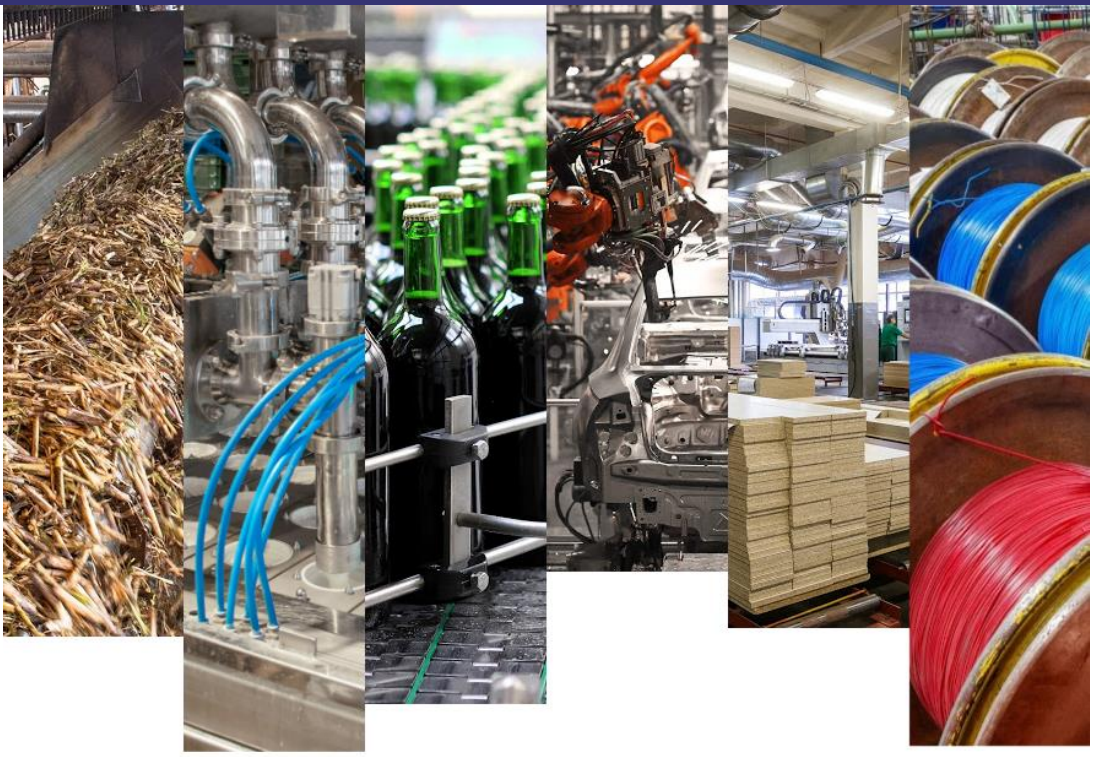
AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

# Compressed air systems, emerging efficiency improvements and alternative technologies:

## Review, background research and examples



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**AUTHORSHIP OF THIS REPORT**

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# Executive Summary

Compressed air accounts for up to 10% of industrial electricity use in Australia (E3, 2009). While used for a large range of processes, compressed air systems (CAS) can be very inefficient, experiencing significant additional energy losses caused by poor operation and maintenance, leaks, heat loss and inappropriate uses. However, there are proven ways to address these issues, increase the efficiencies of CAS and in some instances, replace CAS with more efficient alternative technologies.

This research review explores additional emerging options to optimise the efficiency of CAS, and alternatives that can replace part or all of a CAS. Smart, flexible, connected electronic and electrical technologies can reduce energy waste from CAS and improve overall process and business productivity.

There appears to be a significant opportunity for development of new business models that offer a comprehensive range of options and advice on selection of appropriate combinations from the alternatives to traditional CAS. Governments, industry organisations, academics, research organisations and business leaders could all make useful contributions to development of resources, tools, supply chains and funding of Australian demonstration and pilot projects.

Technologies, systems and solutions in this field are moving rapidly. It is important to use the latest information in any consideration of opportunities. Many of the references used for this report were published between 2018 and 2020 or are on current websites. This review departs from older publications which typically refer to higher capital and installation costs, more limited applications and fewer benefits from alternatives.

This report may serve as a resource for industry and consultants, and, may be a useful reference for the consultants conducting compressed air use reviews as part of the NSW Department of Planning, Industry and Environment's compressed air and steam services offer.

# Contents

# 1 Introduction: Compressed air system issues

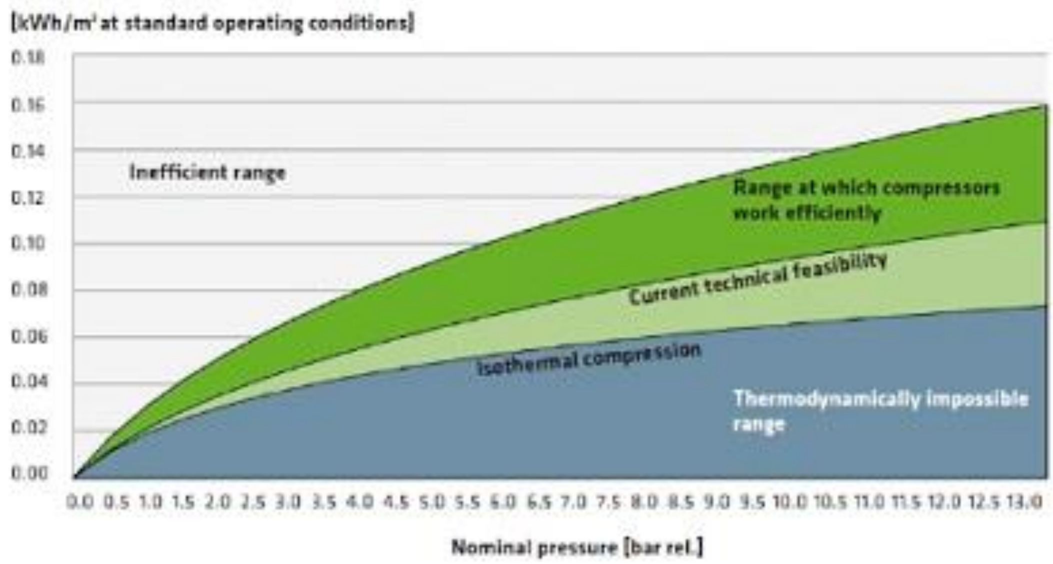
Compressed air systems (CAS) can be very expensive to operate, and experience high energy losses, which can be difficult to measure and manage on an ongoing basis. CAS can be noisy, dangerous, and may require significant maintenance and regular replacement of components. Yet they are widely used across industry, and CAS is often described as the 'fourth utility', in addition to electricity, gas and water. Once a CAS is installed, it is relatively easy and cheap to connect additional end-use equipment. Most CAS end-use equipment is compact, light, and reliable. It is not surprising that compressed air is widely used.

However, compressors are relatively inefficient. To put this in context, a typical compressor operating at 6 bar (approximately 600 kPa) works at about 28% efficiency, though 'current technological feasibility' is around 45% efficient (Festo, 2013). Overall CAS efficiency is further reduced to around 10-20% (Saidur et al, 2010) due to poor management and control, high standby losses, lower efficiency when operating at low load, losses from distribution, leaks and end-use equipment inefficiencies.

***Figure 1. Efficiency indices of compressors***

Higher value is less efficient – more electricity used per unit of air.

Source: Festo (2013), originally produced in EnEffAH project *Energy efficiency in production in the drive and handling technology field (2008-2012)*




However, technologies and industrial process requirements are changing fast. New flexible, precise, reliable and fast-acting electric equipment can be connected into 'smart', adaptive control, diagnostic and monitoring systems to support modern, high productivity business practices. This equipment can improve the efficiency and performance of CAS and in many cases remove the need for compressed air completely. As discussed in this report, energy savings of 50 to 90% or even more can be achieved while increasing process and business productivity, delivering financial savings much larger than the value of the energy savings alone.

Given these rapid technological developments, there appears to be a clear opportunity for new business models that can support proper consideration and implementation of alternatives to traditional CAS. Governments, industry organisations, academics, research organisations and business leaders could all make useful contributions to development of resources, tools, supply chains and funding of Australian demonstration and pilot projects.

This report documents A2EP's investigation into more efficient alternative technologies that can partially or completely replace compressed air systems, or deliver large energy savings and business productivity benefits beyond those achievable by traditional leak surveys and audits. The report also provides examples of international applications in this space.

It is important to note there is limited literature or information on alternatives to CAS as almost all government, academic and other public information resources focus on optimising performance and reducing waste from existing CAS. Most of the information on alternatives to CAS was sourced from suppliers of specific types of equipment used to deliver end-use services in industry. This required research into the range of services provided across the sector, then searches for suppliers of equipment that provided those services.

The report is structured as follows:

- Section 1 sets out the context of this report, including the systems and services approach to compressed air displacement.
- Section 2 identifies emerging enhancements and alternatives to compressed air and discusses the benefits and challenges that face industry.
- Section 3 describes international examples of compressed air demand being replaced or significantly reduced by more efficient alternative technologies.
- Appendix A: References and useful resources.

## 1.1 Taking a systems and services approach to compressed air replacement

As compressed air is fundamentally inefficient, the Australian Alliance for Energy Productivity (A2EP) recommends a systems and services approach to evaluating opportunities to replace compressed air where possible and optimise compressed air systems (CAS) where use of compressed air cannot be avoided. Under this approach the steps listed below are followed:

1. Define the end use service(s) that are to be provided.
2. Define the system/equipment currently used to deliver end use(s). Identify all the equipment using compressed air to deliver a service and any site-specific factors, such as end-use services at the end of long lengths of pipe. If possible, this should be done on a diagram.
3. Identify and prioritise potential opportunities to better deliver end use services with higher efficiency alternatives to compressed air and thereby:
    a. Avoid the use of compressed air and/or
    b. Reduce the use of compressed air.
4. Identify where there is a physical or other constraint to reducing or eliminating compressed air. Examine the compressed air distribution system to identify opportunities to improve the efficiency of production and distribution of compressed air, for example, by minimising losses due to leaks and flow resistance.

The systems and services approach to compressed air displacement is discussed above to provide context, however the focus of this report is step 3 – the identification of opportunities to avoid or reduce use of compressed air by utilising higher efficiency alternatives. To support this, this report explores the following:

- Considerations an individual business may take into account when comparing the pros and cons of the existing CAS against emerging alternative(s).
- Discussion of a variety of emerging enhancements and alternatives to compressed air systems. This includes consideration of key factors regarding the operation of these alternatives, suitability for various situations, potential availability and relevant features.
- The results of a literature review and engagement with academics, government and industry-based research and industry groups to collect information and identify examples of applications of alternatives to CAS.

# 2 Emerging enhancements and alternatives to compressed air

## 2.1 Considerations when assessing options

The objective of this report is to provide an aid for businesses seeking to identify opportunities to avoid or reduce use of compressed air by utilising higher efficiency alternative technologies and/or processes. Such alternatives might involve addition of smart devices to an existing CAS, changes in product or process design or material, or a shift from pneumatic devices to portable battery-powered equipment or micro-electric motors. The context in which each business considers their existing use of compressed air and opportunities to reduce or avoid it varies. Many factors need to be taken into account when considering whether and which alternative is most appropriate. A non-exhaustive list of factors to be considered includes:

- **Health and Safety considerations:** Some industries use compressed air for health and safety reasons. For example, compressed air is often used instead of electricity driven equipment in processes requiring water or other conductive liquids due to safety.
- **Consider low load, standby and part load efficiency of the existing CAS:** These are the modes the compressors and related equipment operate in most of the time. Peak loads should also be analysed, as these drive capital investment or bottlenecks may be constraining opportunities to increase production. When considering alternatives, it is very important that realistic assessment of existing system performance and other factors such as noise, maintenance, product reject/damage rates, desired production rates and other costs are factored into the benchmark for comparisons, and that potential 'multiple benefits' of alternatives (IEA, 2014) are also appropriately valued.
- **Identify 'fringe' activities that disproportionately increase CAS costs:** Is there a single end-use a long way from other uses (where pipe losses and maintenance costs may be high) or an item of equipment that is used when most or all other CAS equipment is not operating, that increases operating hours of the CAS, which could be cost-effectively replaced without having to make major changes to overall processes?
- **What are the space constraints** for equipment near the point of use?
- **Levels of performance required or possible** using alternatives (e.g. speed at which tasks can be done)? Could alternatives free up existing bottlenecks or production constraints, so process and productivity can be increased?
- **Noise:** What are the relative noise levels of the CAS versus the alternative(s)?
- **Electricity supply issues:** If the alternative is electrified, is there access to sufficient electricity supply, and what impacts may there be on electricity demand charges and on-site infrastructure costs? It's important to note that CAS already uses electricity, and alternatives should be much more efficient, so site-level electricity consumption and demand should fall for a given level of production (Zolkowski, 2019), but demand in some parts of the site may increase.
- **Evaluate implications:** If compressed air can be replaced by an alternative technology for a process, the potential positive and negative implications for the rest of the process and the

overall site and business need to be taken into account. This includes transition and installation issues, risks and opportunities, maintenance costs, skill requirements and impacts to overall process productivity. Some of these issues are discussed in Section 2.3.

## 2.2 Summary of compressed air emerging options and alternatives

This section and the section *2.3 Detailed discussion of innovative options and alternatives to compressed air* describe emerging options to enhance performance of existing CAS and alternatives to compressed air for different circumstances. An overview of suggested alternatives is provided in Table 1 below, with more detailed commentary on the more innovative of these alternatives provided in the following sub-section.

***Table 1: Compressed air emerging options and alternatives***

| Actions/End-use services | Examples of alternatives |
|---|---|
| **Organisation level changes – Refer to section 2.3.1 for more information** | |
| Change process inputs, process and/or specifications for outputs to avoid or reduce need for CAS | • Work with supply chain and customers to reduce need for CAS operation on your site(s)<br>• Product/process redesign<br>• Efficient process and system design |
| Build capability to implement emerging options | • Set up ongoing 'watching brief' for relevant innovations, cost trends etc |
| **Enhancements to CAS – Refer to section 2.3.2 for more information** | |
| Improve CAS performance | • Recover heat lost from compressors<br>• Install 'smart, connected' modules/actuators near each major point of use and compressors and use the data and insights |
| Monitor and optimise actual system performance of CAS | • Digital analytics and machine learning<br>• Digital 'twinning'<br>• Real time monitoring and reporting of multiple data streams, and integration into management and operational practices |
| **Alternatives to compressed air driven technology – Refer to section 2.3.3 for more information** | |
| Conveying and sorting | • Electronic actuators<br>• Electric or magnetic motors |
| Energy supply and alternative, equipment to deliver end-use services, replacing pneumatic tools and/or pneumatic production equipment | • Electric portable or fixed motor-driven equipment, e.g. pumps, tools, processes<br>• Additive manufacturing (3-D printing)<br>• Solenoids<br>• Magnetic conveying |

| Actions/End-use services | Examples of alternatives |
|---|---|
| Low pressure air opportunities: cleaning, cooling, drying | • Avoid/reduce need for task<br>• Brushes, sponges, mops<br>• Water or other solvents<br>• Mechanical motion: 'centrifugal', shaking<br>• Low pressure fans, blowers, air knives<br>• Low pressure dust collection systems or point-of-use filters<br>• Waste heat from other sources<br>• Heat pumps, microwave, radiation, induction |
| Tools: screwdrivers, hammers, riveters, etc | • Avoid/reduce need for fixings<br>• Alternative fixing, e.g. glue<br>• Plug-in or portable electric tools<br>• 'Smart' screwdrivers and tools<br>• 3-D printing or other innovative processes |
| Aeration; atomisation; mixing | • Avoid need for service or use alternative, e.g. dipping, auto-deposition, gravity, buoyancy<br>• Agitate with piston-type electric, shaking and other forms of motion, not vane agitators<br>• End-use hydraulic equipment, e.g. airless, centrifugal |
| Cooling | • Avoid/reduce need for cooling of enclosures, staff, electronics<br>• Improve thermal performance of enclosures<br>• Use natural ventilation<br>• Fans, evaporative cooling<br>• Compressor-driven refrigeration<br>• Thermo-electric devices |
| Vacuum | • Avoid or reduce need for vacuum to move product by alternative materials handling methods, electric actuators<br>• Electric motor-driven vacuum pumps at point of use with high efficiency motor/fan, VSD etc |
| Cleaning surfaces or parts | • Brushes<br>• Low pressure blower<br>• Low pressure vacuum |
| Sandblasting | • Chemical cleaning<br>• Motor-driven abrasive belt<br>• Sand-blasting blower |

## 2.3 Detailed discussion of innovative options and alternatives to compressed air

This section provides a more in-depth discussion of some of the more innovative and significant options that enhance performance of CAS and alternatives to compressed air summarised above.

Key aspects of these alternatives are considered in relation to their operation, suitability for various situations, potential availability and relevant features. Technology is moving fast in this area, so it is important to refer to the latest information and costings when considering options. Many of the references used for this report were published between 2018 and 2020, or are on current websites. Older publications typically refer to higher capital and installation costs, more limited applications and fewer benefits from alternatives.

Existing CAS will be able to increasingly improve performance and overall business/process productivity by integrating smart, connected controls and multi-purpose electric actuators. These may be used for pressure management, process control and condensate management in systems. Additionally, these will allow two-way interaction via Industry 4.0 systems with 'the cloud' that improves individual business outcomes and shares experience to deliver broad benefits to the user, suppliers of equipment and other users of CAS. This will significantly improve real world efficiency of CAS across all sectors. However, for many purposes, fundamental inefficiencies are associated with compressing air. More efficient alternative technologies to compressed air can provide multiple benefits such as declining ongoing costs, improved performance as well as offering multiple productivity benefits. However, one disadvantage of more efficient alternative technologies is the high initial capital costs.

Costs and levels of expertise required to adopt electric technologies are declining. Ongoing technology development, capture of economies of scale, maturing supply chains and 'learning from experience' are driving these trends. An example of change is the separation of software from hardware, so that standardised actuators can be installed and remotely programmed to do many different tasks (Anon, 2019).

Faster response, improved diagnostics and flexible programming can allow electric alternatives or complements to CAS to support higher speed process operations, remove bottlenecks in processes and reduce standby energy waste, with fewer interruptions and failures. They can adapt to fill different containers, apply varying forces and range of movement, and vary performance in response to changing behaviour of other process system elements. This can increase profitability or reduce operating time for similar production, so that less labour or fewer shifts are required, and all process equipment is better utilised.

### 2.3.1 Organisational actions

#### *2.3.1.1 Avoid or reduce the need for the process*

Review of the inputs and outcomes associated with a process may allow compressed air to be avoided in some or all activities at a site. Some examples of potential changes include:

- **Change specifications of input materials:** It may be possible to engage with supply chains to provide clean, sterilised or more consistent quality inputs, for example, through improved upstream quality control, changed packaging, or a change in supplier. Purchasing a product such as pre-coated/painted metal, stainless steel or composite materials may avoid the need for multiple processes that may involve compressed air and other energy-intensive processes such as galvanising or painting.
- **Changing method of conducting a process using new techniques:** Some metal fabricators have shifted from riveting and screw fixing to gluing (Durr, 2020). The need for fixing components together may be avoided using a variety of strategies. For example, more

complex products that replace multiple components may be produced using plastics, composites or more sophisticated metal forming techniques. Redesign of components so they clip together may also be possible.

- **Redesign of product or process:** This may permit lower precision assembly, while still delivering a product of acceptable quality. For example, this may be achieved by designing openings with a more tapered inlet or lid shape, so reject rates are reduced.
- **Influence behaviour of customers:** If the product is an input to a separate downstream customer business that assembles, fabricates or manufactures products using inputs from a range of sources, redesign of their product or process could avoid the need for compressed air at your site, and potentially reduce their input costs through sharing of the avoided cost, or through improvements in their production processes. The 'value chain' approach applied by the Australian Alliance for Energy Productivity (2018) has facilitated recognition that all the participants in a value chain are actually inter-dependent and can potentially benefit from each other's innovation efforts.
- **Efficient process and system design:** The viability of alternatives to CAS may depend on optimisation of the efficiency of the manufacturing process, so that less material must be moved or lower forces used, while highly valued benefits such as flexibility, precision and communications can be gained. Improvements in process efficiency may mean less power is required to provide enough functionality. These process improvements may offer improved business/process productivity beyond facilitating use of alternatives to CAS.

#### *2.3.1.2 Build capability to change*

CAS is often taken for granted as an essential utility to provide services around a site. But, as this report highlights, there is rapid innovation in this area. Failure to identify and implement relevant innovations risks losing competitiveness. Each organisation should establish a mechanism to maintain a formal 'watching brief' for relevant innovations, cost trends, market factors, outcomes of measures implemented in demonstration projects and by early adopters. Such a mechanism can identify business potential of change, overcome concerns about risk, accelerate innovation and create a more positive culture.

While suitable staff should be responsible for this activity and reporting to management, it can include approaches such as regular scans of key industry publications and research journals, engaging vacation students to bring 'fresh eyes', ongoing networking with key researchers and industry organisations, encouraging 'cross-cultural' staff events within the business and publishing articles in internal newsletters that describe the achievements of early adopters.

### 2.3.2 Enhancements to CAS: it's not 'all or nothing'

While the really big energy savings and productivity improvements will come from replacement of CAS, large savings and multiple benefits can still be captured through less dramatic changes.

#### *2.3.2.1 Recover heat lost from the CAS*

Up to 30% of compressed air costs can be saved by recovering useful heat (Festo, 2013), if there is a use for it at the site. However, overall compressed air and heat production efficiency would still only be 30 to 40%. If there are options to avoid compressing air by using alternative equipment to deliver the same service, this waste heat recovery is a very inefficient way of producing heat from electricity in comparison to a heat pump (with typical efficiency of around 300%) combined with use of high efficiency alternatives to CAS. However, if CAS cannot be replaced, a heat pump that uses the waste heat from a compressor can raise the temperature and improve efficiency of heat recovery.

#### *2.3.2.2 Install smart, flexible, connected actuators and sensors and high efficiency end-use equipment*

Adding improved real time monitoring, digital analytics and machine learning, 'digital twinning' (where a computer model of the process is built and used for real time benchmarking) and smart management systems to existing CAS can significantly cut waste. For example, manufacturers such as Festo provide smart electronic control devices that can manage or shut down elements of the CAS, such as sections of pipe and specific end-use equipment, when some equipment is not operating, but maintain system pressure during short breaks. Smart monitoring capability can track and manage real time compressor system efficiency, air leakage and air pressures at end-use equipment.

Smart pressure regulation at end-use equipment and improved aerodynamic design of compressed air driven equipment, such as air-knifes that entrain large volumes of ambient air to amplify effectiveness (e.g. Exair, 2018), can also cut waste. While such strategies can achieve impressive-sounding and very worthwhile CAS energy savings of 50% or more, from the original 10-20%, overall efficiency may still only reach 20 to 40%.

#### *2.3.2.3 Monitor and optimise actual system performance*

Electronic control devices such as smart electronic actuators that communicate with 'the cloud', inserted into compressed air pipes, can monitor, report and control air pressures and flows. They can enhance business productivity by increasing production rates due their rapid and precise response capabilities.

Further, utilisation of data from these actuators combined with multiple data streams, such as weather, transport logistics, market information, reject rates, etc can facilitate application of data analytics, machine learning, real time fault prediction. Over time, 'digital twins', computer models that simulate expected performance under changing conditions, can be developed. These not only improve process management but also support simulation of changes without involving physical changes to plant, so options can be explored quickly and without risk to production. These capabilities, often described as 'Industry 4.0' techniques, help to optimise business operations and process management, and reduce the risk of change, offering business value far beyond the savings on energy costs (see A2EP, 2018).

### 2.3.3 More efficient alternative technologies

#### *2.3.3.1 Electronic actuators for many tasks*

Electric actuators are far more precise, react much faster, can vary speed and pressure of application to product, and can be reset for different tasks far quicker than compressed air devices. A single electric actuator can move between several positions, while each compressed air unit moves between two positions. Electric actuators are becoming 'smarter' and can be integrated into Industry 4.0 smart, connected systems to capture many benefits (Festo, 2018). Standardisation of hardware and more user-friendly software are reducing capital and installation costs (Anon, 2019).

Electric actuators can provide linear or rotational movement. There are different types for different load levels and purposes, such as screw mechanisms (often with ball bearings to reduce friction), belts, rack and pinion, linear motors (Maw, 2018) and piezo-electric devices (Physik Instrumente, 2020). Some types of electric actuator can have very long lives.

Electric actuators can be used for a wide range of tasks. These include (list is non-exhaustive):

- Screwing caps on containers while checking that they are properly fitted;
- Quickly and precisely removing defective product from fast-moving production lines with minimum damage;
- Injection moulding (Fanuc, 2020) where some low-pressure processes also operate at lower melt temperature and faster cycles (e.g. see Ptonline, 2017);
- A wide variety of tasks in automotive, brewing, dairy, packaging, electronics, robotics, pharmaceutical, medical assembly, laser cutting, high speed scanning, glass cutting, dispensing, switch testing, spot welding, soldering, and measuring applications.

Actuators can communicate with control systems, monitoring and other 'Industry 4.0' solutions that are increasingly being adopted across manufacturing processes (A2EP, 2018; Festo, 2018). These features can support flexible production, preventive maintenance and integration of system-level optimisation to drive improved business productivity. Where equipment suppliers, other users of the technologies, consultants or in-house staff share experience and knowledge, all participants can benefit. As noted earlier, adding electronic monitoring and controls connected to Industry 4.0 systems can also optimise performance of existing CAS.

#### *2.3.3.2 Motors*

Electric motors and associated point of use alternatives to compressed air driven equipment have traditionally been heavier and bulkier. However, developments in motor efficiency, fan design and overall system fluid flow efficiencies have been dramatically reducing weight and improving performance. For example, domestic cordless 'stick' vacuum cleaners now use light, compact motors with high density neodymium magnets, high efficiency fans and optimised fluid flows, with lightweight, high power density lithium ion batteries to deliver impressive cleaning performance. European domestic vacuum cleaners since 2017 have been limited to 900 watts maximum capacity, compared with up to 2200 watts pre-2014 (Metro, 2017).

Developments such as compact, fast response piezo-electric devices linked to magnetic motors can actuate, rotate and move product even more efficiently, quickly and precisely than small electric motors (Physik Instrumente, 2020). Present products offer up to 230mm movement range.

When replacing CAS with electric motors and associated pumps, fans and other machinery, it is important to optimise selection. Improved process efficiency may mean much smaller motors are needed, and oversizing motors leads to lower efficiency. In the past, many designers have deliberately oversized motors to provide a 'safety factor' in case wear or faults increase loads. Today, real time monitoring can not only avoid overloading, but can identify small changes in loads to underpin preventive maintenance and help avoid unplanned failures and loss of production. Variable Speed Drives are far more efficient to vary level of activity than using valves or dampers, which increase resistance to flow and therefore increase energy waste as load decreases.

#### *2.3.3.3 Tools (screwdrivers, hammers, riveters etc)*

Because of the improvements noted above, plug-in electric tools with cords are increasingly competing with compressed air driven equipment that must be attached by a hose to the CAS: so, the power cord competes with air hose. Modern portable electric tools are becoming lighter, and do not require an air hose or power cable. The efficiency and speed of recharging is improving, while the standby power use of chargers is declining and battery technologies are improving. As commercial vehicles shift towards Plug-in Hybrid (PHEV) or electric drive (EV), the capability to recharge spare batteries at work sites or while travelling between sites means the bulk, weight, noise and need for access to a power supply, engine or generator and portable air compressor can be avoided. In factories, electric equipment can often be relocated (subject to adequate electricity supply capacity) more easily than extending or modifying compressed air systems.

Electric tools offer substantial electricity savings over compressed air tools of comparable performance. Zolkowski (2019) compared electricity use between a compressed air, corded electric and battery-powered tool. The compressed air tool had a peak electricity demand and annual electricity cost almost six times higher than the corded electric alternative. The savings from the battery-powered tool were very sensitive to the efficiency and standby energy use of the battery charger, though his analysis, in which the charger consumed 70% of total electricity, still showed 40% savings relative to the compressed air tool. Battery charger technology is improving rapidly, and charger consumption may also be offset by higher efficiency than plug-in equipment: but care is needed when selecting battery chargers.

Electric tools, like actuators, offer increasingly ‘smart’ capabilities that can increase productivity and reduce reject rates. For example, one ‘smart screwdriver’ (SMAC, 2020) turns counter-clockwise until the screw thread is properly positioned, then monitors torque, rotation and position to ensure it is correctly inserted, minimising rejects and interruption of production.

More fundamental innovations such as 3-D printing (additive manufacturing) may also avoid the need for traditional tools and activities.

#### *2.3.3.4 Low pressure air for cleaning, cooling and drying*

Cleaning and drying often use CAS with poorly controlled nozzles or even open hoses. This is inefficient and wasteful. As noted earlier, avoiding the need for these activities is often feasible. Point of use air pressure management and high aerodynamic efficiency nozzles and air knives (e.g. Exair, 2018) can also dramatically reduce CAS energy waste.

There are many alternatives to CAS, including brushes, brooms, sponges, mops, water or other solvents, mechanical motion such as spinning (‘centrifugal’) or shaking, electrostatic and other types of filters, dust collection systems, low pressure vacuum cleaners, electric fans and low pressure blowers and air knives (see Industrial Air Compressors, 2020 for examples).

Heat pumps can be efficient dryers. For example, domestic heat pump clothes dryers operate at up to 400% efficiency and can operate with a ‘closed loop’ of air, while condensing the water, potentially for other uses. This avoids adding humidity to the nearby air, and may help to reduce localised air pollution. Microwaves, radiant heat and induction heating are other options for drying, for example see NSW OEH (2016).

#### *2.3.3.5 Electric driven pistons or shakers, gravity, buoyancy for aeration/atomisation/mixing*

Compressed air is often used to drive paint spraying, for aeration of liquids, and to mix or blend combinations of liquids or powders.

Painting and coating have traditionally been key roles for compressed air. Major activities include agitation and mixing, spraying or applying product and need for heat to dry or set the coating. Important factors for users include quality of finish, transfer efficiency (percentage of paint that actually coats the product and is not 'lost') and management of Volatile Organic Compounds, which impact on occupational health and compliance with air pollution regulation. Some options can improve space utilisation and overall business productivity (e.g. Durr, 2020a).

According to Elberson (2020), agitation can consume more than half of the air consumed by a finishing system. Piston-type pneumatic and electric technologies are far more efficient than traditional vane pneumatic motors. Other means of agitating and mixing, using electric actuators may also be effective.

Spraying is just one of many forms of coating. Izzo (2011) outlines many options, some of which, such as dipping, electrostatic coating (often using centrifugal atomisation with discs or bells, or even inkjet-like 'nozzle plates' (Durr, 2020b)), flow coating and auto-deposition (chemical curing), can avoid use of CAS. He points out that traditional paint spraying releases polluting VOCs from organic thinners that require high ventilation rates to protect operators, and has relatively low transfer efficiency. The overall system is energy intensive.

Poll (1997) describes the range of alternatives to traditional compressed air spray guns. These include airless, air assisted and high-volume low pressure (HVLP) guns, and centrifugal atomisation. Supercritical carbon dioxide spraying was originally developed by Union Carbide (Pollution Prevention Infohouse, 2001), but this still seems to be used for other higher value processes (Applied Separations, 2020). Many of these alternatives still rely on CAS, but achieve higher efficiency and lower environmental impacts. Others use hydraulic equipment, often at point of use, to produce high pressures. Hydraulic equipment for activities that require high power is also being superseded by much more efficient, faster, smart and more precise electric alternatives (see Rise Robotics, 2020).

Compressed air is used for aeration processes. Alternative processes often exist, for example, in wastewater treatment (see case study 3.2 of Biogill in Section 3 of this report, where limited pumping and gravitational flows over biofilms are utilised instead of traditional aeration).

#### *2.3.3.6 Cooling*

Compressed air is used for cooling in various ways, particularly to run fans for cabinets containing heat-emitting or sensitive equipment. Blowers are a potential alternative for cooling and were discussed earlier. Other alternatives are discussed below.

The other main existing CAS approach utilises the Vortex Tube or Ranque-Hilsch tube. Compressed air is fed into a tube where it creates a vortex or 'whirlpool'. The design of the system produces two separate air outlets, one hotter, and one colder than the inlet air. This technology can deliver cold air at up to 70C lower temperature than the inlet air and is compact. This may be used for targeted cooling and other specialized purposes (e.g. see Meech, 2020). There may be potential to utilize the heat from the high temperature air flow.

In considering alternatives, all elements of the system should be considered. Design of enclosures to reduce solar and ambient temperature loads, and to utilise natural ventilation techniques, may avoid or minimise the need for cooling.

Appropriate selection of equipment can reduce or avoid the need for cooling. For example, modern telecommunications and computing equipment is often capable of operating reliably in a wide range of temperature conditions. Problems may be caused by rapid temperature changes or transient condensation issues, not extreme temperatures, so smoothing of transients may be more important than maintaining a narrow temperature range.

Simple fans or evaporative coolers can cool very efficiently, and efficiencies of motors, fans and controls have improved dramatically in recent years. Conventional compressor-driven refrigeration units are also typically far more efficient than compressed air solutions. For smaller cooling loads, compact thermo-electric (Peltier Effect, see Tritt ,2002) devices with no moving parts can provide cooling, though efficiency is low compared with compressor-driven refrigeration, and falls rapidly as temperature difference increases. The temperature difference across a thermo-electric device can be reduced by finned heat exchangers, evaporative or cold-water cooling of the hot side, or 'stacking' of multiple devices in series.

#### *2.3.3.7 Vacuum for picking-up and transporting material*

Vacuum eductors or ejectors use the venturi effect to create rapid expansion of compressed air that causes cooling. This method of creating a vacuum, if used for continuous activities, is very inefficient: Heney (2019) notes that a venturi consumes around ten times as much power as an electrically powered mechanical vacuum pump for the same flow rate, due to the inefficiency of the overall CAS. However, eductor efficiency is improving: SMC (2020) is an example of a supplier that is integrating digital solutions with CAS vacuum equipment.

Compressed air vacuums may be suited to low duty cycle activities, small pressure reductions with small air volumes, and corrosive environments or where there is high particulate pollution. Where there are multiple compressed air vacuum units, their substantial demand for compressed air supply may mean additional compressor capacity must be purchased or operated (Bott, 2020). Optimised management of pressure and operation can improve efficiency.

As in other areas, review of processes that avoid the need for a vacuum can cut CAS costs and energy use. Changing the way input materials are stacked, packaged or conveyed may allow alternative handling methods to be used to replace suction cups. Electric actuators, discussed earlier, may replace a vacuum. Point of use electrically driven pumps can provide targeted vacuums at optimal pressures. As noted earlier, developments in high efficiency domestic vacuum cleaners illustrate the scope for improvement in efficiency of electric vacuum solutions.

### 2.3.4 Challenges for adoption of more efficient options and alternative technologies

Adoption of alternatives to CAS, as with most innovation, involves risks and opportunities. Some of the risks are very real, but others are based on perceptions that may reflect lack of familiarity, immaturity of supply chains, narrow framing of business models and other factors. Figures 2 and 3 show the outcomes of two studies of barriers to energy efficiency innovation in industry. Many of these apply to alternatives to CAS. The 2018 A2EP report *Transforming Energy Productivity in Manufacturing* discusses many relevant barriers and offers paths towards their resolution.

Different challenges apply to existing and new sites. At new sites, or when process replacement is proposed, important factors include:

- Capital costs and access to finance;
- Confidence in process designers, suppliers, installers to deliver claimed performance on time and on budget;
- Process reliability, productivity and safety;
- Confidence that plant will not become 'orphan' due to ongoing technological and business model change, or lack of future maintenance services and replacement components;
- Access to competent operators, and associated training; and,
- Under-valuation or lack of recognition of the benefits of change.

For existing sites, additional factors may include:

- Retraining of existing staff or new staff with the required skills and knowledge;
- Writing-off sunk capital in existing plant;
- Transition issues such as loss of production during changeover and 'teething problems', finding space for equipment, changes in perceived quality of product within the site and among customers; and,
- Resistance to change.

These issues can be addressed, but they require comprehensive, well designed and adequately resourced policies and programs and market transformation strategies over a sufficiently long period to build business confidence and demonstrate outcomes.

***Figure 2. Perceived barriers against adopting energy efficiency measures in industry***

Source: Reproduced from *Industrial energy efficiency data analysis project*, ClimateWorks Australia, 2013

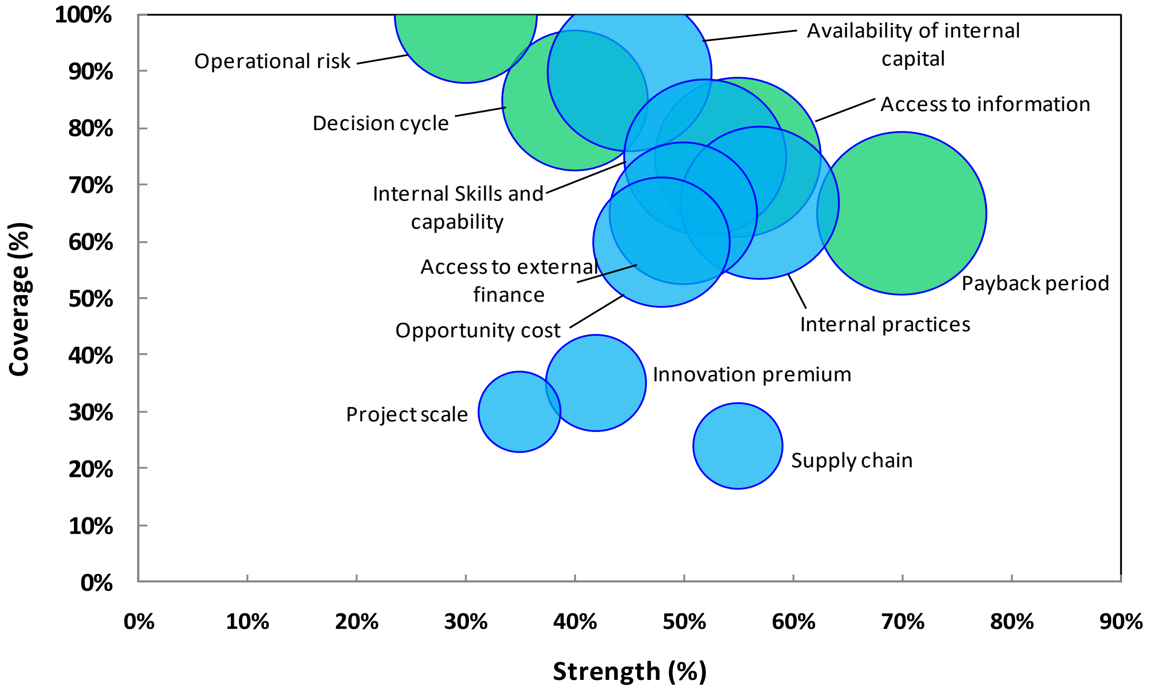
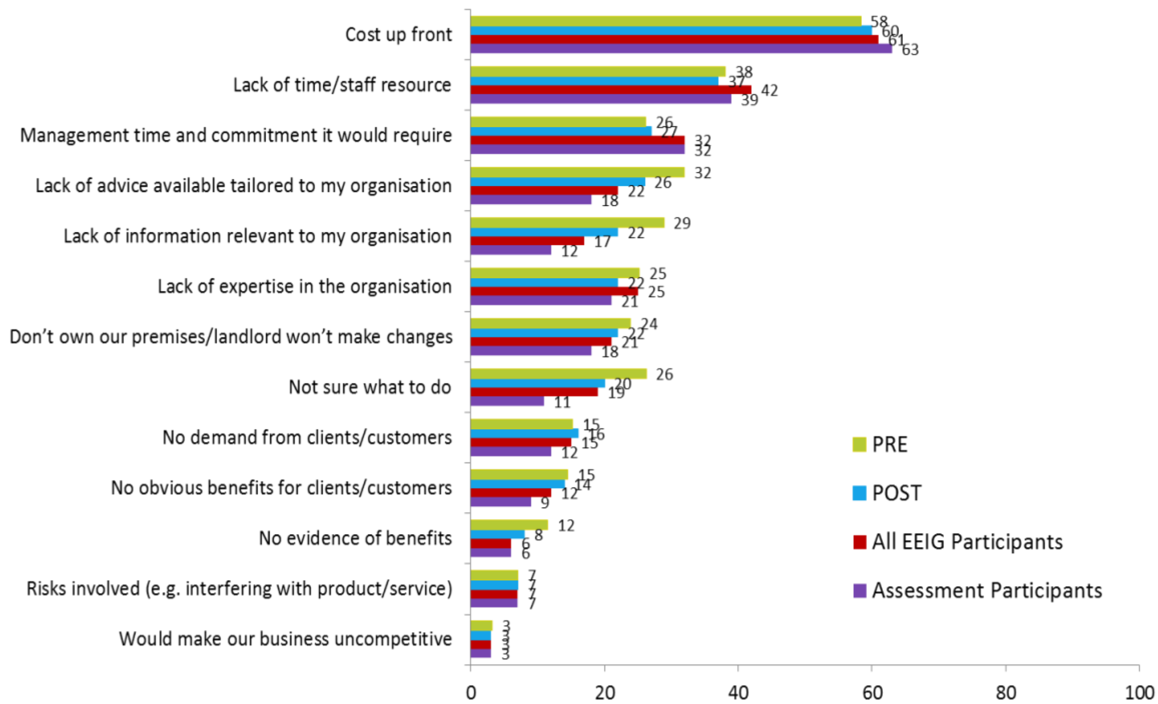



***Figure 3. Perceived Barriers to Energy Efficiency Action by SMEs***

Source: *EEIG Program Evaluation – pre & post activity survey report by Instinct and Reason,* 2015 [EEIG=Energy Efficiency Information Grants Scheme]



# 3 International examples

This section provides international examples of innovative solutions to reduce or avoid use of compressed air. It should be read in conjunction with Section 2, which refers to many practical examples and industry sources, and incorporates the results of a literature review and engagement with academics, government and industry-based research and industry groups to collect information and identify best practice examples.

The case studies provided cover a range of applications and technologies from a variety of geographical locations which illustrate real world solutions to reducing or avoiding use of compressed air. It is noted that the key business driver for the uptake of more energy efficient technologies is sometimes not reducing energy costs but other productivity benefits, such as improved operational flexibility, safety or labour productivity, that result from deploying these technologies.

Technologies and industries covered in the case studies include:

| Case Study | Technology | Industry |
|---|---|---|
| 3.1 | Electrical, digital robot grippers | Horticulture |
| 3.2 | Biological wastewater treatment | Dairy |
| 3.3 | Blower-driven air | Transmissions manufacturing |
| 3.4 | Electric actuators | Fuel cell power plant |
| 3.5 | Cable dryers | Cable manufacturing |
| 3.6 | Air knifes | Wood-based panel production |
| 3.7 | Bottle reject system | Bottling |
| 3.8 | Linear actuator positioning system | Car manufacturing |
| 3.9 | Linear motor | Automated manufacturing |
| 3.10 | Compressed air control system | Tool manufacturer |
| 3.11 | Compressed air efficiency | Sugar processing |

## 3.1 Electrical, digital robot grippers: Greenhouse, Denmark

**Replace compressed air powered vacuum (venturi) with electric vacuum unit**

### Technology: Dual vacuum robot gripper

- Conventional vacuum gripper solutions are typically powered by compressed air, however the OnRobot digital gripper has an integrated electric pump, eliminating the requirement for compressed air, hoses and cables.
- The OnRobot gripper has built-in intelligence and advanced technology that mimics the way humans use their sense of touch to grasp and move things. The dual vacuum gripper gives the robot arm two 'hands' and thereby the ability to handle several items simultaneously. Its increased flexibility and sensitivity allow a greater variety of tasks to be automated compared to conventional robot grippers.

### Application: Greenhouse cultivating herbs and mini plants

- Rosborg Food Holding is Denmark's largest producer of herbs and mini plants. At the 120,000 square metres of greenhouses in Odense 130 employees produce, pack, manage and sell 28 million herb plants and 12 million mini flowers each year.
- As part of radical modernisation of the company's production system, the owners have invested 37 million Danish crowns in new high-efficiency greenhouses equipped with automation technology and robots. This investment includes automation of a flexible packaging line featuring a cobot (collaborative robot i.e. designed to safely interact with humans) fitted with an OnRobot gripper. The gripper is able to lift herbs and flowers gently without squashing them.
- Due to the fast return on investment, Rosborg plans to invest in another cobot and OnRobot gripper to feed a cutting machine that cuts herbs.



Reference: https://onrobot.com/en/rosborg-greenhouse-packs

## 3.2 Wastewater treatment: Dairy, Australia

**Eliminate compressed air use in bioreaction process**

### Technology: Biological wastewater treatment

- BioGill manufactures above ground, attached growth bioreactors for wastewater treatment. These gravity-fed units are compact and modular. They do not require expensive aeration, which is often provided by compressed air, and therefore consume up to 80% less energy than some alternative wastewater solutions.

### Application: Dairy production

- Binnorie Dairy produces a range of cheese, specialising in soft cheeses. The company had previously installed a below ground wastewater treatment unit, but it was ineffective in reducing odour.
- In November 2012, Binnorie Dairy installed its first BioGill bioreactor containing 246m$^2$ of media. The bioreactor was installed over the existing storage tank. Wastewater from the cheese-making process is pumped from this tank to the top of the BioGill and then gravity fed down the gills.
- A key business driver for the decision to install the BioGill was reducing odour. However, by deciding to install the BioGill, the business also avoided installing an alternative solution to reduce odour, which may have required aeration provided by compressed air. The bioreactor achieved a dramatic reduction in odour and there was a significant improvement in the water quality within the storage pond. Binnorie Dairy has since increased production and installed a second BioGill to treat the additional wastewater.


Reference: https://www.biogill.com/

## 3.3 Blower-driven air: Transmissions manufacturer, United Kingdom

**Low pressure blowers replace compressed air**

### Technology: Blower-driven air

- Blower-driven air provides a safer and more economical means of removing deposits such as dust, fibres and water from people, product surfaces and work environments than equivalent compressed air.

### Application: Racing transmission manufacturing

- XTRAC are a leading supplier of custom-engineered transmissions for applications on land, sea and air.
- XTRAC uses low pressure, high velocity air produced from the JetBlack Safety Cleaning system to clean and dry components as they pass through a ten-stage rust inhibitor application process. Compressed air had been considered but the risk of moisture-contaminated air potentially causing rust promotion plus the inherent dangers from using high pressure air for the operative resulted in the decision to use the JetBlack system in preference to compressed air.

Reference: https://www.aircontrolindustries.com/project/xtrac/

## 3.4 Electric actuators: Fuel cell power plant, South Korea

**Replace compressed air devices with electric actuators in fuel cells**

### Technology: Electric actuators

- An electric actuator is a mechanical device used to convert electricity into kinetic energy in either a single linear or rotary motion.
- Electric actuators are far more precise, and can be reprogrammed for different tasks more quickly than compressed air devices. They are very energy efficiency while delivering productivity improvements.

### Application: Fuel cell power plant

- Electric actuators will operate globe and ball valves which control the flow of hydrogen gas in fuel cells at the Hanhwa Total Co. Ltd fuel cell power plant in Daesan, South Korea. Each fuel cell will include two Rotork CVL linear electric actuators and four ExMax quarter-turn electric actuators.
- The CVL actuators use a 1-phase or DC power supply to provide highly accurate and responsive continuous modulation of control valves without the complexity and cost of a pneumatic supply.

Reference: https://www.controlengeurope.com/article/172304/Electric-actuators-supplied-to-Korean-fuel-cell-power-plant.aspx

## 3.5 Cable dryer: Cable manufacturer, United Kingdom

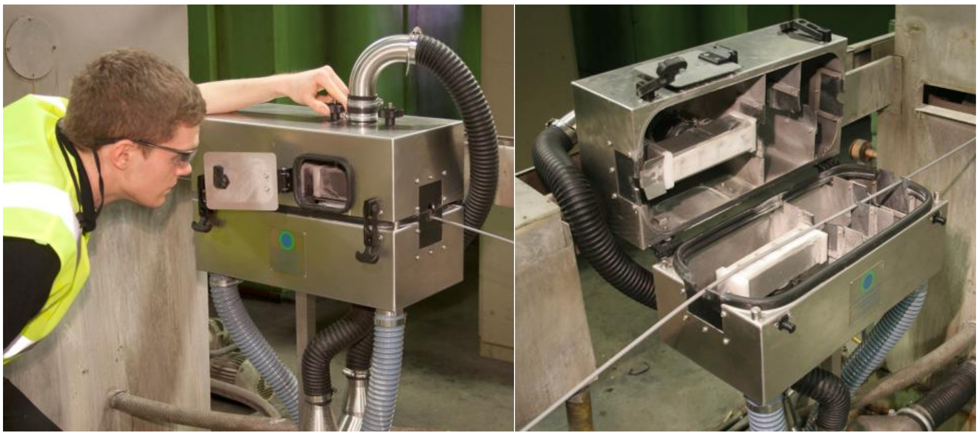
**Improve drying process with cable dryer instead of compressed air water removal system**

### Technology: Cable dryer

- Cable dryer engineered to effectively remove residual moisture from water-cooled insulated wire, cable and extruded products. It works by closely focusing powerful angled jets against the flow of the product. Removed water is ducted away from the underside of the enclosure.

### Application: Cable manufacturing

- Compressed air-based systems had been used at Prysmian's Aberdare cable manufacturing facility but these failed to remove the excess carry-over water adhering to the wire after leaving the cooling troughs. The random water dispersal had the effect of causing corrosion, increasing maintenance requirements and shortening equipment life.
- A "LINE-Dry" cable and wire dryer, comprised of a drying station and a free-standing blower housed in an ABS enclosure, was installed to replace the compressed air system.
- The cable dryer resulted in lower running costs than the previous compressed air system. In addition, cable drying is more efficient because the air is from a dedicated source whereas previously variations of load-demand upon the compressed air compressor impacted upon the drying line and packing operations. The new cable drying system also reduced the health and safety hazards resulting from water carry-over dripping on the ground.



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https://www.aircontrolindustries.com/us/products/drying-systems-us/for-cable-wire-extrusion-us/cable-dryer/

https://www.aircontrolindustries.com/project/prysmian-cables/

## 3.6 Air knife: Wood based panel producer, Wales

**Replace compressed air with precisely controlled air knife**

### Technology: Air knife

- Air knives project an uninterrupted sheet of precisely controlled, high velocity air supplying a powerful flow across the entire surface of the product being processed.
- When compared to compressed air driven nozzle systems, blower-powered air knife systems are: more cost effective to operate, with running costs reduced by up to 90%; quieter due to lower pressure operation; cleaner as the air is both dry and oil free; and safer as the centrifugal blowers operate on the principle of high velocity, low pressure air.

### Application: Wood based panel production

- Kronospan, a wood-based panel producer, had been using a compressed air system to remove dust and manufacturing debris from laminated flooring panels at its Chirk plant in North Wales.
- The compressed air system was replaced with an ACI blower powered air knife system. Compared to the compressed air system, the air knife system has the advantages of delivering a more controllable and better direction of air flow while avoiding potential product contamination with an integral air filter. In addition, the air knife system has lower maintenance requirements and noise levels.
- Kronospan calculated operating cost savings of 96% would be achieved by replacing compressed air with the air knife system and would payback in nine months.


References:

https://www.aircontrolindustries.com/air-knife-systems/

https://www.aircontrolindustries.com/project/kronospan/

https://www.aircontrolindustries.com/technical/blower-systems-vs-compressed-air/

## 3.7 Bottle reject system: Bottle inspection solutions provider, United States

**Moving coil electric actuator device to eliminate compressed air for bottle reject system**

### Technology: High speed moving coil actuator bottle reject system

- Moving coil electric actuator device designed to reject damaged stability-sensitive bottles on a bottling line at high speed.

### Application: Bottle inspection

- A major bottle inspection system provider required a solution to reject damaged bottles at speeds up to 1,200 ppm. The solution had to work with a variety of size and material bottles, whether the bottles were filled or empty, and be capable of being washed down as many of the company's systems are integrated into food and beverage filling lines.
- The company installed a SMAC a moving coil actuator system to reliably reject damaged containers off the bottling line. The device has the ability to reject a 3 inch bottle every 30 milliseconds from a stream of bottles that are closely packed together and is programmed to allow for different bottle profiles. The moving part of the reject arm of the moving coil actuator has a lower mass, and can be moved faster, than a device with a standard and servo motor, because the windings, not the magnets, are on the shaft.
- The moving coil actuator system has lower operating costs than the alternative, compressed air, which is costly to produce, transport and use. It also has the advantage of being able to be repaired, rather than becoming landfill, at the end of its initial life cycle.


Reference: https://www.smac-mca.com/documents/PDFs/Case%20Study%20-%20High%20Speed%20Bottle%20Eject%20System.pdf

## 3.8 Positioning system: Car manufacturer, United States

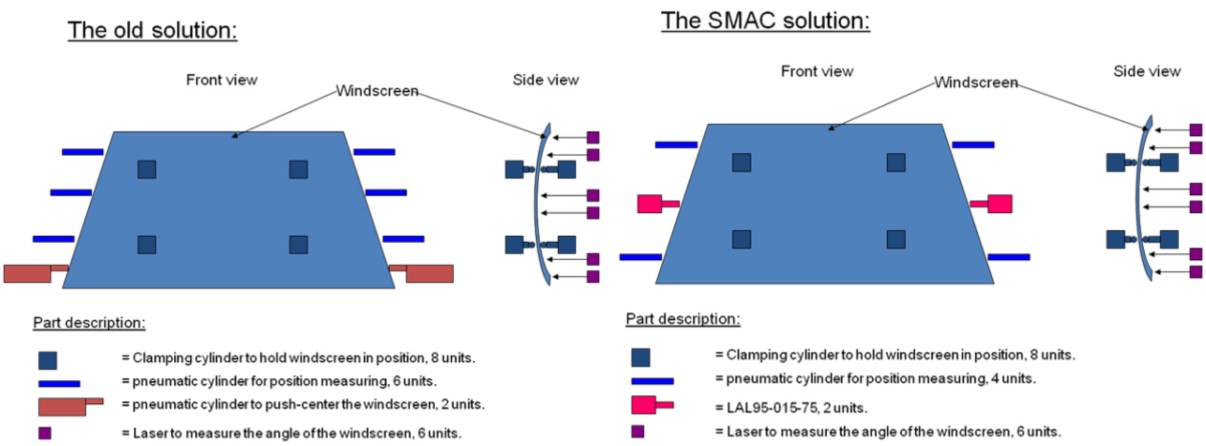
**Programmable linear actuators reduce compressed use in car manufacturing positioning system**

### Technology: Linear actuator positioning system

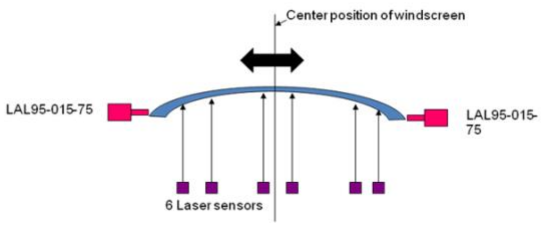
- Programmable linear actuator positioning system to ensure the integrity of placement of rear car windscreen during car manufacturing process.

### Application: Car manufacturing

- Prepared windscreens at a car manufacturer are placed by a robot into a gauge fixture prior to fitting. The manufacturer replaced the existing pneumatic fixture with a linear actuator positioning system to address the following issues related to the pneumatic fixture: lack of positioning accuracy; poor control of the pneumatic cylinders which caused intermittent damage to screens; and, after placement by the pneumatic cylinders there was no further opportunity to adjust the position of the windscreen.
- Two of six pneumatic cylinders for centring the windscreen were replaced with two SMAC LAL95 linear actuators. The advantages of the LAL95 linear actuators are: no damage to windscreens during QC due to Soft-Land function; capability to move the windscreen after test to accommodate tolerances, minimising rejects; and, minimal changes were required to the existing system.




Reference: https://www.smac-mca.com/applications/glass/rear-car-window-installation



## 3.9 Linear motor: Production plant, United States

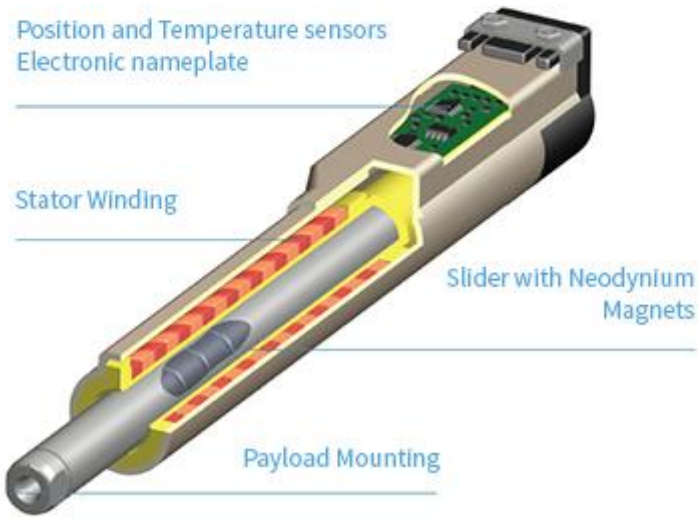
**Electric linear motors replace pneumatic cyliners in manufacturing**

### Technology: Linear motor

- Linear motors can be used in applications where translational motions need to be performed dynamically, with low friction and high flexibility.
- Electric linear drives can be used to replace conventional pneumatic cylinders in a variety of applications and have advantages including higher efficiency, greater control capabilities and significantly lower energy costs.

### Application: Automated manufacturing

- An automated production plant used a LinMot linear motor electric actuator for 18 months in an exact duplicate of a pneumatic application.
- A high efficiency compressor was then installed to create a leak free air delivery system to run the pneumatic cylinder machine. In a comparison of the performance of the linear motor electric actuator with the compressed air system it was found that the linear motor solution used 3% of the electricity of the air cylinder. The payback period for the linear motor replacement solution was less than a year.

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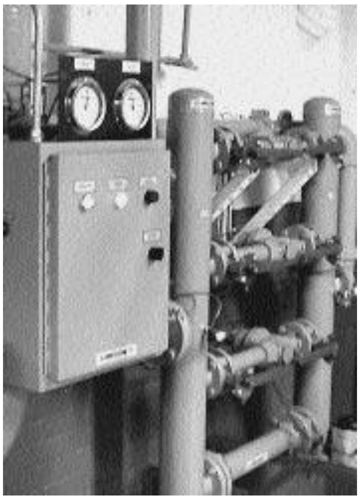
https://linmot-usa.com/products/linear-motors/

## 3.10 Eliminate need for new air compressor: Tool manufacturer, United States

**Control system to reduce compressed air demand and eliminate requirement for new air compressor**

- Snap-on Tools manufactures professional tools that are used in many industries including the automotive, aviation and aerospace, collision, construction and agriculture industries.
- When Snap-on Tools experienced increased demand for compressed air at its Kenosha, Wisconsin plant it sought a quote for a new compressor. When quoting, Cochrane Compressor Company and ConservAIR Technologies Co. also provided an alternative to a new compressor – a control system that would eliminate the need for a new compressor. Snap-on Tools elected to purchase the control system rather invest in a new compressor. The control system included a sequencing controller to increase the efficiency of existing compressors and a flow controller to reduce pressure fluctuations.
- Using the control system, Snap-On Tools followed a process to reduce compressed air demand: 1. Evaluate compressed air pressure and flow requirements; 2. Increase compressed air storage capacity; 3. Reduce system distribution pressure; 4. Minimise part-load compressor operation.
- The control system cost Snap-On Tools US$30,000 less than a new compressor and reduced operating costs by 40%. Pressure fluctuations were reduced by +/-8 psi.



Reference:
https://www.compressedairchallenge.org/data/sites/1/media/library/casestudies/Snap_on_Tools.pdf

## 3.11 Increase compressed air efficiency: Sugar processor, United Kingdom

**Measuring and reducing compressed air use**

- British Sugar is the sole processor of the UK's beet sugar crop. It is the leading producer of sugar for the British and Irish food and beverage markets, processing around eight million tonnes of sugar beet and producing up to 1.4 million tonnes of sugar each year.
- An audit of the compressed air system at British Sugar's Bury site found evidence of waste due to multiple air leaks in the system.
- A non-intrusive ultrasonic flow measuring device was used to measure the site's compressed air usage to understand the site's current compressed air usage. This data was used to identify and eliminate air leaks and periods when compressed air was being produced when it wasn't needed, resulting in reduced production of compressed air.
- Compressor efficiency was then improved with a variable speed system and automation to ensure the compressor always operates at the correct system pressure according to need.
- Improving the efficiency of compressed air systems at British Sugar's Bury site has resulted in a 15% reduction in compressed air energy usage, equating to savings of around £25,000.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**Useful resources**

*Compressed Air Factsheets,* published by the Compressed Air Association of Australasia, Australia. www.energyrating.gov.au/

*Good Practice Guide: Energy Efficient Compressed Air Systems,* published by the Carbon Trust, United Kingdom. www.bcas.org.uk/

*Improving Compressed Air System Performance,* published by the Compressed Air Challenge, United States. https://www.compressedairchallenge.org/library/#Sourcebook

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https://www.energy.gov.au/business/technologies/compressed-air

https://www.energy.gov/eere/amo/compressed-air-systems Includes case studies, tools and techniques

https://www.energy.gov/sites/prod/files/2014/05/f16/compressed_air11.pdf Includes discussion of inappropriate uses

https://www.sustainability.vic.gov.au/Business/Energy-efficiency-for-business/Efficiency-by-system/Compressed-air

www.elsevier.com/locate/rser .Very detailed review of energy saving measures and their economics.

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