Replacement of Pneumatic Tools with Electric Alternatives

A study to quantify Minnesota's opportunity
for industrial energy conservation
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Abstract

The purpose of this project was to estimate the energy consumption of pneumatic hand tools throughout the state of Minnesota, to estimate the savings potential if these tools were switched to electric tools, and to develop a calculator tool for businesses to easily identify the costs, benefits, and simple payback period associated with switching from pneumatic to electric hand tools.

Energy consumption estimates for pneumatic hand tools in Minnesota were developed by collecting NAICS codes of businesses with assessment recommendation codes for compressed air efficiency improvements from Department of Energy industrial assessment centers. These NAICS codes were used to develop a spreadsheet of all Minnesota businesses within these subsectors via Mergent Intellect. Industries within these subsectors were then researched and classified based on their likelihood to use compressed air. Businesses within these industries were called and surveyed with regards to their use of pneumatic and electric hand tools. The survey responses were used to estimate pneumatic tool compressed air consumption. These values were weighted based on number of employees at each business. Weighted average airflow per employee values were then applied to each industry based on survey results, and corrected for the likelihood of that industry to use pneumatic tools. In this way, an overall estimate for airflow and electric consumption was developed for pneumatic hand tools in Minnesota. The electric consumption was multiplied by the average Minnesota blended industrial energy rate of $.0702 per kWh to develop the cost estimate.

Pneumatic hand tools in Minnesota use an estimated 148.8 million kWh of energy per year, for an energy cost to industry of $10,450,000 per year. Equivalent electric tools would use an estimated 11 million kWh of energy, for a cost to industry of $772,000 per year. This is an overall savings potential of roughly 137.8 million kWh and $9,678,000 per year. This equates to emissions reductions of 114,100 tons of carbon dioxide (CO_2).

The Minnesota Technical Assistance Program then developed a Pneumatic/Electric Hand Tool Cost Savings Calculator[1] to assist businesses with calculating their savings potential and simple payback period for switching from pneumatic to electric hand tools. Typical payback periods for these projects are less than one year.

[1] MnTAP Pneumatic to Electric Tool Cost Calculator (http://z.umn.edu/toolcalc)

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Definition of Terms and Acronyms

ARC	Assessment Recommendation Codes
IAC	Industrial Assessment Center
Industry	Collection of businesses sharing the same six digit NAICS code
Mergent Intellect	An online business directory used to gather data in this project.
MnTAP	Minnesota Technical Assistance Program
NAICS	North American Industrial Classification System
Sector	Collection of businesses sharing the same first two digits of their NAICS code
Subsector	Collection of businesses sharing the same first three digits of their NAICS code
USDOE	United States Department of Energy

Executive Summary

The purpose of this project was to estimate the energy consumption of pneumatic hand tools in the industrial sector throughout the state of Minnesota, to estimate the savings potential if these tools were switched to electric tools, and to develop a calculator tool for businesses to easily identify the costs, benefits, and simple payback period associated with switching from pneumatic to electric hand tools.

This is a relevant question since compressed air use in industry is widespread and it is has been shown that for doing mechanical work, the use of compressed air is relatively inefficient when compared to electromechanical alternatives. A common rule-of-thumb is that only about 10% of the energy that goes into an air compressor is retrievable in the form of pressure to do work, with massive losses to heat. Making matters worse, compressed air systems are prone to leakage – figuratively wasting energy into thin air. Due to the noise they generate, compressors are often placed into their own room or stuck into a back corner. The air generated is piped throughout facilities silently, and much like electric and water utilities, compressed air is often considered a utility resource, ever-available, and it is easy to forget that yards away there is a large, multi-horsepower compressor running to generate this air. Electric-driven (wired or battery-operated) power tools on the other hand require a fraction of the energy that the same pneumatic tools would use.

To estimate the electricity used by pneumatic tools, industrial sectors where tools are used were determined. Significant industries were identified through review of existing data and through interviews with representatives from industry, utilities, and compressed air and pneumatic tool experts. Representative samples of respondents' information was averaged for a number of industries and the information obtained from existing data and interviews was used to mathematically model estimated energy use by both tool types to determine existing energy consumption and anticipated savings achievable through tool switching.

Pneumatic hand tools in use by industrial and manufacturing facilities in Minnesota use an estimated 148.8 million kWh of energy per year, for an energy cost to industry of $10,450,000 per year. Equivalent electric tools would use an estimated 11 million kWh of energy, for a cost to industry of $772,000 per year. This is an overall savings potential of roughly 137.8 million kWh and $9,678,000 per year. This equates to emissions reductions of 114,100 tons of carbon dioxide (CO_2).

Primary Metals Manufacturing and Transportation Equipment Manufacturing were two subsectors with significant opportunity for conservation due to their relatively higher reliance on manually-operated tools. Sites within these industries are fewer in population throughout the state, but on average, use significantly more pneumatic tool energy. Utilities seeking to drive conservation should therefore prioritize their efforts on encouraging their industrial customers in these subsectors to make the switch to electric driven tools. Five additional significant subsectors with larger population sizes but with lower average pneumatic tool energy use were also identified.

There are a number of potential barriers for facilities seeking to switch tool types. These barriers range from overcoming operational inertia, re-configuring workspaces to accommodate new tool types, and

determining the overall benefits to tool switching, including those related to cost savings for ditching pneumatic tools for electric alternatives. Each facility's current situation is varied and difficult to predict, but understanding the energy use and cost implications is more straightforward. A savings calculator was developed to aide in making this decision based on the energy and cost savings to be expected by switching tool types.

The Minnesota Technical Assistance Program then developed a Pneumatic/Electric Hand Tool Cost Savings Calculator[2] to assist businesses with calculating their savings potential and simple payback period for switching from pneumatic to either wired or battery-operated electrically-driven hand tools. Typical payback periods for these projects are less than one year.

[2] MnTAP Pneumatic to Electric Tool Cost Calculator (http://z.umn.edu/toolcalc)

Introduction

Compressed air-driven – pneumatic – power tools use approximately seven to thirteen times as much energy as electric motor-driven power tools. This relative inefficiency of compressed air is often an overlooked aspect of efficient manufacturing which translates into an opportunity to reduce costs at many manufacturing companies. Minnesota Technical Assistance Program (MnTAP) quantified this opportunity by identifying Minnesota manufacturing subsectors and industries that have significant pneumatic power tool usage, estimating the air consumption of pneumatic power tools, and the electric consumption rate of the air compressors, and estimating the potential energy and cost savings from replacing pneumatic power tools with electric-driven power tools. Estimating the consumption of pneumatic power tools in Minnesota required a quantitative knowledge of parameters such as power tool use in various industries. To gain this knowledge, data was collected through phone interviews with Minnesota businesses in order to create a basis for the power tool energy estimates.

A more detailed methodology describing the means by which MnTAP constructed the statewide usage and savings estimates follows this introduction. After estimating the potential for energy savings by switching from pneumatic to electric hand power tools, MnTAP developed a Pneumatic/Electric Hand Tool Cost Savings Calculator[3] to help businesses estimate their energy savings, cost savings, and payback period associated with switching from pneumatic to either wired or battery-powered electrically-driven hand tools.

[3] MnTAP Pneumatic to Electric Tool Cost Calculator (http://z.umn.edu/toolcalc)

Methodology

Determination of Subsectors & Industries Using Power Tools

The first objective was to identify which sectors may heavily use pneumatic hand power tools. The terms "subsector", and "industry" will be used throughout this document. For our purposes, subsector and industry refer to the number of digits used in the North American Industry Classification System (NAICS) codes[4]. The more digits used, the more specific the classification. Subsector refers to initial three digits and industry refers to the entire six digits of which a code may be comprised. The US Department of Energy (USDOE) has Industrial Assessment Centers (IAC)[5] that organize energy saving recommendations provided to businesses into a publicly available database[6]. Assessment Recommendation Codes (ARC)[7] relevant to compressed air usage identified which NAICS codes are likely to correspond to significant users of compressed air, and are listed in Table 1.

Table 1. ARC Codes Related to Compressed Air

ARC Code	Description
2.4221-7	Air compressor hardware
2.4231-8	Air compressor operations
2.4324	Replace hydraulic/pneumatic equipment with electric equipment
2.2434	Recover heat from air compressor
2.2435	Recover heat from compressed air dryers

Mergent Intellect[8], an online business directory database, was filtered by the identified NAICS codes to obtain variables on the businesses in Minnesota such as number of employees and annual sales. The identified industries use compressed air, but it cannot be determined from the IAC data alone whether or not they use pneumatic power tools.

Narrowing down the list of industries to the ones most likely to use pneumatic hand power tools was done by reviewing the websites of businesses in Minnesota in these industries. Some factors that were considered in the review were likeliness of automation, product size, which tools are required for the products/services, and the potential for customization. MnTAP reasoned that products whose manufacturing processes are primarily manual are the most likely to use hand power tools while less

[4] North American Industry Classification System (NAICS) Frequently Asked Question #5: What is the NAICS structure and how many digits are in a NAICS code? (https://www.census.gov/eos/www/naics/faqs/faqs.html)

[5] Industrial Assessment Centers (IAC) | Department of Energy (https://energy.gov/eere/amo/industrial-assessment-centers-iacs)

[6] Industrial Assessment Center (IAC) Download Data (https://iac.university/download)

[7] Industrial Assessment Center (IAC) Assessment Recommendation Code (ARC) List, version 9.1 (https://iac.university/technicalDocs/ARC_list_9.1.pdf)

[8] Mergent Intellect database product description (http://www.mergent.com/solutions/research/mergent-intellect)

power tool use is expected in mostly/completely automated processes. Very small products and products which require specialized tools or very large machinery are not expected to have a high amount of hand power tool use. In general, products that are more customizable are less likely to be automated and are more likely to require hand power tool usage. In all, the seven subsectors most likely to use hand power tools are shown in Table 2. Inside these seven subsectors, there were 55 industries identified as likely to use hand power tools.

Table 2. Subsectors & Industries in Minnesota with High Potential for Pneumatic Tool Use

NAICS Code	Description
321xxx	**Wood Product Manufacturing**
321918	Other Millwork (including Flooring)
321911	Wood Window and Door Manufacturing
321992	Prefabricated Wood Building Manufacturing
331xxx	**Primary Metal Manufacturing**
331110	Iron and Steel Mills and Ferroalloy Manufacturing
331523	Nonferrous Metal Die-Casting Foundries
331511	Iron Foundries
331524	Aluminum Foundries (except Die-Casting)
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331513	Steel Foundries (except Investment)
331529	Other Nonferrous Metal Foundries (except Die-Casting)
332xxx	**Fabricated Metal Product Manufacturing**
332311	Prefabricated Metal Building and Component Manufacturing
332323	Ornamental and Architectural Metal Work Manufacturing
332313	Plate Work Manufacturing
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332321	Metal Window and Door Manufacturing
332510	Hardware Manufacturing
333xxx	**Machinery Manufacturing**
333120	Construction Machinery Manufacturing
333318	Other Commercial and Service Industry Machinery Manufacturing
333999	All Other Miscellaneous General Purpose Machinery Manufacturing
333111	Farm Machinery and Equipment Manufacturing
333249	Other Industrial Machinery Manufacturing
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333241	Food Product Machinery Manufacturing
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing
333993	Packaging Machinery Manufacturing

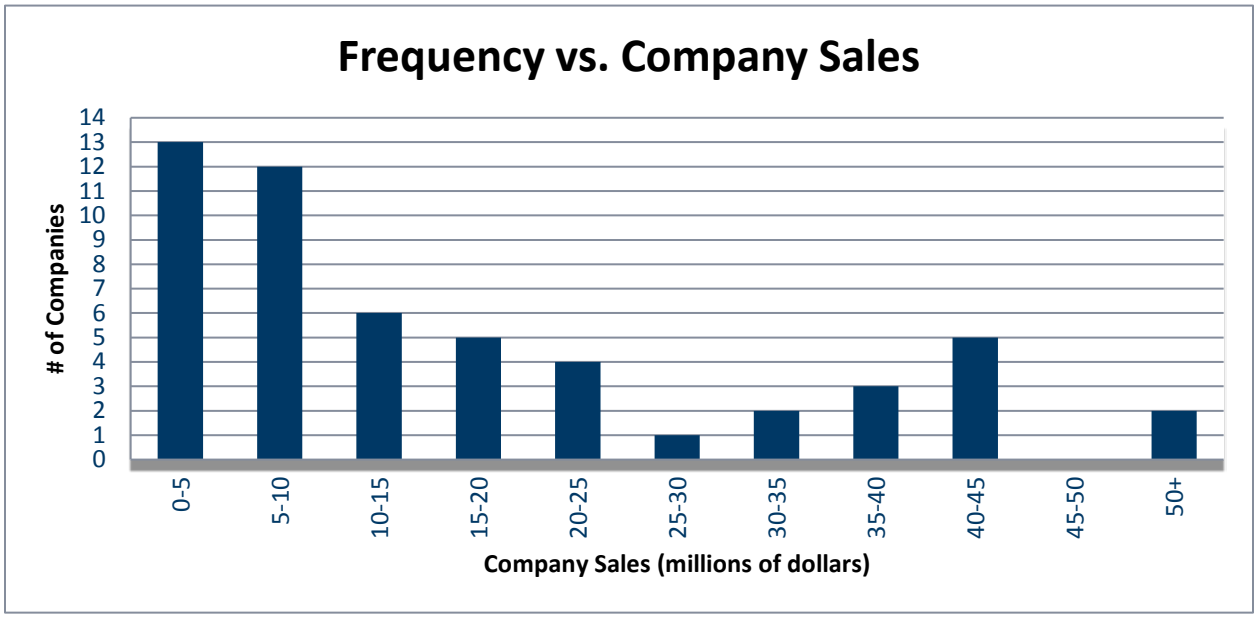
NAICS Code	Description
333517	Machine Tool Manufacturing
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing
336xxx	**Transportation Equipment Manufacturing**
336612	Boat Building
336999	All other Transport Equipment Manufacturing
336211	Motor Vehicle Body Manufacturing
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336214	Travel Trailer and Camper Manufacturing
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing
336111	Automobile Manufacturing
336411	Aircraft Manufacturing
336212	Truck Trailer Manufacturing
336991	Motorcycle, Bicycle, and Parts Manufacturing
336412	Aircraft Engine and Engine Parts Manufacturing
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing
336370	Motor Vehicle Metal Stamping
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing
336510	Railroad Rolling Stock Manufacturing
336120	Heavy Duty Truck Manufacturing
336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing
336611	Ship Building and Repairing
336112	Light Truck and Utility Vehicle Manufacturing
336360	Motor Vehicle Seating and Interior Trim Manufacturing
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing
337xxx	**Furniture and Related Product Manufacturing**
337110	Wood Kitchen Cabinet and Countertop Manufacturing
337127	Institutional Furniture Manufacturing
337212	Custom Architectural Woodwork and Millwork Manufacturing
337122	Unupholstered Wood Household Furniture Manufacturing
337910	Mattress Manufacturing
339xxx	**Miscellaneous Manufacturing**
339920	Sporting and Athletic Goods Manufacturing
339995	Burial Casket Manufacturing

Interviews

After identifying which industries were likely to use power tools, the next step was to contact businesses that represented such industries to collect representative data on their amount of compressed air – and thus energy – usage from power tool use. Businesses in each subsector were chosen to be interviewed in a systematic way.

As summarized in Table 4, MnTAP called approximately 285 businesses and successfully interviewed 63 businesses in 40 different industries. Respondents were asked to redirect the call to a shop manager, plant manager, or someone familiar with the businesses' power tool usage. Anywhere from four to nineteen businesses of all industries in a subsector were interviewed by phone. Initially, a balanced approach of calling equal parts small, medium, and large businesses was performed. In this context, a small sized business is defined as having annual sales, as reported in Mergent Intellect, of less than $5 million. Medium sized business is defined between $5-40 million in annual sales, and large is greater than $40 million in annual sales. Eventually, more medium-sized businesses were called due to a low response rate from small and large businesses. With the experience of the first 31 interviews, MnTAP was able to improve the business selection process for the next set of interviews. Interviews 32-63 were done with a simple random sample of businesses, in a given industry, with annual sales approximately between $5 and $100 million. The overall frequency of interviews is shown in Figure 1.

Figure 1. Number of interviewed companies versus company sales



As highlighted in Table 3, the first 17 interviews were the most comprehensive; questions regarding satisfaction with their tools, which characteristics are most important to them, and frequency of tool use were asked. The rest of the interviews were more streamlined and asked questions almost strictly about parameters relevant to estimating the annual air use per employee such as the number of tools and how much they were used. There are multiple reasons this was done. First, it is much easier to get

people to answer questions when they know the interview will only last five minutes instead of 20 minutes. Secondly, with fewer questions, more interviews could be done in the same amount of time, allowing MnTAP to collect more data points to provide better representation of the contacted industries. The phone interviews were critical to this project because they supplied all of the power tool usage data required to make energy use estimates.

Table 3. Summary of Interview Questions

Questions Asked	Interviews 1-17	Interviews 18-31	Interviews 32-63
What are your two most commonly used hand power tools?	✓	✓	✓
How many of those tools do you use?	✓	✓	✓
How much do you use those tools?	✓	✓	✓
How long do those tools typically last?	✓		✓
What do you look for when buying new tools?	✓		
What are barriers in switching to electric powered tools?	✓		
What is your shop size in square feet?	✓		
How many employees work where you work?	✓	✓	✓
How many production employees work where your work?			✓
How consistent is the performance of your power tools?	✓		
How many hours are in a typical business day?	✓	✓	✓
Is there any difference in comfortability between electric and pneumatic tools?	✓		
Generally, how do you like your tools?	✓		
In your industry, are pneumatic or electric power tools more common?			✓

Table 4 contains the list of subsectors that were successfully surveyed, in order of the number of interviews within the subsector.

Table 4. Interviews Completed by Sector

Subsector	# of Interviews
Machinery Manufacturing (333xxx)	19
Fabricated Metal Product Manufacturing (332xxx)	16
Furniture and Related Product Manufacturing (337xxx)	8
Wood Product Manufacturing (321xxx)	6
Primary Metal Manufacturing (331xxx)	6
Transportation Equipment Manufacturing (336xxx)	4
Miscellaneous Manufacturing (339xxx)	4
TOTAL	**63**

More detailed explanation of the interview and estimation process is available in Appendix A.

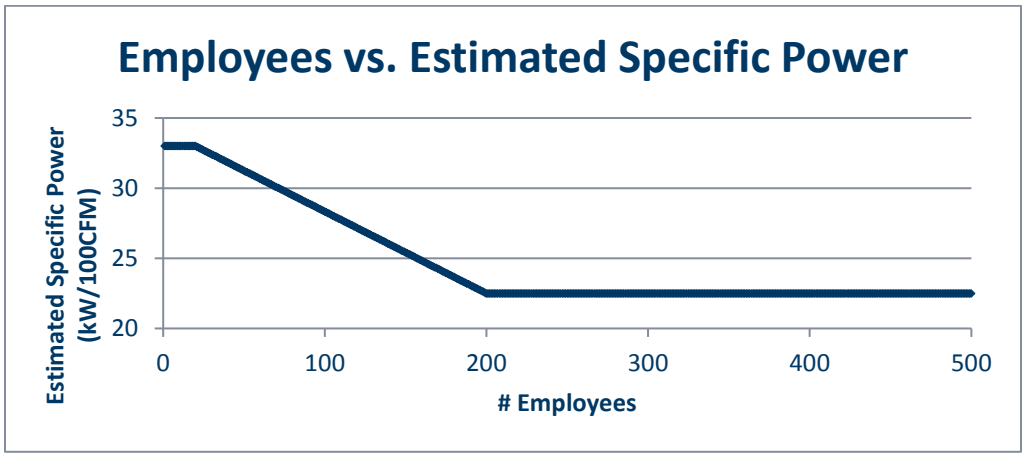
Cost of Air Usage in Minnesota

A primary goal of this project was to determine an estimate for the energy usage and cost of using pneumatic powered hand tools by Minnesota industry. The estimation method relied on a compressor specific power model based on the number of employees at a given business, an estimated annual air use per employee derived from the phone interview data, and a qualitatively determined quantitative correction factor based on MnTAP's knowledge of the industry. A crucial assumption made is that there is a positive linear correlation between the number of employees and power tool usage. This is a reasonable assumption considering that the tools in question are hand-operated; there is a higher likelihood of reliance on hand power tools at facilities with higher staffing numbers. Low employee counts similarly suggest a higher degree of automation or reliance on robotically operated tools.

Every business in the database was listed with their employee count, and was assigned an estimated compressor efficiency rating referred to as *specific power* (kW/100 CFM) based on this number. Put simply, specific power is the ratio of compressor power demand in kilowatts (kW) per a standard output capacity of 100 cubic feet per minute (CFM). A less-efficient compressor will have a higher specific power rating as more kilowatts are needed to provide the same output of compressed air, while more-efficient compressors will have a lower specific power value. Higher capacity air compressors have smaller specific power values than small compressors – a result of larger motors being more efficient than smaller motors. To address this reality, it was necessary to assign large businesses' (those with higher employee counts) compressors a lower specific power value than small business' compressors. A heuristic relating employee counts to specific power was generated to accommodate the variety of business sizes, and is provided in Figure 2. A business' estimated annual air use per employee (CFM/employee count) and hours of air use per day were derived from interview results. These values (employee count, air use per employee, specific power (kW/100 CFM), and hours per day of tool use (h)) are used in order to get an estimated amount of kilowatt-hours (kWh) of pneumatic tool use per year for a given business. Businesses within the same industry were assumed to have equal air consumption per employee, on the assumption that businesses within the same industry have reasonably similar manufacturing processes. The average air consumption per employee for interviewed industries within a sector was used for industries within the sector that were not surveyed. For all of the businesses in a particular industry, the kWh per year estimates were totaled. The sum was multiplied by a correction factor corresponding to how likely MnTAP believes that industry uses power tools. In order to convert the energy (kWh) to a cost, MnTAP multiplied the total energy (kWh) per year by $0.0702 per kWh (the average industrial blended electric rate in Minnesota)[9].

[9] U.S. Energy Information Administration (EIA), State Electricity Profile, Minnesota 2016 (http://www.eia.gov/electricity/state/minnesota/)

Figure 2. Heuristic Model Relating Number of Employees to Anticipated Compressor Efficiency



Additional information including correcting for likelihood of tool use between industries can be found in Appendix A.

Results

The final estimated annual cost to run pneumatic hand power tools in Minnesota is approximately $10.5 million, which equates to about 148.8 million kWh of electricity annually. The estimated annual cost of using equivalent electric-driven tools is estimated to be about $0.8 million, equating to about 11 million kWh of electricity annually, representing a potential savings of approximately 138 million kWh, $9.6 million, if all pneumatic tools were replaced by electric alternatives. These results are summarized in Table 5. Lastly, it is estimated that the electric savings achievable by swapping tools, assuming all Minnesota businesses were to switch from pneumatic tools to electric, would result in a greenhouse gas emission reduction equal to about 114,100 tons of carbon dioxide-equivalent (CO_2e) annually.

Table 5. Total Annual Savings Potential

Statewide Estimated Pneumatic Hand Tool Energy Consumption (kWh)	Estimated Electric Equivalent Tool Energy Consumption (kWh)	Energy Savings (kWh)	Cost Savings ($)
148,800,000	11,000,000	137,800,000	$9,673,560

There are seven subsectors that are believed to make up the majority of hand power tool usage in Minnesota. These subsectors, their estimated populations, total energy consumption due to pneumatic tool use, and the average energy use per facility due to pneumatic tool use are displayed in Table 6.

Table 6. Estimated kWh of the Seven Major Subsectors with High Pneumatic Tool Potential

NAICS	Manufacturing Description	Estimated Count of Subsector Facilities with Opportunity	Estimated Annual Energy Use by Pneumatic Tools (kWh)	Average Annual Energy Use (kWh) by Pneumatic Tools per Facility
331xxx	Primary Metal	325	67,200,000	206,800
336xxx	Transportation Equipment	750	38,100,000	50,800
333xxx	Machinery	2,392	17,900,000	7,500
332xxx	Fabricated Metal Product	2,421	12,500,000	5,200
321xxx	Wood Product	1,534	6,700,000	4,400
337xxx	Furniture and Related Product	1,018	3,200,000	3,100
339xxx	Miscellaneous Manufacturing	3,753	3,200,000	900
	TOTALS	**12,193**	**148,800,000**	

Table 6 shows that companies with NAICS codes within the Primary Metal, Transportation Equipment, Machinery, Fabricated Metal Products, Wood Products, Furniture and Related Products, and Miscellaneous Manufacturing subsectors should be the major focus of outreach and programming with regards to helping businesses to save energy by switching from pneumatic to electric hand power tools.

It is important to note that these subsectors are not equal in terms of the opportunities present on a per-facility basis. The subsectors are listed in order of suggested prioritization, from highest priority (Primary Metal) to lowest priority (Miscellaneous Manufacturing). Primary Metal facilities, while fewer in statewide count than all other subsectors, present the greatest opportunity for conservation through tool swapping since this subsector relies most heavily on hand-operated tools. Industries in the Primary Metal Manufacturing subsector smelt and/or refine ferrous and nonferrous metals from ore, pig or scrap, using electrometallurgical and other process metallurgical techniques. The output of these processes, usually in ingot form, is used in rolling, drawing, and extruding operations to make sheet, strip, bar, rod, or wire, and in molten form to make castings and other basic metal products. The end products of these secondary processes are nearly complete, but often have functional or aesthetic defects. This work is very frequently done manually as workers rely on hand-operated grinders, sanders, buffers. Pneumatic versions of these tools use constant streams of compressed air and represent a constant demand for air compressors. Typical businesses in this subsector have large compressors to meet these demands. It is estimated that pneumatic tool use at an average business in the Primary Metal Manufacturing subsector may use approximately 207,000 kWh of electricity annually.

Similarly, Transportation Equipment manufacturers rely heavily on pneumatic fasteners, torque-wrenches, sanders, and buffers, among other tools, throughout their highly manual operations. It is estimated that the annual average electric use by pneumatic tools is approximately 51,000 kWh. Prioritizing tool-switching conservation efforts in these subsectors first is recommended as the annual average pneumatic tool energy use is at least six times greater than the remaining subsectors identified in Table 6.

Cost Savings Calculator

MnTAP has developed a cost-savings calculator[10] to help industrial facilities to compare current costs of running pneumatic tools to the new costs associated with running electric tools. The tool shows how much energy and money the facility spends on pneumatic tools, and how much energy and money would be spent on replacement with electric tools. It provides an annual savings as well as an estimated payback period associated with making a change.

The purpose of the tool is to show shop managers the costs and potential savings associated with their tool options. Running tools with compressed air tends to be much more expensive and resource intensive than using electric tools.

[10] MnTAP Pneumatic to Electric Tool Cost Calculator (http://z.umn.edu/toolcalc)

The basic calculator takes in:

- Tool type
- Quantity of tools
- Hours per day
- Days per year
- Replacement Type (corded or cordless)

The calculator uses data from various tool catalogues collected in 2017 to estimate the airflow (cubic feet per minute, or CFM) needed to run the pneumatic tools, and to estimate the amount of energy (kWh) needed to run an electric equivalent. Pneumatic tool energy (kWh) is calculated by taking that amount of airflow, and multiplying it by specific power values for both efficient and inefficient compressor airflow generation values. The calculator uses the assumption that efficient compressors use 20 kW / 100 CFM of compressed air, while inefficient compressors use 30 kW / 100 CFM. The power in kW is multiplied by the total number of hours per year the tool runs to calculate its energy use in kWh.

The tool also accounts for compressed air system leaks, maintenance costs, tool costs, tool lifetime, blended energy rate, and compressor efficiency. The basic tab uses standard, default values for these parameters, which were estimated based on informational interviews with plant managers and compressed air experts. The advanced tab allows users to go into more depth, modifying these assumptions to provide greater accuracy to their own situation as desired.

Figure 3 is an example of the basic calculator with its results. It shows that for three, 5'' pneumatic sanders, run for four hours per day, 250 days per year, to be replaced with corded electric sanders, the payback period is 2-3 months, with annual energy savings of 32,000 kWh – 51,000 kWh, and annual savings of $2,300 - $3,600. A more detailed explanation of the calculator with example calculations is provided in Appendix B.

Figure 3. A screenshot example from the Pneumatic/Electric Hand Tool Cost Savings Calculator.

Help	Questions	Tool #1	Tool #2	Tool #3	Tool #4	Tool #5	Tool #6	Tool #7	Tool #8	Tool #9	Tool #10
?	Tool Type	5" Sander/Grinder									
?	Quantity	3									
?	Hours used per day	4									
?	Days used per year	250									
?	Replacement Type	Corded									

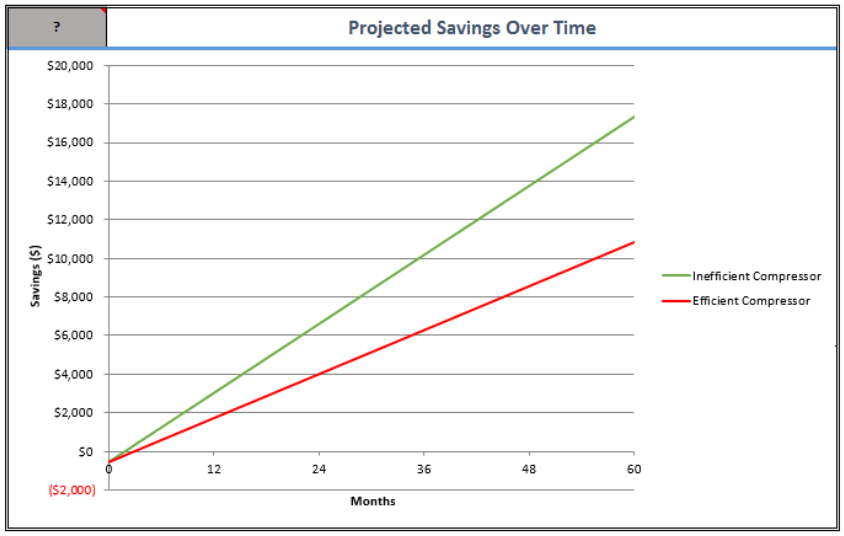
Results

Cost Comparison of Tool Systems		Annual Costs			Annual Savings	
		Pneumatic Tools		Electric Tools	Pneumatic Cost	
?	Compressor Efficiency	Efficient	Inefficient	Electric	Efficient	Inefficient
	Annual Energy (kWh)	37,075	55,613	4,180	32,895	51,433
	Annual Energy Cost ($)	$2,603	$3,904	$293	$2,309	$3,611
?	Annual Tool Cost ($)	$263	$263	$293	($30)	($30)
?	**TOTAL**	**$2,866**	**$4,167**	**$587**	**$2,279**	**$3,581**

Your Projected Payback Time			
?	Compressor Efficiency	Efficient	Inefficient
	Total Annual Savings	$2,279	$3,581
?	Cost to Implement Electric Tools	$587	$587
?	**Payback Period (months)**	**3**	**2**

Interpretation of Results

If you replace all of the tools you have entered in above, using solely the default values, it will take an estimated 3 months to recover your initial investment of $587 to get the new electric-driven power tools. For every year after your money is recovered, you will save an estimated $2,279 . Click on the "Advanced" tab near the bottom left of this spreadsheet to use values other than the default values. For more information on the different aspects between pneumatic and electric besides cost, such as performance, refer to the power tool transition guide at (insert website or how to find this guide here).



Discussion of Results

Implication of Findings for Industrial Users

The results suggest a large savings opportunity for industrial hand power tool users, simply by switching from pneumatic power tools to electric power tools. The magnitude of the savings and the approximate payback period can be calculated using the Pneumatic/Electric Hand Tool Cost Savings Calculator. The calculator will help industrial users to quickly estimate the costs and benefits associated with switching to electric hand power tools. If the transition from pneumatic to electric tools is broadly implemented throughout industry, it will result in millions of dollars of energy savings for businesses in Minnesota.

Another way to consider the magnitude of energy savings is to consider that for the same energy and energy cost, a company can run one pneumatic grinder, or ten electric grinders. For industrial businesses that trigger these tools for thousands of hours per year, the resulting cost and energy savings are staggering.

Consider a typical four foot T8 fluorescent lamp, which draws 32W. It is extremely common and cost effective for businesses to switch these out for LEDs. A common T8 LED replacement will run on roughly 17W. This is a 47% reduction in power needed for lighting. Now consider a 5'' pneumatic sander, which draws 49.4 CFM. An average compressor specific power is 25 kW/100CFM, with a 20% leak rate. This results in 15.4 kW draw to trigger the pneumatic sander. A similar 5'' electric sander draws 1.39 kW. This is a 91% reduction in power needed for sanding! This change, for one 5'' sander, is 14,010 W, the equivalent reduction in power to installing 934 T8 LED replacement bulbs. Now consider that industrial tool users tend to use many power tools, and consider that the tool upgrade is likely to be much less expensive than a lighting upgrade. Finally, consider that taking pneumatic tools offline will also help reduce stress on other systems in the facility that require compressed air, and is likely to result in less compressor maintenance and fewer future compressor purchases. Only tool cost and energy costs to run compressors are accounted for in the calculator, but these additional benefits will also have real, positive impacts on industrial users.

Implication of Findings for Utilities

Utilities are constantly striving to meet their Conservation Improvement Program (CIP) goals. Switching pneumatic tools for electric is a low-cost, quick payback solution that is applicable to a wide variety of industrial customers. Utilities are advised to spread the word about the energy savings potential and other benefits of making the change from pneumatic to electric tools. We also recommend offering a small incentive to get businesses to test or fully implement the initial change from pneumatic to electric hand tools as an energy savings measure. Regardless of the quick payback period, there is a certain activation energy involved with initially making the change to electric tools, or any change in a facility. Once the change is made, it is likely that cost-effectiveness and inertia will keep these companies using the cost-effective electric tools, especially if the life cycle energy costs are understood by the customer.

Barriers to Implementation

It should be understood that it is not realistically possible for all Minnesota businesses to reduce their energy costs by switching out tools. MnTAP realizes that there are multiple barriers which can make switching out tools more difficult or impossible. Some barriers include: a lack of knowledge about the relative inefficiency of compressed air, a lack of electrical outlets where work needs to be done, workers who prefer/are more comfortable with pneumatic tools, difficulty getting management to get excited and buy into replacing tools, potentially disrupting production, company policy and/or office politics, and the difficulty of breaking traditions and habits. These are just some of the issues that can make switching out power tools less likely to happen.

Use of either pneumatic or electric tools present their own unique safety considerations and each have trade-offs[11]. For example, pneumatic tools are often selected in environments where a spark from an electric tool may cause an explosion/fire, however flexible compressed air hoses may then present a trip hazard. Battery-powered, cordless tools can alleviate trip hazards, but are potentially more likely to produce a spark than a pneumatic equivalent. Another example, the use of corded electric tools in damp environments may require use of additional safety equipment, such as ground-fault circuit interrupters. Every working environment should be considered carefully in the context of switching tool types and what hazards may be present.

Other issues related to safety can make it dangerous – or illegal – to switch out pneumatic power tools with anything electric that could more readily present a spark-induced explosion hazard in certain environments. Using electric tools near combustible dust hazards[12], combustible chemicals/materials/coatings[13], or in very damp environments may cause fires, explosions, or electric shocks. Many businesses may technically be able to replace their pneumatic hand power tools with electric safely and legally, but may face some of the other barriers mentioned. These barriers reduce the amount of realistic savings attainable in Minnesota. It is difficult to estimate how many tools and/or facilities may be affected because working environments vary considerably by facility.

The industries in Table 7 and Table 8 have safety barriers related to combustible dust explosion/fire hazards. MnTAP recommends that these industries, which combine for an estimated 30.51 million kWh/year of pneumatic power tool usage, or about 20% of the total estimated pneumatic power tool usage in Minnesota, carefully consider the risks and how to comply with safety regulations before making a decision to switch to electric tools.

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[11] U.S. Occupational Safety and Health Administration (OSHA), HAND and POWER TOOLS informational booklet (https://www.osha.gov/Publications/osha3080.html)

[12] U.S. Occupational Safety and Health Administration (OSHA), Safety and Health Topics / Combustible Dust: An Explosive Hazard (https://www.osha.gov/dsg/combustibledust/)

[13] U.S. Occupational Safety and Health Administration (OSHA), Authority for 1910 Subpart H - 1910 Subpart H (https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10117)

Table 7. Industries with More Frequent and/or High Consequence Combustible Dust Explosions/Fires[14].

NAICS Code	Description
321113	Sawmills
321219	Reconstituted Wood Product
321920	Wood Container and Pallet
331314	Secondary Smelting and Refining of Nonferrous Metals
331524	Aluminum Foundries
332813	Electroplating, Plating, Polishing, Anodizing, Coloring
336320	Motor Vehicle Electrical and Electronic Equipment

Table 8. Industries that may have Potential for Combustible Dust Explosions/Fires[15].

NAICS Code	Description
321213	Engineered Wood Member (except Truss)
321214	Truss Manufacturing
321911	Wood Window and Door Manufacturing
321992	Prefabricated Wood Building
321999	All Other Miscellaneous Wood Product
331313	Alumina Refining and Primary Aluminum Production
331318	Other Aluminum Rolling, Drawing, and Extruding
331529	Other Nonferrous Metal Foundries (except Die-Casting)
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)
332812	Metal Coating, Engraving (except Jewelry and Silverware
332999	All Other Miscellaneous Fabricated Metal Product
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery
333992	Welding and Soldering Equipment
336415	Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts
337110	Wood Kitchen Cabinet and Countertop
337920	Blind and Shade Manufacturing
339995	Burial Casket Manufacturing

[14] Adopted from: U.S. Occupational Safety and Health Administration (OSHA), CPL 03-00-008 - Combustible Dust National Emphasis Program (Reissued), Appendix D-1 (https://www.osha.gov/OshDoc/Directive_pdf/CPL_03-00-008.pdf)

[15] Adopted from: U.S. Occupational Safety and Health Administration (OSHA), CPL 03-00-008 - Combustible Dust National Emphasis Program (Reissued), Appendix D-2 (https://www.osha.gov/OshDoc/Directive_pdf/CPL_03-00-008.pdf)

Recommendations for Overcoming Barriers

The first major barrier to be overcome is simply one of information. It is not yet common knowledge that compressed air and pneumatic tools are extremely expensive to run. While information on renewable energy or electric vehicles is becoming ubiquitous, the costs to use compressed air and to run pneumatic tools is not commonly understood. Making the knowledge easy to access and understandable will help considerably in this effort.

The next major barrier is one of inertia, people tend to continue doing what they have done in the past unless acted upon by an outside force. If facilities are incentivized to replace a small amount of their pneumatic tools with electric to see how they perform, or are otherwise incentivized to replace their pneumatic tools with electric tools and also taught the energy and cost savings associated with the change, it is likely that this measure will be successful.

Another important consideration is determining what changes are needed to workspaces to accommodate electric driven tools. Facilities already relying on pneumatic tools typically have more complex compressed air distribution layouts. Multiple hoses leading to individual manual workspaces may connect to manifolds that are served by hard-piped compressed air. Many facilities use compressed air hose reels and flexible hoses to allow pneumatic tools to be quickly detached and hoses retract out of the way when tools aren't needed. These accommodations represent a sunken investment for many sites, and it may be difficult to persuade business owners to rethink their layouts. A move to electric driven tools may require additional investment to re-configure workspaces to accommodate new air-less tools. Wired tools require a constant physical connection to an electrical outlet. If workspaces lack adequate outlets, more may be necessary. What was once a pneumatic hose reel might be exchanged for an extension cord reel to provide power where it is needed. Battery-driven tools may present a more attractive solution; instead of bringing electrical outlets to every workstation, a smaller number of "charging stations" can be designated where workers can swap spent rechargeable batteries with freshly charged batteries to continue their work. To reduce complications presented by discharged batteries, it is recommended that sites have more batteries than they do tools, allowing chargers enough time to do their job.

A final barrier is one of feasibility, some plants have flammability or explosive risks that make pneumatic tools safer. This is one barrier that may be better not to overcome in many cases; for these facilities safety concerns will outweigh the possible energy savings. Some facilities with only minor spark risk concerns will be able to use non-sparking electric tools. These tools significantly reduce the risk of a spark, but do not eliminate it, making them suitable for sites where sparking should be avoided, but will not pose a serious safety risk on the rare event that sparking does occur.

Conclusion

The goal of this project was to develop an estimate for the current energy use for pneumatic hand power tools in Minnesota, and to then create a cost savings calculator to help individual industrial businesses to estimate their savings potential. A key result is that 148.8 million kWh used for pneumatic hand tools could be reduced to 11 million kWh with replacement of these tools with electric alternatives for a savings of 137,800,000 kWh, and $9,700,000 in electric costs. Due to the many unknowns, the estimates have a wide confidence interval but show the relative order of magnitude of the energy usage and costs.

The most important next step is to spread the word regarding the energy savings opportunity associated with using electric tools as an alternative to using compressed air driven tools. The idea that a company can draw the same amount of power to run one pneumatic sander or ten electric sanders is largely unknown, as is the concept that switching out just one pneumatic sander reduces power draw more than switching out 900 T8 Fluorescent bulbs with LEDs.

In addition to spreading the word about the magnitude of opportunity associated with switching from pneumatic to electric tools, this measure will likely see more success with utility support. If businesses are incentivized to start using electric hand tools, and the energy savings benefits are explained to them, it is likely that the energy savings and cost savings will serve to make the use of electric tools much more common throughout industry. This transition from pneumatic to electric hand tools will save Minnesota businesses millions of dollars and will save Minnesota utilities tens of millions of kilowatt hours to put towards their Conservation Improvement Programs.

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Appendix A:

Estimating Pneumatic Power Tool Use

Introduction

The United States Department of Energy (USDOE) Industrial Assessment Centers (IAC) make recommendations on energy saving measures[16]. When an IAC conducts an energy assessment, the NAICS code relevant to the facility receiving the assessment is recorded. IAC's recommendations relating to compressed air give a picture of which industries use compressed air[17]. The IAC database identified 46 unique three-digit NAICS codes representing subsectors that use compressed air. There were 420 unique six-digit NAICS codes identifying industries. These NAICS codes were used to filter and download Minnesota business information from Mergent Intellect, an online business directory[18]. The Mergent Intellect data was used to define the industrial compressed air using population within the state of Minnesota. The selection of subsectors and industries was done solely on the determination of IAC data. Doing the selection with one source allows the possibility for some industries that may use pneumatic power tools to be ignored. Luckily, a review of NAICS codes showed that only a few industries may have been missed with the most major likely being 3353 Electrical Equipment Manufacturing. The selection of subsectors and industries suggests a given NAICS code is likely to use compressed air, but does not necessarily imply pneumatic tool use. A deeper review of the subsectors, industries, and the individual businesses within them was needed to further narrow the population of businesses that are likely to use pneumatic tools.

Methodology

MnTAP's goal was to evaluate the likelihood that businesses within the previously found compressed air using industries use hand power tools. The websites of businesses in these subsectors and industries were examined for information that could help determine the likelihood of power tool usage. Some factors that were considered include: likeliness of automation, product size, the tools required for the products/services, and the potential for customization. A review of pneumatic tool types, use scenarios, and typical flowrates was used to focus the website review – the businesses that would benefit most from electric tool adoption would generally use pneumatic tools with high flowrates, long use times, or both. Businesses were sorted into qualitative groups and assigned a color based on their perceived

[16] Industrial Assessment Centers (IAC) | Department of Energy (https://energy.gov/eere/amo/industrial-assessment-centers-iacs)

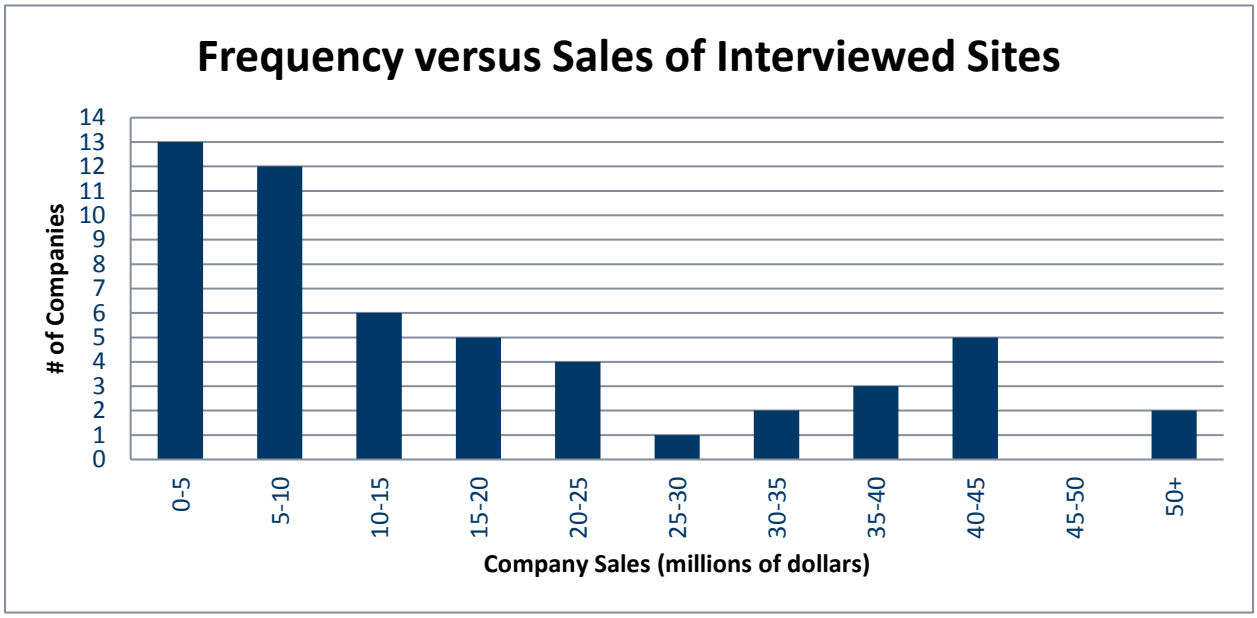
[17] The recommendations used are: recover heat from air compressor, recover heat from compressed air dryers, replace hydraulic/pneumatic equipment with electric equipment, and various other recommendations related to air compressor operation and hardware.

[18] The recommendations correspond to Standard Industrial Classification codes of 20, 22-39, and 49 which are all manufacturing sectors except 49 which is Electric, Gas, and Sanitary Services.

likelihood of using pneumatic tools. This subjective grouping, performed by a human, may have introduced systematic and/or random bias. This bias was partially tested for by interviewing companies in these subsectors and industries. The interviews, discussed below, have shown this method to predict which sectors are more likely to use pneumatic power tools in most cases. In all, seven likely hand power tool using subsectors were identified. Inside these seven subsectors, there were 55 industries identified as likely to use hand power tools.

The next goal was to determine the proportion of businesses within a subsector and industry that use a considerable amount of pneumatic hand power tools. Industrial markets are very specialized and it is unreasonable to assume that every individual business within a given subsector or industry uses power tools to the same extent. To accommodate such variation, a handful of businesses from each subsector and a variety of industries were interviewed by phone. This was done in an attempt to validate and quantify the qualitative groups generated in the determination of power tool using subsectors and industries. Two different methods to select businesses to interview were used due to administering the interviews at different time periods. With the knowledge of the first set of interviews, MnTAP was able to improve the business selection method for the second set of interviews. In both sets of interviews, variously sized companies (by their annual sales as reported in the Mergent Intellect database) were interviewed in order to reduce potential bias in business size. In the first set of 31 interviews, a balanced approach of calling equal parts large, medium, and small companies was performed at the start. It quickly became apparent that the equal parts approach was not working as intended. Thus, about halfway through the first set of interviews, MnTAP shifted to calling more medium sized companies and fewer large and small companies. The second set of 32 interviews was done using a simple random sample of businesses, in a given industry, with annual sales approximately between $5 and $100 million. Companies with sales approximately between $5 and $40 million per year were the most commonly sized interviewed companies due to companies in this range having the highest successful interview rate. MnTAP generally observed that companies on either side of this range were less willing to participate in phone interviews, which was the reason for the shift to calling more medium sized companies in the first set of interviews. It is believed that smaller companies are more likely to have employees that are too busy with their day-to-day duties to answer questions about their power tool usage. On the other end, some larger companies may have multiple divisions which makes it difficult to talk to employees that are knowledgeable about the entire businesses power tool usage. While a simple random sample of businesses within each subsector and industry may have been a better way to choose the first 31 interviewees, the results are expected to be similar due to the challenges with the response rate of smaller and larger businesses.

Figure 4. Number of Sites Interviewed in Each Sales Category



The approximate number of businesses called is 285. MnTAP successfully interviewed 63 businesses in 40 different industries. The vast majority of calls to companies were cold-calls to the main business number or receptionist. Receptionists were asked to redirect the call to a shop manager, plant manager or someone familiar with the power tool usage. Most phone calls to businesses resulted in leaving voicemails for the shop manager or plant manager with typically no reply. When a contact familiar with the on-site power tool usage was reached, almost all were willing to answer questions.

The first 17 interviews were the most comprehensive and asked questions regarding their satisfaction with their tools, which characteristics are most important to them, and how much their tools are used. The rest of the interviews were more streamlined and asked questions almost strictly about parameters relevant to estimating the annual air use per employee such as the number of tools and how much they were used. There are multiple reasons this was done. First of all, it is much easier to get people to answer questions when they know the interview will only last around 5 minutes instead of upwards of 20 minutes. Secondly, more interviews could be done in the same amount of time since the questions were streamlined which allowed MnTAP to collect more data. Finally, it became slightly redundant to keep asking certain questions when the answers simply repeated what was already heard from other companies. The questions that had very similar responses were omitted in the later interviews. For example, the barriers in switching pneumatic tools to electric tools were not asked because the same barriers were being repeated over and over again. The phone interviews were critical to this project because they supplied all of the power tool usage data required to make estimates.

Estimating Savings Opportunity

It is reasonable to expect that as the number of employees increases, the power tool usage will increase as well. This is the most fundamental assumption in all of the energy estimation methods in this project.

Some drawbacks of this assumption include overestimating companies with many employees and relatively little power tool usage – for example a combined headquarters and manufacturing site with a higher proportion of non-tool using office workers – and underestimating companies with few employees and high power tool usage – for example a small custom fabrication shop. A problem in this methodology could arise if the ratio between the number of power tool using employees and the total number of employees does not remain fairly constant for variously sized businesses. It may be the case that smaller sized businesses have a higher percentage of their workforce using power tools compared to larger businesses. MnTAP noticed a small trend in the ratio from the first set of interviews but the combined data from the first and second set of interviews showed no significant trend. Thus, this study assumes that the ratio between the number of power tool using employees and the total number of employees is constant across every business within a subsector or industry. Even if the ratio was not constant, the effect was partially mitigated by interviewing variously sized businesses.

Annual Air Use per Employee Calculation

The unit for air use is CFM which stands for cubic feet per minute and is a measure of how much liquid/gas flows through something. Annual air use per employee measures how much compressed air one employee is expected to use with pneumatic hand power tools over the course of one year. This estimated value is very critical to getting an accurate estimate of pneumatic hand power tool usage in Minnesota. The expectations for how much air one employee will use will change depending on which industry a given employee works in. Calculating the annual air use per employee uses the interview data such as power tool types, number of tools, use percentage, and number of employees combined with the power tool usage data from Grainger.

It may be easiest to illustrate the calculations through way of an example (Table 9). Suppose MnTAP interviewed Construction Company A and they have an 8 hour work day and employ 100 people. They use 10 pneumatic grinders for 15% of the day and 5 pneumatic drills for 20% of the day. From the Grainger data, MnTAP knows that pneumatic grinders use 49 CFM at full flow and pneumatic drills use 21 CFM.

Table 9. Example Power Tool Information.

Tool	Quantity	Use %	CFM at full flow
Grinder	10	15	49
Drill	5	20	21

MnTAP assumes that Construction Company A operates for 50 5-day work weeks per year. Thus, their operating hours are 8 hours per day, 5 days per week, 50 weeks per year, or 2000 hours per year. Calculating the amount of annual air use is as simple as multiplying the number of tools by the percentage of hours they are used, the annual operating hours, and CFM at full flow for each tool. Compressed air systems typically also contain leaks. Based on informational interviews and surveying, MnTAP used a value of 20% for a typical compressed air leak rate. MnTAP also considered including terms to consider “dryer and filter pressure drop factor” and “filter regulator lubricator, valve, hose and

disconnect pressure drop factor" but ultimately decided that these losses can be accounted for within the overall leak factor. Construction Company A's total annual air use is the sum of the air use for the grinders and for the drills.

$$Grinder\ Air\ Use = \frac{Number\ of\ Grinders * Grinder\ Use\ \% * Grinder\ CFM * Op.Hours\ per\ Year}{(1 - Leak\ Rate)}$$

$$Grinder\ Air\ Use = \frac{10 * .15 * 49\ CFM * 2000\frac{h}{yr}}{(1 - .2)}$$

$$Grinder\ Air\ Use = 183{,}750\ CFM * \frac{h}{yr}$$

$$Drill\ Air\ Use = \frac{Number\ of\ Drills * Drill\ Use\ \% * Drill\ CFM * Op.Hours\ per\ Year}{(1 - Leak\ Rate)}$$

$$Drill\ Air\ Use = \frac{5 * .20 * 21\ CFM * 2000\frac{h}{yr}}{(1 - .2)}$$

$$Drill\ Air\ Use = 52{,}500\ CFM * \frac{h}{yr}$$

$$Total\ Air\ Use = Grinder\ Air\ Use + Drill\ Air\ Use$$

$$Total\ Air\ Use = 183{,}750\ CFM * \frac{h}{yr} + 52{,}500\ CFM * \frac{h}{yr} = 236{,}250\ CFM * \frac{h}{yr}$$

$$Annual\ Air\ Use\ Per\ Employee = \frac{Total\ Annual\ Air\ Use}{\#\ of\ Employees} = \frac{236{,}250\ CFM\frac{h}{yr}}{100\ Employees}$$

$$Annual\ Air\ Use\ Per\ Employee = 2{,}362.50\frac{CFM * h}{employee * yr}$$

Suppose there is one more company MnTAP interviewed in the same industry. MnTAP estimates, in the exact same manner as before, that they use 100,000 CFM hours per year and have 25 employees, resulting in $4000\frac{CFM*h}{employee*yr}$. The annual air use per employee for this industry is calculated by summing all of the CFM per year at these two companies and then dividing by the sum of their employees.

$$Industry\ Annual\ Air\ Use\ per\ Employee =$$

$$= \frac{Sum\ of\ CFM\ per\ year\ for\ all\ interviews\ in\ this\ industry}{Sum\ of\ employees\ for\ all\ interviews\ in\ this\ industry}$$

$$= \frac{236{,}250\ CFM * \frac{h}{yr} + 100{,}000\ CFM * \frac{h}{yr}}{100\ employees + 25\ employees}$$

$$= 2690 \frac{CFM * hr}{employee * yr}$$

It is a simple matter of repeating this procedure to calculate the annual air use per employee for each industry that has been interviewed. This value is then applied to the rest of the businesses within the same industry as Construction Company A.

While this method works for industries that were interviewed, MnTAP needed a method to estimate pneumatic tool air consumption for industries that were not interviewed. In an initial attempt at estimation, industries that had no survey respondents used an average airflow per employee value from other industries within their subsector. In this way, all industries were assigned an airflow per employee, and then an energy consumption.

The issue is that it became clear that this methodology was overestimating pneumatic tool air consumption because not all industries within a subsector use the same amount of compressed air for hand tools, and the industries that were interviewed were generally more likely to use compressed air than the industries that were not interviewed.

In order to resolve this issue, MnTAP completed industry by industry research in order to estimate each relevant industry's likelihood of using pneumatic tools. Industries were assigned a color correction factor as a result of this research (Table 10), indicating that the industry was either very likely to use tools (green), possibly uses tools (yellow), unlikely to use tools (orange), or very unlikely to use tools (red).

Table 10. Color Factor Correction Values

Likelihood of Tool Use	Color	Correction Factor
Very Likely	Green	1
Equally Likely as Unlikely	Yellow	0.5
Unlikely	Orange	0.1
Very Unlikely	Red	0

Each industry uses one of three formulas to estimate the pneumatic hand power tool usage depending on two factors (Table 11). The two factors are whether or not MnTAP has interviewed businesses in that industry and whether or not that industry has been labelled with a color. The main idea in all of the formulas is to determine an annual average air use per employee in each industry.

The first formula is applied if MnTAP has interviewed at least one business in that industry. If a particular industry has been interviewed at least once, then every employee in that industry is expected to have an air use equal to the annual air use per employee information derived from the interviews in that industry. Those industries use the correction factor corresponding to their color label. The second formula is applied if no businesses in that industry have been interviewed but it has been labelled with a color. The annual air use per employee calculation is a two-step process for those industries. First, take all of the industries that have been interviewed in the subsector and normalize their air use by dividing by their correction factor. Average those values, and then apply the correction factor corresponding to

this industry's color label. The third formula applies to industries that have not been interviewed and have not been labelled with a color. These industries use the same value for annual air use per employee as the second method but use a correction factor equal to the average correction factor in that subsector.

Table 11. Estimation Methodology for Pneumatic Tool Air Use by Industry

A	≥1 Interview in Industry	Labelled with Correction Factor	Air Usage used in Calculation	Correction Factor used in Calculation
1	✓	✓	Air use derived from interviews in industry	Correction factor for industry
2		✓	Average of normalized air use of industries in same subsector	Correction factor for industry
3			Average of normalized air use of industries in same subsector	Average correction factor of labelled industries in same subsector

In summary, airflow per employee is calculated for businesses in an industry based on 63 survey results spanning 40 industries. The weighted average airflow per employee for these businesses is applied to the rest of that industry. Industries with no survey results use a weighted average value from other industries within the same subsector, corrected by the industry's estimated likelihood of using hand tools. This process resulted in an estimate of total air use for pneumatic hand tools in the state of Minnesota.

Compressor Efficiency Calculation

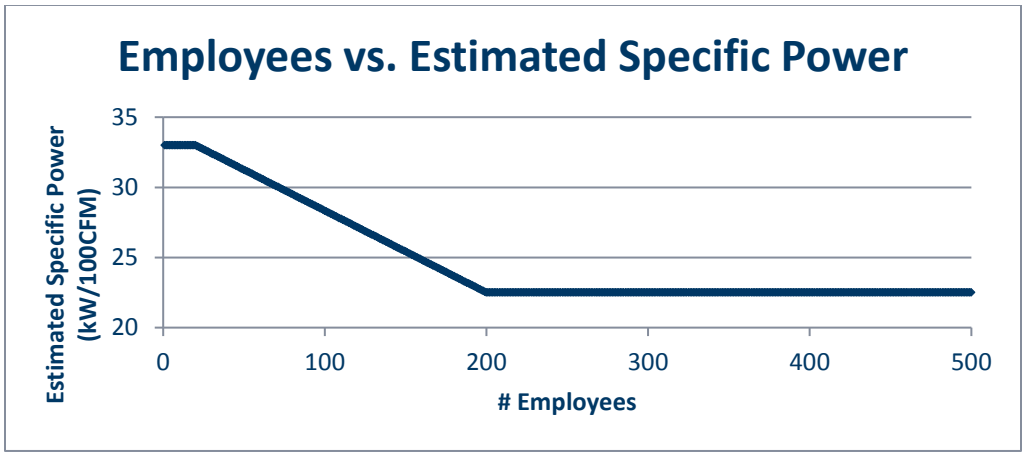
All compressed air is not created equal. The energy cost to run a drill at one facility compared to the cost to run it at another facility will not be the same. The specific power of the compressed air systems is typically measured by the amount of kilowatts (kW) of power it takes to produce a certain airflow (CFM). The higher the specific power, the less efficient the system is. Specific power depends on the compressor system that is unique to each business in Minnesota. Information was gathered from calls with compressed air system experts, compressed air experts at utility companies, air compressor datasheets[19] and partial loading efficiency charts[20.] In order to develop a method to estimate system efficiency at all relevant businesses throughout the state. This information was combined to develop a simple model based on the concept that larger businesses tend to have more efficient compressor systems. In this context, business size was defined by its number of employees. There are at least two

[19] Data Sheets - Performance Verification - CAGI - Compressed Air And Gas Institute (http://www.cagi.org/performance-verification/data-sheets.aspx)

[20] Compressor Control Methods – CASCO USA (http://cascousa.com/compressed-air-101/types-of-compressors/compressor-control-methods/)

lines of reasoning that show that this is a reasonable assumption. The first is noting the fact that larger companies need larger compressors which are inherently more efficient. The second is the assumption that larger companies typically have more employees dedicated to maintenance. Maintenance could be replacing filters, checking valves, adjusting control systems, reducing leaks, etc. All of these maintenance activities improve the efficiency of the compressor system.

Figure 5. Specific Power Model



Companies with more than 200 employees are estimated to draw 22.5 kilowatts of power to maintain 100CFM of airflow. Companies with fewer than 20 employees are estimated to draw 33 kilowatts of power to maintain 100CFM of airflow. Companies with a number of employees between 20 and 200 are estimated by linearly connecting the two endpoints.

$$Compressor\ Efficiency\ Estimate =$$

$$If\ ((Employees < 10)\ , = 32.5\frac{kW}{100CFM}$$

$$Else\ If\ (Employees \leq 100), = \frac{1255}{38} + (-\frac{1}{19} * Number\ of\ Employees)$$

$$Else = 22.5\frac{kW}{100CFM})$$

For reference most brand new 110-120PSI compressors running at their most efficient operating point (running at full load) have a specific power of about 19-20 kW/100 CFM. Controlling these brand new compressors with a load/unload control system with about a 50% load (as compared to full load) will have a specific power of about 30 kW/100 CFM. According to data from 12 custom compressed air projects, the average compressor was loaded to 47% of its full load[21]. The employee cutoff numbers are chosen based on best judgment through the knowledge gained from this project. The output pressure of

[21] Technical Reference Manual, version 2.1 | Department of Commerce | Division of Energy Resources | Minnesota.gov (http://mn.gov/commerce-stat/pdfs/mn-trm-v2.1.pdf) see references of low pressure drop filter section

a compressor does affect the efficiency of the compressor. The output pressure also fluctuates between businesses so an average pressure assumption of roughly 110-115PSI is used in the model.

The current Conservation Improvement Program Technical Reference Manual (CIP TRM) assumes a specific power of 19-20[22]. Utilities use these very conservative values, which represent compressors running at their most efficient operating point, to make sure they recoup the money they are investing. Practically no facilities are always running their compressors at optimal efficiency. MnTAP's model is still conservative in that the most efficient companies are still operating their compressors nearly fully loaded (fully loaded has the ideal efficiency) and the least efficient companies are operating their compressors near the average load% which can be thought of as the average efficiency. MnTAP's model attempts to bridge the gap between the ideal and real world cases while still keeping it conservative enough for the CIP program.

Energy and Cost Calculation

The final step in calculating the energy and cost to industry of using pneumatic hand tools involves combining the values identified in the above section.

At this point, an airflow per employee has been estimated for each industry $\frac{CFM*h}{employee*yr}$. This value is then applied to each business within the industry. It is multiplied by an estimated compressor specific power based on the number of employees as defined above $\frac{kW}{100\ CFM}$, and by the number of employees to calculate the energy consumed for compressed air for pneumatic hand tools.

For example, assume company X is in the same industry as Construction Company A above, with an industrial average airflow per employee is equal to 2690 $\frac{CFM*h}{employee*yr}$. Company X has 100 employees, corresponding to an estimated compressor specific power of 22.5 $\frac{kW}{100\ CFM}$.

$$Company\ X\ Annual\ Energy\ Consumption\ for\ Pneumatic\ Hand\ Tools\ per\ Year =$$

$$= Airflow\ per\ Employee * Compressor\ Specific\ Power * Number\ of\ Employees$$

$$= 2690\ \frac{CFM * h}{employee * yr} * 22.5 \frac{kW}{100\ CFM} *\ 100 \text{ employees}$$

$$= 60{,}525 \frac{kWh}{yr}$$

The industrial average blended electric rate per kWh in Minnesota is $.0702/kWh. The annual cost for energy can be calculated by multiplying this value by the annual energy consumption.

[22] Technical Reference Manual | Department of Commerce | Division of Energy Resources | Minnesota.gov http://mn.gov/commerce/industries/energy/utilities/cip/technical-reference-manual/

$$Energy\ Cost = Energy\ Consumption\ (kWh) * Cost\ per\ unit\ Energy\ \left(\frac{\$}{kWh}\right)$$

$$Energy\ Cost = 60{,}525\frac{kWh}{yr} * \ .0702\frac{\$}{kWh}$$

$$Energy\ Cost = \$4248.86$$

This calculation was completed for each business within the subsectors expected to be using pneumatic power tools. The sum of these values over all of the subsectors resulted in the total energy and cost values described in this study.

Appendix B

Pneumatic / Electric Tool Calculator Example Calculation

This section will describe how energy and cost estimates are calculated within the pneumatic tool calculator. A business provides its pneumatic tool types, quantity of tools, hours the tools are triggered each day, the number of days per year the tools are triggered, and a replacement type of corded or cordless electric.

The tool type includes size and equipment type taken from tool catalogue. Examples include a "3/4'' Impact Wrench", "5/8'' Pistol Grip Drill", "5'' Sander Grinder," and so on. Each of these tool types corresponds to a catalogued value of compressed air consumption to operate in CFM, as well as tool cost. It also corresponds to a similar electric tool with a catalogued energy to run in kWh, and tool cost.

Basic Calculator - Tool Annual Energy

The basic calculator uses the quantity, hours per day, and days per year values and multiplies by the airflow requirements to calculate the number of airflow * hours needed to run the pneumatic tool for a year. This number is then corrected for the leak factor (default of 20%), and multiplied two different compressor specific power options (inefficient = 30 kW /100 CFM, efficient = 20 kW / 100CFM). This provides the kWh required to run the pneumatic tools for one year on both an efficient an inefficient compressor system. This kWh value is multiplied by the industrial average blended energy rate of $.0702/kWh to calculate the cost of electricity to run the pneumatic tool.

The electric tool is estimated by using a catalogued electric tool that most closely matches the given pneumatic tool. Each electric tool has a listed kW power draw. This draw is similarly multiplied by the number of hours per day and days per year that the tool is in use to result in a kWh energy consumption value. This value is multiplied by the average industrial blended energy rate to calculate the cost of electricity to run the electric tool.

Basic Calculator – Tool Annual Cost

The basic calculator also estimates annual tool cost for the pneumatic and electric tools. The calculator takes the catalogue value for tool price and divides that over the estimated tool lifetime. Pneumatic tools were assigned a default lifetime of 3 years based on survey and interview findings. Electric tools were assigned a default lifetime of 2 years to be conservative in estimation.

Basic Calculator - Tool Total Annual Cost

The total annual cost is calculated as the sum of the total annual energy cost and the total annual tool cost. The difference in these values between the pneumatic tool and the electric tool results in the total annual estimated cost savings between the tool options.

Basic Calculator – Projected Payback Time

The payback time is estimated by dividing the total annual savings by the total cost to purchase the electric tools.

Basic Calculator – Example

For example, assume a company is using two pneumatic 5'' Sander / Grinders for 5 hours per day, 250 days per year. The company wants to calculate the energy and cost benefits of switching these sanders to corded electric sanders.

The calculator searches and finds a catalogued cost of $171for a 5'' pneumatic sander/grinder, and $127 for a 5'' corded electric sander / grinder. According to the catalogue data, the pneumatic grinder will use roughly 49.4 CFM, while the electric version will use 1.392 kW. The calculations are shown below.

$$Pneumatic\ Tool\ Energy\ Consumption\ (\boldsymbol{Efficient\ Compressor}) =$$

$$= Number\ of\ Tools * \ Airflow\ (CFM) * hours\ per\ day\ \left(\frac{h}{d}\right) * days\ per\ year\ \left(\frac{d}{y}\right) * compressor\ efficiency\ \left(\frac{kW}{100CFM}\right) * \frac{1}{1-Leak\ Rate}$$

$$= 2\ grinders * 49.4\frac{CFM}{grinder} * 5\frac{h}{d} * 250\frac{d}{y} * \mathbf{20}\frac{\mathrm{kW}}{100\mathrm{CFM}} * \frac{1}{(1-.2)}$$

$$= 30{,}875\ kWh/yr$$

$$Annual\ Pneumatic\ Tool\ Energy\ Cost\ (\boldsymbol{Efficient\ Compressor}) =$$

$$= Industrial\ Cost\ per\ kWh\ \left(\frac{\$}{kWh}\right) * Energy\ Use\ per\ Year\ \left(\frac{kWh}{yr}\right)$$

$$= .0702\frac{\$}{kWh} * 30{,}875\frac{kWh}{yr}$$

$$= \$2{,}176.43\ per\ year\ (\boldsymbol{Efficient\ Compressor})$$

$$Pneumatic\ Tool\ Energy\ Consumption\ (\boldsymbol{Inefficient\ Compressor}) =$$

$$= 2\ grinders * 49.4\frac{CFM}{grinder} * 5\frac{h}{d} * 250\frac{d}{y} * \mathbf{30}\frac{kW}{100CFM} * \frac{1}{(1-.2)}$$

$$= 46{,}312.5\ kWh/yr$$

$$Annual\ Pneumatic\ Tool\ Energy\ Cost\ (\boldsymbol{Inefficient\ Compressor}) =$$

$$= .0702\frac{\$}{kWh} * 46{,}312.5\frac{kWh}{yr}$$

$$= \$3251.14\ per\ year\ (\boldsymbol{Inefficient\ Compressor})$$

$$Pneumatic\ Hand\ Tool\ Annual\ Cost\ (Tool) =$$

$$= \frac{Tool\ Cost\ from\ Catalogue * Number\ of\ Tools}{Estimated\ Tool\ Lifetime}$$

$$= \frac{\$171 * 2\ tools}{3\ years}$$

$$= \$114\ per\ year$$

$$Electric\ Tool\ Energy\ Consumption\ =$$

$$= Number\ of\ Tools * Power\ draw\ (kW) * hours\ per\ day(\frac{h}{d}) * days\ per\ year\left(\frac{d}{y}\right)$$

$$= 2 * 1.392\ kW * 5\frac{h}{d} * 250\frac{d}{y}$$

$$= 3{,}480\ kWh$$

$$Electric\ Tool\ Energy\ Cost =$$

$$= 3{,}480\ kWh * .0702\frac{\$}{kWh}$$

$$= \$244.30\ per\ year$$

$$Electric\ Hand\ Tool\ Annual\ Cost\ (Tool) =$$

$$= \frac{Tool\ Cost\ from\ Catalogue * Number\ of\ Tools}{Estimated\ Tool\ Lifetime}$$

$$= \frac{\$127 * 2\ tools}{2\ years}$$

$$= \$127\ per\ year$$

$$Pneumatic\ Tool\ Total\ Annual\ Cost\ (\boldsymbol{Efficient\ Compressor}) =$$

$$= \ Pneumatic\ Tool\ Energy\ Consumption\ (\boldsymbol{Efficient\ Compressor}) + \ Pneumatic\ Hand\ Tool\ Annual\ Cost\ (Tool)$$

$$= \$2{,}176.43\ per\ year\ (\boldsymbol{Efficient\ Compressor}) + \ \$114\ per\ year$$

$$= \$2290.43\ per\ year\ (\boldsymbol{Efficient\ Compressor})$$

$$Pneumatic\ Tool\ Total\ Annual\ Cost\ (\boldsymbol{Inefficient\ Compressor}) =$$

$$= \ Pneumatic\ Tool\ Energy\ Consumption\ (\boldsymbol{Inefficient\ Compressor}) + \ Pneumatic\ Hand\ Tool\ Annual\ Cost\ (Tool)$$

$$= \$3251.14\ per\ year\ (\boldsymbol{Efficient\ Compressor}) + \ \$114\ per\ year$$

$$= \$3365.14\ per\ year\ (\boldsymbol{Efficient\ Compressor})$$

$$Electric\ Tool\ Total\ Annual\ Cost\ =$$

$$= \ Electric\ Tool\ Energy\ Consumption\ + Electric\ Hand\ Tool\ Annual\ Cost\ (Tool)$$

$$= \$244.30\ per\ year\ (\boldsymbol{Efficient\ Compressor}) + \$127\ per\ year$$

$$= \$371.30\ per\ year\ (\boldsymbol{Efficient\ Compressor})$$

$$Pneumatic\ to\ Electric\ Total\ Annual\ Cost\ Savings\ (\boldsymbol{Inefficient\ Compressor})\ =$$

$$= Pneumatic\ Tool\ Total\ Annual\ Cost\ (\boldsymbol{Inefficient\ Compressor}) - \ Electric\ Tool\ Total\ Annual\ Cost$$

$$= \$3365.14 - \$371.30$$

$$= \$2993.84$$

$$Pneumatic\ to\ Electric\ Simple\ Payback\ Period\ (\boldsymbol{Inefficient\ Compressor}) =$$

$$= \frac{Initial\ Tool\ Cost}{Annual\ Tool\ Savings}$$

$$= \frac{(\$127 * 2\ tools)}{\$2993.83}$$

$$= .085\ years = 1.02\ months$$

Advanced Calculator Explanation

The basic calculator is a quick tool that makes assumptions on compressor efficiency, compressor leak rate, tool lifetime, and energy costs. The basic tool also neglects maintenance costs, and uses catalogue values for tool costs, power draw, and airflow draw of tools. The advanced tool gives users the ability to customize all of these values to more accurately estimate savings potential for their actual systems. The advanced tool asks for:

- Leak Rate
- Energy Cost
- Tool Type
- Quantity
- Hours per Day
- Days per Year
- Replacement Type
- Pneumatic Tool Lifetime
- Replacement Tool Lifetime
- Pneumatic Initial Cost
- Replacement Initial Cost
- Pneumatic CFM
- Replacement Amps
- Pneumatic Maintenance Cost per Tool
- Replacement Maintenance cost per Tool
- Compressor Efficiency

The advanced calculator uses these values in with the same methodology of the basic calculator, simply replacing any default values with the custom values supplied by the user.