). This means the payback period for this equipment will be a little **less than one year**.

Implementation Status: Not yet reassessed to determine impact.

Example #1b: Train employees in proper use of compressed air system (adapted from report by Caleb Peterson, 2011)

Justification: Using compressed air for things like minor cleanups and cooling employees is a convenient but inefficient practice and is relatively hazardous use of compressed air.

Recommendation: Management should adopt and communicate a policy for proper compressed air use. Inform all employees on the details of the policy such as stating that compressed air should not be used for personal cooling. It is important to train new employees, and to randomly monitor and supervise/remind existing employees until correct practices are established. Having procedures to prevent wasting compressed air will lead to less energy used by the compressor. This can be accomplished by training sessions or informational posters around the facility that describe the benefits of using the air properly. Though it is a very difficult thing to change employees' habits and make them put more effort into cleanups, proper usage should be stressed and the fact that air is not as "free" as it is commonly believed to be. Employees should take the extra time to clean up with manual tools like brooms and rags and cool themselves with a fan. An indirect benefit of doing this would be preventing employees from getting hurt by improper usage of the system. This is because dust and dirt particles, which may become entrained in compressed air, can cause serious health problems such as irritating lungs or damaging an eye, or compressed air can also penetrate the skin and cause air bubbles to form in the bloodstream, which may result in death.

Implementation Status: Not yet reassessed to determine impact.

Example #1c: Inform employees about cost of compressed air (adapted from a report by Nathan Vanis, 2008)

Justification: In certain departments, compressed air is used to keep work stations clean. Compressed air is blown constantly around the drill bits to keep the area free of debris. An example of this can be seen in Figure 2 below.

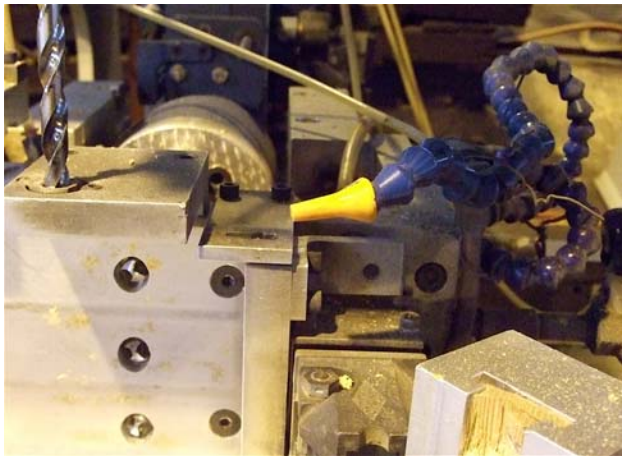

Figure 2. Compressed Air Blower

During lunch breaks and weekends, some airlines in a number of departments were observed to be still running. This results in excess air being used and could easily eliminated by simply shutting off the valves.

Recommendation: Inform employees about the costs of compressed air and how much can be saved by reducing compressed air use to help the company reduce costs and electricity use. To implement this suggestion, informative posters could be placed in/around work areas as well as break rooms to help explain potential savings. An example poster was created and can be seen in Figure 3 below. By implementing this P2 recommendation, the benefits would include the following:

- increased employee awareness of compressed air & energy costs
- reduced air compressor operating time
- less energy consumed
- less wear and tear on parts due to excessive operation
- less maintenance on compressor
- better performing tools and machines from maintaining constant pressure in lines

Implementation Status: Unknown but likely Not Implemented (adapted from P3 program case study publication, 2010)

Key Barriers/Benefits:
While this was considered an "easy" suggestion to implement, employers are often reluctant to adopt practices which require behavior change on the part of employees, especially if the potential impact is not well calculated/documented or if the savings are minimal.

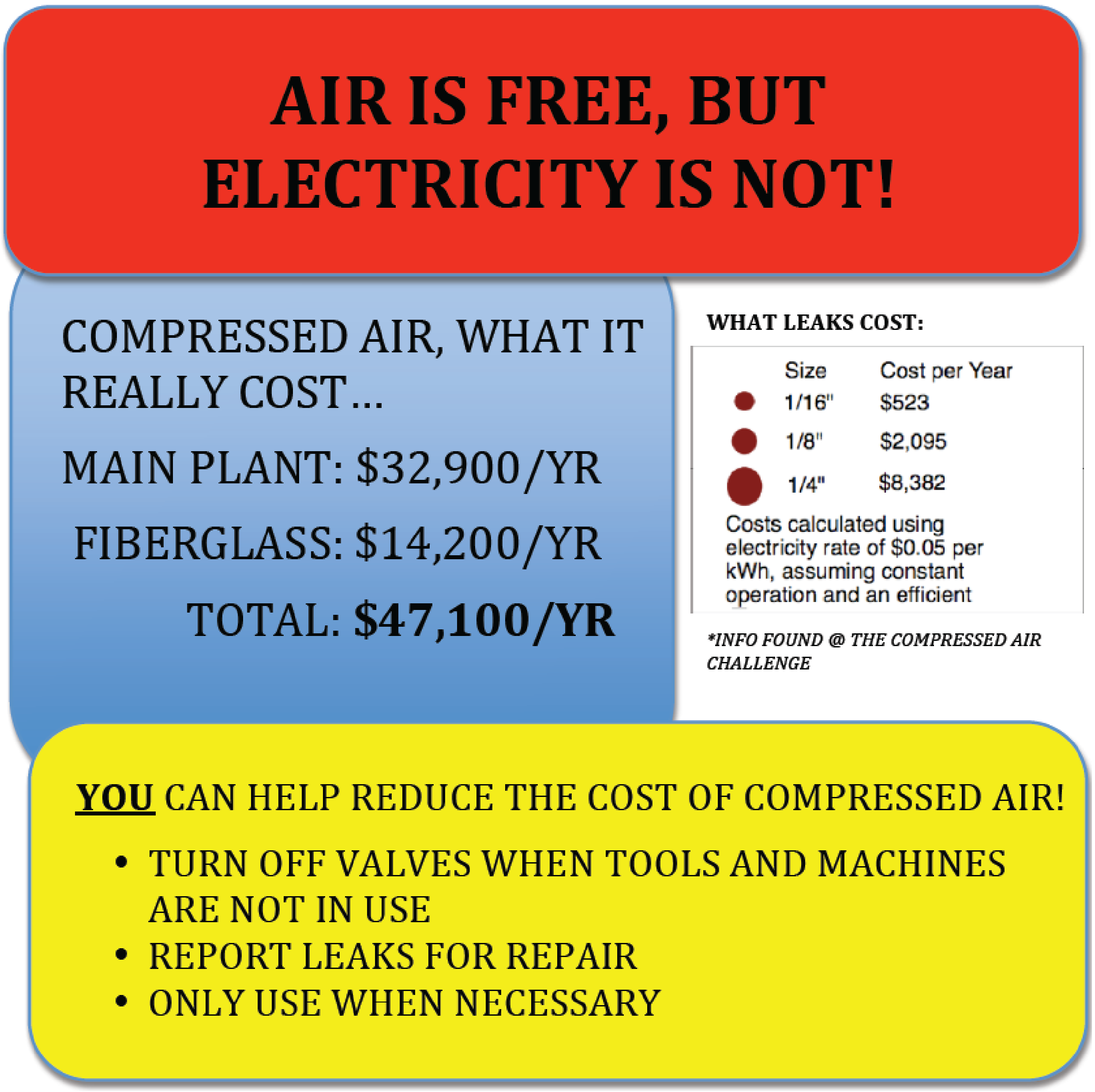

Figure 3. Poster to Inform Employees

Area #2. Repair Leaks

Justification: Leaks in an air compressor system continually release air, decreasing pressure in the system and resulting in wasted energy as the compressors engage repeatedly and unnecessarily. Repairing leaks will reduce energy demand and allow primary compressors to operate only intermittently during the day, thereby reducing energy consumption.

Example #2a: Fix the identified compressed air system leaks (adapted from reports by Blake Coleman, 2005 and Benjamin Stewart, 2008)

Recommendation: Fix the compressed air system leaks identified in the system assessment with a high-pressure sealant, using Teflon tape around all threaded connections, and replacing all leaking and damaged equipment. Based on an estimate from the company, labor costs are approximately $12 per hour. It is assumed that each inaudible leak will require 30 minutes to repair, and each audible leak will require one hour with an estimated cost of $860 for labor and materials. As seen in the calculations below in Tables 1 and 2 repairing leaks requires modest investment and will result in energy savings over time.

Table 1. Calculations of Resulting Waste from Compressor System Air Leaks

Type of Leak	*Quantity*	*Air Loss (m^3/yr)*	*Energy Costs per year*
Inaudible (<1mm)	34	362,055	$30
Audible (1-3mm)	12	646,907	$53
Total	46	1,008,962	$83

Table 2. Calculation of Cost-Savings of Leak Repairs

Labor Cost (per hour)	*Total Repair Time (hrs)*	*Total Repair Labor Costs*	*Repair Materials Costs*	*Total Annual Savings*	*Payback Period (yrs)*
$12	30	$360	$500	$83	10.3

Simple Payback Period:

Initial costs/annual savings = $860/$83/yr = 10.3 years

Implementation Status: Implemented

The company repaired all of the tagged leaks and has saved approximately $80/year in energy costs and 1,000,000 m^3/year in compressed air.

For another company (adapted from report by Eric Lueshen, 2006), fixing the air compressor system leaks was a priority. It was estimated that fixing the leaks decreased kWh usage by about **346,000 kWh/year**, for a cost savings of about **$15,500 per year.**

Key Barriers/Benefits: Waste and benefits were well documented. The projects were simple. The implementation costs were reasonable. The companies save on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Example #2b: Establish routine maintenance procedures to identify and fix compressed air system leaks (adapted from a report by Tom Soucie, 2006)

Recommendation: Use a regular maintenance regime to identify and repair compressed air leaks at all locations. Three-part tags are available throughout the facility for employees to tag audible leaks as they are noticed. Leaks can then be repaired and rechecked by maintenance. Additionally, a display board that shows pipes, tools, fittings, and other common air leak sources can be used to teach employees and maintenance workers how to be aware of and identify compressed air leaks. An ultrasonic leak detector is currently available for all qualified employees to use to identify leaks around the plant.

Tables 3 and 4 below, display the savings and payback periods related to this recommendation and estimated savings if leaks were addressed at a second facility given a similar situation.

Table 3. Air Leak Savings and Payback Period

Departments	KWh	Cost Savings	Payback Period
Assembly	322,180	$13,500	28 Days
Molding	237,800	$9,960	2 Months

Table 4. Potential Air Leak Savings and Payback Period 2nd Facility

Departments	# of Leaks	Cost Savings	Payback Period
Non-filtered	13	$2,308.41	15.4 days
Compressor Room	5	$1,627.68	8.4 days
Hoodloader	12	$2,144.88	15.3 days
New Supply Line	5	$1,118.08	12.3 days
Total 2nd Facility	**35**	**$7,199.05**	**13.3 days**

Implementation Status: Implemented
The company currently has implemented the proposed maintenance regime at both facilities and realized the identified savings.

Key Barriers/Benefits: Waste and benefits were well documented. The project was simple and involved engaging employees in the process. The implementation cost was reasonable and the payback period short. The company saves on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Area #3: Reduce System/Airline Pressure
Justification: A careful analysis to determine the maximum system pressure necessary for any given plant or area of a plant is warranted, because as a general rule, for every two psi reduction in pressure used, energy use is reduced by approximately 1-2% as well. It may be somewhat difficult to determine the lowest acceptable psi for tools/machines in use while still maintaining optimal performance, but the energy savings over time may be worth the effort.

Example #3a: **Reduce system pressure and test to assure demand is met** **(**adapted from report by Nathan Vanis, 2008)

Recommendation: Currently, the compressor system maintains air pressure in the range of 100-125 psi during the workday. Pressure could be reduced to about 100 psi without loss in performance, as the spec plates on equipment indicate the machines could be operated between 85 and 125 psi. A drop in maximum system pressure to 100 psi should be considered. This would result in great energy savings as every two psi reduction in pressure discharge can reduce energy use by about one percent. This recommendation would be especially feasible and effective when coupled with the repair of air leaks as the system would lose far less air to the leaks. It would be advisable to test the system running at the lower level for awhile to assure that overall demand can be met at 100 psi. Assuming all operations would still perform as well at 100 psi, the total amount of annual savings can be seen below in Table 3 (calculations for information in Table 3 can be seen below).

Table 3. Calculation of Annual Savings from Reduced Pressure

Compressor	Current PSI	Annual Cost	Reduce PSI to	Annual Savings
Maintenance	Avg. 115	$32,900	100	$3,700
Fiberglass	Avg. 118	$14,200	100	$1,900
			Total Savings	$5,600

Along with the annual cost savings of **$5600**, the company would also reduce their electric usage by **80,000 kWhrs**. Because implementing this recommendation involves simply adjusting the settings of the compressor, implementation costs were assumed to be zero, thus the payback period for this suggestion would be **immediate**.

Annual Savings from Reduced Pressure

Maintenance Dept.

Known Values:

115 PSI used on average in current operation

100 PSI to be used in future operation

$0.07 per kWh

Assumptions:

$32,900 annual cost of current operation

1.5% annual reduction in cost per 2 PSI

Calculations:

Annual Savings from Reduced Pressure:

$$(115\ psi - 100\ psi) \times \frac{1.5\%}{2\ psi} \times \$32{,}900 = \$3{,}700$$

Fiberglass Dept.

Known Values:
118 PSI used on average in current operation
100 PSI to be used in future operation

Assumptions:
$14,200 annual cost of current operation

Calculations:
Annual Savings from Reduced Pressure:

$$(118\,psi - 100\,psi) \times \frac{1.5\%}{2\,psi} \times \$14{,}200 = \$1{,}900$$

Implementation Status: **Unknown but likely Not Implemented** (adapted from P3 program case study publication, 2010)

Key Barriers/Benefits:
There was difficulty establishing the minimum pressure for various tools used in the plant while still maintaining optimal performance. The savings were modest and the implementation complex.

Example #3b: Reduce airline pressure by installing regulators (adapted from report by Benjamin Stewart, 2008)

Another company has implemented a similar opportunity. They have installed eight regulators, for a total cost of $320, to specific lines lowering the pressure. The basic pressure on the line is between 110 to 120psi. By installing regulators, the company estimated an annual cost savings of $1000 and a decrease of 2,500 kWh/year energy use. The payback period was less than four months (cost/annual savings=320/1000=.32 years)

Implementation Status: **Implemented**

Key Barriers/Benefits: Waste and benefits were well documented. The project was simple. The implementation cost was reasonable. The payback period was short. The company saves on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Example #3c: Use smaller nozzles to allow for lower airline pressure **(**adapted from report by Blake Coleman, 2005)

A third company has implemented a similar opportunity, installing smaller nozzles which allows for reduced system pressure while maintaining performance. The company reduced electricity usage by 133,000 kWh/year, saving over $5,500/year, with a payback period of less than three days.

Implementation Status: **Implemented**

Key Barriers/Benefits: Waste and benefits were well documented. The project was simple. The implementation cost was reasonable. The payback period was short. The company saves on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Area #4: Modify Structural Components of the Airline System

Example #4a: Install foot pedals to control compressed air use for tools (adapted from report by Nathan Vanis, 2008)

Practice Observed: Pedal operated pneumatic impact guns allow the operators to control when the impact guns are running. This drastically reduces compressed air use because air is flowing only when needed and is automatically shut off when not needed and the task is safer for the employees as well.

Implementation Status: Already Implemented

Example #4b: Install solenoid valves to close drains/valves when machines not in use (adapted from report by Blair Debban, 2008)

Justification: During normal operating hours, compressed air drains/valves are frequently left open when machines are not in operation. These should be closed to help reduce the amount of energy used.

Recommendation: If employees leave compressed air drains/valves open when machines are not in use, solenoid valves could be installed to shut the air off to the machines when the machines are not in use. The total cost of installing solenoid valves is estimated to be $13,000 with a simple payback period of 1.45 years. The details of this calculation are found below:

Calculations for Installing Solenoid Valves

Assumptions:

-Solenoid valves such as the 1" McMaster-Carr 4868K34 could be installed on the compressed air lines that feed the mold and print machines.
-Approximately 50 solenoid valves would be required and each solenoid costs $210.
-An estimated additional $50 labor cost would be required to install each solenoid.
-It is estimated that the use of solenoid valves would reduce the unregulated air usage by 10%.
-There is 266kW currently being used to supply the leak load.
-The electricity rate is $0.038526/kWh.

Calculations:

Cost of Installing Solenoid Valves:

$$(\$210 + \$50) \times 50 \ units = \$13{,}000$$

Annual Energy Savings of Installing Solenoid Valves:

$$266 \ kW \times 0.10 \times \frac{\$0.038526}{kWh} \times \frac{365 \ day}{yr} \times \frac{24 \ hr}{day} = \$9{,}000$$

Simple Payback Period:

$$\frac{capital\ cost}{energy\ savings} = \frac{\$13,000}{\$9,000/yr} = 1.45\ years$$

Implementation Status: Not yet reassessed to determine status.

Example #4c: Replace large air nozzles with smaller one (adapted from report by Blake Coleman 2005)

Justification: Some processes are accomplished using larger than necessary nozzles. Determining the minimum operational size will help reduce air and energy use and costs.

Recommendation: All the 1/8" nozzles used for blow off undesirable chemicals and materials in the plating process should be changed to 1/16" nozzles. This can result in a significant reduction of the amount of compressed air and energy used. All 1/16" nozzles that replace the 1/8" nozzles are a different color so that quality control can easily identify and monitor all nozzles that are replaced. The results of replacing the 1/8" diameter nozzles with the 1/16" diameter nozzles include:

- 1259 cfm saved/year
- 1,652,432 kWh saved/year
- $69,237 saved/year
- Payback period: 2.5 days

Detailed calculations are shown below in the attached spreadsheet. (Note to Reader: The attached spreadsheet is extensive and is based on the specific situation of the facility involved. This level of detail may be necessary in some situations and is provided here by example.) The savings from the nozzle replacement could nearly cover the cost of operating one 300 HP air compressors for a whole year.

Implementation Status: Implemented (adapted from report by Tom Soucie, 2007)
The company implemented this recommendation immediately, and the savings were as predicted. The plating department realized no appreciable difference in the blow-off quality after switching to the smaller nozzles.

Key Barriers/Benefits:
The implementation cost was reasonable. The payback period was short. The company saves on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Plating Blowoff Nozzle Replacement Savings

Atomospheric Pressure	0.0419 $/kWh			PI
14.7 psi	0.25 hp/scfm	0.746 kW/hp		3.14

Using Moss Equation $W(lb/s) = 0.5303 \times A\,(in^2) \times C \times P\,(psia)\ /\ \sqrt{T(R)}$

Nozzle Diameter	Gauge Pressure (psig)	C Discharge Coefficient	Temp (F)	Air Density (lb/ft3)	Volume (cfm)	Motor Eff	Time ran hr/ day	kWh/day	Cost ($/day)	$/yr
0.125	35	0.8	80	0.074	**9.03**	0.9	20	37.4283	1.568	572.41
0.063	35	0.8	80	0.074	**2.26**	0.9	20	9.3571	0.392	143.10
0.040	35	0.8	80	0.074	**0.92**	0.9	20	3.8327	0.161	58.61
Super Saver	30	Reported CFM from website			**6.61**	0.9	20	27.3948	1.148	418.96

C Discharge Coefficient	Temp (F)	Air Density (lb/ft3)	Motor Eff	Time ran hr/ day
0.8	**80**	**0.074**	**0.9**	**20**

Using Formula Examples Above

Nozzle Replacement Savings

Nozzle Diameter	Gauge Pressure (psig)	# Of Nozzles / Strand	Total Hours/ Day	Total Volume (cfm)	Cost ($/day)	kWh/day	Hours/ year	Cost ($/year)	kWh/ year	Cfm Saved	$ Saved /Yr	kWh Saved
TFS PLT-1000												
0.040	35	123	18.57	113.75	18.34	437.64	6777	6693.08	159739.45			
TTL PLT-1100												
0.040	35.00	135	17.76	124.84	19.25	459.43	6482	7026.30	167692.01			
OnStar PLT-1200												
0.063	30.00	105	14.81	213.21	27.41	654.14	5404	10004.13	238762.11			
DEL PLT-1300												
0.125	30.00	96	13.18	779.75	89.20	2128.89	4809	32558.23	777046.08	584.81	24418.67	582784.56
0.063	30.00	96	13.18	194.94	22.30	532.22	4809	8139.56	194261.52			
GFS PLT-1400												
0.04	35	120	5.73	110.97	5.52	131.74	2091	2014.74	48084.47			
GL GBL/GDL PLT-1500												
0.125	30	45	24.29	365.51	77.09	1839.79	8866	28136.82	671523.17	274.13	21102.62	503642.38
0.063	30	45	24.29	91.38	19.27	459.95	8866	7034.21	167880.79			
AFS PLT-1600												
0.04	35	114	19.27	105.42	17.64	421.06	7035	6439.51	153687.50			
0.125	35	19	19.27	171.59	28.71	685.32	7035	10480.97	250142.41	128.69	7860.35	187597.92
0.063	35	19	19.27	42.90	7.18	171.33	7036	2620.61	62544.49			
PLT PLT-1700												
0.04	38	108	16.78	105.90	15.43	368.33	6126	5632.98	134438.78			
0.125	38	18	16.78	172.37	25.12	599.49	6126	9168.27	218813.12	129.28	6875.83	164100.91
0.0625	38	18	16.78	43.09	6.28	149.87	6127	2292.44	54712.21			
TLL PLT-1800												
0.04	35	126	24.11	116.52	24.39	582.08	8799	8902.00	212458.18			
0.125	35	2	24.11	18.06	3.78	90.23	8799	1379.90	32933.13	13.55	1034.88	24698.91
0.0625	35	2	24.11	4.52	0.95	22.56	8800	345.01	8234.22			
GSL PLT-2100												
0.04	35	114	17.25	105.42	15.79	376.83	6296	5763.06	137543.21			
0.125	35	9	17.25	81.28	12.17	290.53	6296	4443.15	106041.74	60.96	3332.19	79527.10
0.0625	35	9	17.25	20.32	3.04	72.63	6297	1110.96	26514.65			
SGL PLT-2200												
0.04	35	111	21.93	102.65	19.54	466.45	8004	7133.68	170254.91			
0.125	35	8	21.93	72.25	13.76	328.30	8004	5020.89	119830.31	54.19	3765.51	89868.99
0.0625	35	8	21.93	18.06	3.44	82.08	8005	1255.38	29961.32			
STL PLT-2400 (new line)												
0.04	35	126	20.00	116.52	20.23	482.91	7200	7284.28	173849.17			
0.125	35	2	20.00	18.06	3.14	74.86	7200	1129.14	26948.35	13.55	846.85	20211.26
0.0625	35	2	21.00	4.52	0.82	19.65	7200	282.28	6737.09			
Totals												
		199	**Nozzles**							**1,259.15**	**$69,236.90**	**1,652,432.02**

300HP Costs/Year	200HP Costs/Year
$73,751.84	$49,685.45

200 HP Compressors Ran For 1 Year from Savings **1.39**

300 HP Compressors Ran For 1 Year from Savings **0.94**

Payback Period

8	***Hours for Installation***	***$38.00 / Bag of 50 1/16" Nozzles***
$40.00 /Hour		***$152,916.53 Current Plating Cost***
Payback Period		***2.49 Days***

Example #4d: Modify or change location/temperature of air intake (adapted from report by Eric Lueshen, 2006)

Justification: The warmer the intake air to the compressor is, the more work the compressor must do to compress it to operating pressure. During the warmer months, the temperature of air above the steel roof near the air intake to the compressors will be substantially higher than surrounding air. When inlet air is cooler, it is also denser. As a result, mass flow and pressure capability increase with decreasing intake air temperatures. This holds true particularly in centrifugal air compressors like the one in Plant A.

Recommendations: There are several options that can be implemented to reduce the temperature of intake air:

- Use a highly reflective (Hi-R) roofing material or pigment paint on roof area around the intake stacks.
- Provide shade for the area of the roof where the intake stacks are located or move the stacks to a shaded side of the building.
- Hire a compressed air specialist to design an intake air system that draws cool air from inside the facility without creating a low-pressure problem. This compressed air specialist could also investigate other energy and cost saving opportunities available with the compressed air systems.

Implementation Status: Not Implemented (adapted from report by Scott Barker, 2009)
The company reported that the location of the intake air had not been moved from the roof, nor had they hired a specialist to redesign the compressed air system. They are not contemplating any changes to their system other than repairing leaks.

Benefits and Barriers: The implementation costs were high and the projects very complex. The company opted not to immediately undertake those projects.

Example #4e: Replace the main compressor (adapted from report by Maggie Lock, 2006)

Justification: The facility has two compressors, one of which runs continuously while the other is a back up in case the other fails. Both compressors are water-cooled and use re-circulated, closed-loop water. The company has allotted a certain amount of capital over a 2-year period in the next few years to rebuild the current compressor.

Recommendation: Purchase a new compressor rather than rebuild the existing one. Because there is already some capital budgeted for the compressors, it is well worth considering the purchase of a newer model. A new compressor would be more efficient, and there are several options including air or water-cooled, as well as oil-free models. The following table summarizes the capital costs of a few example products, all of which are 125-hp models, the same horsepower as the current compressors.

Table 1. List of Example Air Compressors

Model	Cooling Method	Capacity	Price
Rotary Screw Air Compressor	Water	543 CFM @ 130 PSIG	$46,150
Rotary Screw Air Compressor	Air	543 CFM @ PSIG	$46,150
Oil-Free Rotary Screw Air Compressor	Water	167-547 CFM @ 130 PSIG	$117,360
Oil-Free Rotary Screw Air Compressor	Air	167-547 CFM @ 130 PSIG	$117,360

Although the oil-free models are significantly more expensive, there would be some environmental advantage in eliminating oil from the compressor. Also, the company would see electricity savings from the new model, regardless of which was chosen. Table 2 provides a summary of the cost and electricity savings of a new model, when compared to the costs of the current compressor. Calculation details can are shown below in Table 3.

Table 2. Calculation of Cost and Electricity Savings of New Compressor

Model	Annual Cost Savings	Annual Electricity Savings	Payback Period
Oil Injected Rotary Screw Compressor	$14,000	280,000 kWh	3.3 yr
Oil Free Rotary Screw Compressor	$14,000	280,000 kWh	8.4 yr

When choosing the new compressor model, one factor to consider is whether to purchase an air or water-cooled model. With the use of an air-cooled compressor, there is the potential for heat recovery that can be distributed throughout the building during the winter months, thus reducing heating costs. There would also be slight water savings with an air-cooled model. However, additional capital costs and the cost for ductwork would have to be factored in before deciding which model is the better option for the facility.

Table 3. Calculation of Cost and Electricity Savings of New Air Compressor

Assumptions: o Annual cost of compressed air is $40,000, based on estimate from data acquired from an engineer with the company o New compressor is a variable speed drive model o According to product information on the variable speed drive model, VSD compressors can save up to 35% of energy costs.	
Annual Cost Savings with New Compressor	*$40,000 x 0.35 =* ***$14,000***
Annual Energy Savings with New Compressor	*($14,000/yr) / ($0.05/kWh) =* ***280,000 kWh***
Payback Period	*Capital Cost of New Compressor = $46,150* *(new model is VSD rotary screw equivalent)* *Annual Savings = $14,000* *Payback = $46,150 / ($14,000/yr) =* ***3.3 yr***
	Capital Cost of New Compressor = $117,360 *(new model is Oil-Free VSD rotary screw equivalent)* *Annual Savings = $14,000* *Payback = $117,360 / ($14,000/yr) =* ***8.4 yr***

Implementation Status: Implemented (adapted from report by Kate Johnson, 2008)
This suggestion has been implemented. The company has replaced one compressor with a 60 hp rotary air compressor, which is much more efficient. The new air compressor cost $22,000 installed and it is an oil injected rotary screw model. They are currently setting aside funds to replace their back-up air compressor next year. The old model emitted 40-50 ppm of oil when new (amount of oil increases with age) and the new model emits 2-5 ppm when new, which is a significant decrease in oil emitted. The anticipated savings from this new model is approximately $10,000 a year, which relates to an estimated 200,000 kWh electricity reduction per year.

Key Barriers/Benefits: The implementation cost for replacing the compressor was anticipated and budgeted for. The payback period was reasonable. The company saves on operating costs, energy consumption, and related environmental impact on an ongoing basis.

Example #4f.: Relocate compressor (adapted from report by Nathan Vanis, 2008)

Justification: By moving the current air compressor unit to a different location, the compressor would run in a cooler, cleaner, and more accessible environment and the employees would experience a better and safer working environment.

Recommendation: Relocate compressor. To implement this change, it would require a capital cost of $6000. This estimate includes the cost of materials and labor ($3600 for a 12x12 shed + $2400 additional parts, labor). If the compressor were to be moved, the benefits would include:

- air used by compressor would be cleaner/cooler
- cleaner work environment for employees
- easier access for maintenance

- filters would last longer
- less dust/debris to contaminate filter
- less noise within the building
- less cost in maintenance

The main advantages of moving the air compressor would be easier access, cleaner environment for the compressor and for employees. However, energy use probably wouldn't change enough to alone justify a large annual savings.

Implementation Status: **Implementation Planned** (adapted from P3 program case study publication, 2010)
The company plans to relocate this compressor in the near future to ensure a safer and more comfortable work environment and decreased risk to personnel.

Key Barriers/Benefits:
Steps to reduce environmental impact often simultaneously have a positive impact on the health and safety of the working environment for employees. Employers are typically sensitive to opportunities to reduce risk for employees.

Example #4g.: **Switch to a mechanical agitator** (adapted from report by Ben Stewart, 2008)

Justification: Using compressed air to keep tanks agitated is very inefficient, pumping air at a relatively high psi for eight or more hours per day.

Recommendation: Implement a mechanical agitation system, powered by electricity, in order to save money and energy.

Implementation Status: **Not Implemented** (adapted from report by Scott Barker, 2009)
The company looked into this opportunity, but is still using a compressed air agitation. The mechanical agitator was not a priority and is no longer being researched.

Key Barriers/Benefits: The implementation cost was not quantified and likely a significant capital investment. The payback period was not quantified and likely to be several years. The annual energy consumption, costs, and related environmental impacts were not quantified but may have been substantial.

Appendix 3
Greenhouse Gas Reductions Explanation and Calculations

Relevance of Greenhouse Gas Emission Estimates

This issue is an increasingly important one for business decision makers as it relates to regulations, stakeholder interests and day-to-day business operations and energy use. There are several important dimensions of analysis for any pollution prevention opportunity. One is certainly direct environmental impact (e.g. reductions in solid or hazardous waste, water use, air pollution, or energy use). Another important dimension is cost. Yet another is the intangible (not quantifiable) impact, such as reduced liability, increased worker safety/satisfaction, or improved corporate image. A final important dimension is indirectly estimating the impact on greenhouse gas (GHG) emissions that can be achieved by implementing any given pollution prevention opportunity.

GHGs include a number of different gases such as carbon dioxide, methane, nitrous oxide, ozone, chlorofluorocarbons and water vapor. These gases contribute to the "greenhouse effect" in the Earth's atmosphere. While GHGs make the planet warm enough to be habitable, an excessive amount of these gases is believed to be building up in the atmosphere and causing the average global temperature to rise, leading to climate change and instability. A significant spike in GHG concentrations in the atmosphere has occurred since the industrial revolution, pointing to the man-made nature of this change. This is why a new emphasis, and discussion of possible regulations, has been placed on reducing GHG emissions in all parts of our society, including government, business and industry.

The most widely recognized unit for measuring GHG emissions is carbon dioxide equivalent (CO2e). Each of the GHGs has a different capacity to heat the earth's atmosphere, called its global warming potential (GWP). Carbon dioxide (CO2) has a GWP of 1, so in order to standardize reporting, when GHG emissions are calculated, they are reported as equivalent to a given volume of CO2.

Reductions in GHG emissions can be estimated using a variety of calculation tools and computer models. The direct environmental/cost benefits estimated or realized are used as quantified input for these calculations, therefore the resulting GHG emission reduction estimates are considered indirect benefits. Some commonly used tools are listed below:

--Nationally recognized conversion factors from the U.S. Department of Energy and the American Water Works Association are used to estimate GHG emissions for electricity, natural gas, and water use. For example, kilowatt-hours (kWh) of electricity used can be converted to GHG emissions using a factor of 1.404 pounds CO2 e per kWh.

--Another tool to determine GHG emissions related to solid waste, is the EPA's WAste Reduction Model (WARM). This online calculator uses a life-cycle approach to determine the change in GHG emissions caused by alternative end-of-life waste management decisions or disposal methods for a number of different kinds of wastes. For example, using the weight of a solid waste diverted from a landfill and recycled, an approximate reduction in GHG can be calculated. WARM is periodically updated and new material types are added by the EPA as new information from climate change research becomes available.

--Another model used to estimate GHG reductions is the Economic Input Output Life Cycle Assessment (EIO-LCA) developed by researchers at Carnegie Mellon University. This model provides a useful approximation of GHG reductions through the full life-cycle production of a material or chemical, based on the cost savings from reductions in use. For example, if a business reduces its lubricating oil purchases by $50,000, the EIO-LCA estimates the GHG emissions to produce that oil through the mining, extracting, refining, packaging and delivery (to list a few) steps in the process of getting that oil to the end user.

--Recycled Content (ReCon) Tool: EPA created the ReCon Tool to help companies and individuals estimate life-cycle greenhouse gas (GHG) emissions and energy impacts from purchasing and/or manufacturing materials with varying degrees of post-consumer recycled content.

A summary sentence stating the amount of GHG reduction should be included with each recommendation, e.g. "Fixing air leaks will save 200,000 kWh/year and reduce GHG by 190 $MTCO_2e$/year. When using one of these models to estimate GHG emission reductions for a client, always provide an explanation of which model was used, why, what assumptions were applied, and the importance of reducing GHG emissions as a business and global sustainability strategy. An example of an Appendix documenting such follows.

Example Appendix of Greenhouse Gas Calculations
(adapted from report by Caleb Peterson, 2011)

Recommendation: Fix Air Leaks – 200,000 kWh/yr saved

- Assumptions
  - 200,000 kWh/yr saved
  - GHG conversion based on Nebraska conversion factor
- Calculations
  - Based on the EPA GHG calculator, conservation of 200,000 kWh/yr results in a reduction of **190 $MTCO_2e$/year**
- Sources
  - U.S. EPA, Clean Energy. "eGRID 2007 Version 1.1." February 2009. Downloadable ZIP file: eGRID20071_1year05_aggregation.xls, tab NRL05 and US05. (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download)

Recommendation: Implement Leak Management System - 20,000 kWh/yr saved

- Assumptions
  - 20,000 kWh/yr saved
  - GHG conversion based on Nebraska conversion factor
- Calculations
  - Based on the EPA GHG calculator, conservation of 20,000 kWh/yr results in a reduction of **19 $MTCO_2e$/year**
- Sources
  - U.S. EPA, Clean Energy. "eGRID 2007 Version 1.1." February 2009. Downloadable ZIP file: eGRID20071_1year05_aggregation.xls, tab NRL05 and US05. (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download)

Recommendation: Reduce Airline Pressure - 200,000 kWh/yr saved

- Assumptions
  - 200,000 kWh/yr saved
  - GHG conversion based on Nebraska conversion factor
- Calculations

- Based on the EPA GHG calculator, conservation of 200,000 kWh/yr results in a reduction of **190 $MTCO_2e$/year**

- Sources
  - U.S. EPA, Clean Energy. "eGRID 2007 Version 1.1." February 2009. Downloadable ZIP file: eGRID20071_1year05_aggregation.xls, tab NRL05 and US05. (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download)

Recommendation: Renovate Airline System – 180,000 kWh/yr saved

- Assumptions
  - 180,000 kWh/yr saved
  - GHG conversion based on Nebraska conversion factor

- Calculations
  - Based on the EPA GHG calculator, conservation of 180,000 kWh/yr results in a reduction of **170 $MTCO_2e$/year**
- Sources
  - U.S. EPA, Clean Energy. "eGRID 2007 Version 1.1." February 2009. Downloadable ZIP file: eGRID20071_1year05_aggregation.xls, tab NRL05 and US05. (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download)

Recommendation: Install Heat Recovery System – 5,000,000,000 Btu saved

- Assumptions
  - 5,000,000,000 Btu saved
  - GHG conversion based on Nebraska conversion factor - 5.32×10^{-8} $MTCO_2e$/Btu
- Calculations
  - Based on EPA GHG calculator, conservation of 5,000,000,000 Btu/yr results in a reduction of **266 $MTCO_2e$/year**
- Sources
  - The Climate Registry, "General Reporting Protocol" 2008. (http://www.theclimateregistry.org/downloads/GRP.pdf)
  - IPCC Second Assessment Report, 1995, Chapter 2, Table 2.14, Page 212. (http://www.ipcc.ch/ipccreports/ar4-wg1.htm)

Recommendation: Purchase Pulsair Blenders - 300,000 kWh/yr saved

- Assumptions
  - 300,000 kWh/yr saved
  - GHG conversion based on Nebraska conversion factor
- Calculations
  - Based on the EPA GHG calculator, conservation of 300,000 kWh/yr results in a reduction of **286 $MTCO_2e$/year**
- Sources
  - U.S. EPA, Clean Energy. "eGRID 2007 Version 1.1." February 2009. Downloadable ZIP file: eGRID20071_1year05_aggregation.xls, tab NRL05 and US05. (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download)

Total Emission Reductions 190 + 19 + 190 + 170 + 266 + 286 = **1,121 $MTCO_2e$/year**

Appendix 4
Tips for Making the Business Case for Change

Tip # 1: Writing an Executive Summary

An executive summary is a brief overview of a report designed to give readers a quick preview of its contents. Its purpose is to consolidate the principal points of a document in one place. After reading the summary, your audience should understand the main points you are making and your evidence for those points without having to read every part of your report in full. It is called an executive summary because the audience is usually someone who makes funding, personnel, or policy decisions and needs information quickly and efficiently in order to make decisions and respond appropriately.

Guidelines:

An executive summary should communicate independently of the report. It should stand on its own as a complete document.

It should explain why you wrote the report, emphasize your conclusions or recommendations, and include only the essential or most significant information to support those conclusions.

Use subtitles, bullets, tables, selective bolding or other types of organizational structure to add clarity to your summary

It should be concise—about 10% of the length of the full report.

It should be organized according to the sequence of information presented in the full report. Don't introduce any new information that is not in your report.

To help with organizing the executive summary, after you have written the full report, find key words; words that enumerate (first, next, finally); words that express causation (therefore, consequently); words that signal essentials (basically, central, leading, principal, major); and contrast (however, similarly, less likely).

Read the completed summary with fresh eyes. Check spelling, grammar, punctuation, details, and content. Ask someone else to read it.

Tip #2: Technical Writing Tips:

Use these tips as a **checklist** as you prepare your report.

- **Proof reading.** Write your report, let it sit, then proof read it for grammar, jargon, clarity, multiple meanings, and technical correctness before submittal. Re-read the report from the recipient's point of view. Reading the report aloud may help.
- **Figures and tables.** Refer to each figure and table in the text prior to inserting it. Always place the figure or table in the report soon after you have referred to it. Include a title and number for all figures and tables, capitalizing the title when referring to a specific table or figure, e.g., "All of the wastes generated by the shop are listed in Table 1
- **Transitions.** Provide brief transition sentences between sections of the report and before a bulleted list to explain what the list consists of and how it is organized.
- **Parallel construction.** Use parallel construction in all numbered or bulleted lists. For example, all items should be a complete sentence or none should be; or all items might begin with an active verb, e.g., "use," "change," "remove" or a noun, like this list.
- **Format.** A general format/outline has been suggested, although this may need to be modified to address a client's requests. Generally you should:
  - Move from generalities to specifics, in each section and across the report as a whole.
  - Use page numbers.
  - Keep section headings with the narrative that follows at page breaks.
  - Rarely split a table across two pages.
- **Abbreviations.** On first use, spell the term out completely, followed by the abbreviation in parentheses. For example, "Volatile Organic Compounds (VOCs) are another waste that could be minimized." Subsequently, just the abbreviation is sufficient unless it is used at the beginning of a sentence. Never start a sentence with an abbreviation or a numeral.
- **Professional tone.**
  - Avoid slang, informal terminology (inexpensive vs. cheap), or imprecise (there, that, it) language.
  - Be careful how you word suggestions. Avoid making recommendations outside of your area and level of expertise in source reduction and waste minimization.
  - Use tact and be positive in your conclusions. Remember a reader likes to be complimented, but can see through phoniness.
  - Be careful to confirm your information if you state it as a fact; or cite your source, e.g., "According to Mr. Jones, Plant Engineer, . ." or state that the information is a potential based on xyz assumptions.
- **Common errors.**
  - i.e. vs. e.g.: i.e. means "that is" or "in other words," and e.g. means "for example."
  - compliment vs. complement: a compliment is a nice comment, and a complement is a part of a whole
  - how many vs. how much: how many can be counted, and how much is uncountable, e.g., how many bottles of water vs. how much water.
  - policies vs. procedures vs. practices: policies are formal written positions or statements about some issue; procedures are written directives aimed at accomplishing a task or complying with a policy; practices are typically informal steps people take, which may or may not follow written policies and procedures

Tip #3: General Recommendations

General recommendations are made to help a company establish the culture and infrastructure needed to establish and sustain a commitment to source reduction and sustainability. Examples of commonly made general recommendations include:

1. A pollution prevention policy statement should be generated and periodically updated by management to formally reflect management's commitment to incorporating pollution prevention in the company's operations. Some examples of formal policy statements follow:

> *This company is committed to continued excellence, leadership, and stewardship in protecting the environment. Environmental policy is a primary management responsibility, as well as the responsibility of every employee.*
>
> *The corporate objective is to reduce waste and achieve minimal adverse impact on the air, water, and land through excellence in environmental control.*
>
> *Minimizing or eliminating the generation of hazardous waste is a prime consideration in process design and plant operations and is viewed by management as having a priority as high as safety, yield, and loss prevention.*

2. To further implement the corporate pollution prevention policy, one or more "cause champions" should be selected to lead the pollution prevention program and overcome the resistance present when changes are made to existing operations. These "cause champions" may include a project manager, an environmental coordinator, or anyone else dedicated to implementing the pollution prevention ideal and company policy. These individuals must be given authority by management to carry out the policy.

3. Input from employees should be considered, encouraged, and valued. Since the employees must deal with the waste, they may have insight into how a specific pollution prevention opportunity may be implemented. Many companies offer incentives to employees who suggest innovations to minimize or reduce waste generation.

4. Goals should be established to help implement and track the progress of the corporate pollution prevention policy. Specific, quantitative goals should be set that are acceptable to those willing to work to achieve them, flexible to changing requirements, and achievable with a practical level of effort. To document the progress of the pollution prevention goals, a waste accounting system should be used.