TRANSFORMING ENERGY PRODUCTIVITY IN MANUFACTURING

July 2018

2xEP Doubling Australia's Energy Productivity

AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

AUTHORSHIP OF THIS REPORT

This report is published by the Australian Alliance for Energy Productivity (A2EP). A2EP is an independent, not-for profit coalition of business, government and environmental leaders promoting a more energy productive and less carbon intensive economy.

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In particular A2EP would like to acknowledge the assistance provided by Jim Davis of the US-based Clean Energy Smart Manufacturing Innovation Institute (CESMII) in generously providing input and feedback on the parts of this report that relate to the digitalisation of industry.

Note: Acknowledgement of this support does not indicate stakeholders' endorsement of the views expressed in this report.

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Executive Summary

Rapid escalation in energy prices over the last decade, combined with Australia's poor energy productivity relative to the developed world, has resulted in plunging energy competitiveness. High energy prices and energy policy are now the two biggest economic challenges currently facing Australian businesses, according to a recent report from the Australian Institute of Company Directors[1]. The Australian Industry Group's (Ai Group) most recent annual survey of Australian CEOs found energy prices and energy policy to be major concerns impacting their members' expectations of business conditions in 2018, with almost three quarters of CEOs expecting energy costs to rise in 2018 - on top of reported energy price increases of 65% in 2017[2]. And our energy competitiveness continues to deteriorate as our energy productivity is increasing very slowly compared to competitors, many of which are investing heavily to further accelerate improvements in energy productivity.

A2EP's report investigates the opportunity to substantially improve energy productivity in manufacturing through applying flexible, intelligent, connected equipment and practices associated with 'Industry 4.0' - the 4th industrial revolution - and 'Smart Manufacturing'.

This project involved desktop research and analysis on the optimal ways to achieve energy productivity benefits from Industry 4.0 technologies and business models, that is, by utilising the Internet of Things (IoT), data analytics, cloud computing, flexible smart equipment and artificial intelligence (AI)/machine learning.

An important element of the process to gain energy benefits was found to be replacing central energy services with distributed, digitally-controlled electricity technologies, which are compatible with Industry 4.0 approaches. Boilers/steam systems (and also compressed air systems) have low energy productivity, high standing losses, poor flexibility, and it is difficult to measure services use.

A key output of A2EP's work was the development of practical guides to assist business to identify and implement these opportunities: '*Guide for business to implement Industry 4.0 to boost energy productivity*', and '*Guide for business: Process heating innovation to boost energy productivity'*. These are appended to this Report and are designed so they can be used as stand-alone documents. We plan to further enhance these guides over time with feedback from stakeholders.

This report is structured as follows:

- Sections 1 and 2 explain the purpose, scope and process for developing this report.
- Section 3 describes the characteristics and key technologies of Industry 4.0 and the relationship between Industry 4.0 and improving energy productivity.
- Section 4 provides an overview of process heating uses and more energy productive alternatives to steam systems.

[1] https://aicd.companydirectors.com.au/-/media/cd2/resources/advocacy/research/pdf/dsi/2017/06154-1-pol-dsi-second-half-oct-17-ppt-template-43-final.ashx
[2] https://cdn.aigroup.com.au/Reports/2018/AiGroup_CEO_Business_Prospects_Report_2018.pdf

Key findings of this project:

1. Industry 4.0 technologies and business approaches, and new electricity technologies such as high temperature heat pumps, if effectively deployed, could very substantially increase energy productivity in the manufacturing sector through:

    - Enhancing visibility of energy use, and key product parameters that impact energy use, across the information boundaries that traditionally have limited information flows across systems, plants, enterprises and entire supply chains.
    - Application of IoT and AI/machine learning to optimise energy using systems and processes. International case studies demonstrate up to 20-30% improvement in operation of energy intensive processes using these tools, and IT models developed and refined in one location can be readily replicated in other similar operations.
    - Application of high energy productivity distributed electricity technologies to displace fossil fuel use in process heating. These technologies include highly energy productive technologies like heat pumps, as well as non-thermal processes like membrane dewatering and high-pressure processing. If a steam system with 50% overall efficiency was replaced with heat pumps with a COP_h of 5, this would provide an energy efficiency improvement of 10X. Better reliability, improved working conditions, and digital control from this change can deliver an even larger energy productivity dividend.
    - Electrification of plants, supplied by increasing levels of on-site renewable energy (and/or off-site Power Purchase Agreements), which is becoming increasingly financially attractive.
    - Optimisation of the electricity supply chain to facilities, and particularly optimising the timing of electricity purchases to reduce average electricity prices, facilitated by Industry 4.0 technologies. Increased information availability along the chain facilitates industry load flexibility which can be attained by optimising energy storage (thermal/material/ batteries), demand management and on-site generation. This flexibility can allow energy consumers to make real-time decisions to maximise production in low energy price periods.
    - The combination of modular, highly automated and ultimately self-optimising electricity technologies, with energy from solar and batteries, and material supply chain visibility, can facilitate manufacturing activity earlier or later in the supply chain (and provide extra energy productivity benefits by potentially reducing the transport task and optimising activity to better match customer requirements).

2. The uptake of Industry 4.0 technologies and business approaches for overall productivity and quality benefits will not automatically drive these substantial energy productivity gains. Businesses must understand their current energy use and the services being delivered, and plan to specifically address energy productivity in their implementation of Industry 4.0. Otherwise their energy benefits, and broader business benefits gained will be limited by:

- Lack of energy metering, monitoring and information tools.
- Inflexibility and high standing energy losses of existing central energy distribution services e.g. steam and compressed air.
- Lack of knowledge of the scope for alternative production approaches to capture energy productivity benefits.
- Inadequate energy management know-how in many businesses and the equipment and services companies supplying them. This becomes critical when addressing more technically challenging issues like process optimisation, or determining the optimal use of heat pumps for heating and cooling, which requires the ability to apply heat balances, and pinch studies in more complex facilities.

3. Application of these approaches can capture multiple business benefits through improved product and service quality, higher productivity, improved matching of product to consumer preferences, and reputational benefits.
4. It is important for businesses and governments to consider the timeframe and process for implementing Industry 4.0 to drive energy benefits. Even the introduction of variable speed drives, through retrofitting in existing facilities, has meant a significant change in a manufacturing process, requiring downtime and commissioning. Achieving incremental improvements of energy efficiency within existing facilities will continue to be difficult, requiring change management and time. New facilities (and new market entrants) can by-pass many of these legacy challenges by implementing these technologies from scratch.

Recommended actions for Government to accelerate this transition:

1. Implement information and training related to the application of Industry 4.0 and new electricity technologies for improving energy productivity. A2EP and the project sponsors have attempted to take a first step down this path with the development of this material, but this job has just started. There is very limited business knowledge and understanding of energy productivity transformation opportunities through these initiatives. This extends right through from the businesses that could benefit to the Australian technology and services supply industry, including specifiers and consultants.
2. Conduct pilot studies and demonstration implementations of heat pumps and other electricity technologies to demonstrate the application of these technologies for fossil fuel steam system displacement, and the business benefits of their implementation.
3. Establish an electricity technology centre to accelerate introduction and demonstration of these technologies in Australia. This could be part of a broader research centre aimed at ensuring co-ordinated and consistent efforts to harness innovation to drive forward Australia's energy productivity and improve business competitiveness.

4. Assist companies who are piloting Industry 4.0 initiatives to incorporate energy in their programs, so that the pilot projects can also demonstrate the ability of these technologies and business models to drive energy transformation. These projects may incorporate modernisation/replacement of central energy services as discussed above.
5. Increase cooperation between industry and energy/environment government departments, and between university faculties addressing IT, manufacturing technology and energy/environment. The application of Industry 4.0 to energy requires a broad vision and a multi-disciplinary approach.
6. Accelerate development and deployment of energy metering. The lack of real-time measurement and reporting on energy use needs to be addressed to support the ability of companies to gain the maximum energy productivity benefits from Industry 4.0 implementation. This should include incentives to encourage companies to implement more comprehensive sub-metering, and also support for start-up companies to develop and demonstrate non-invasive monitoring processes e.g. using AI to infer energy use of plant and equipment through recognition of their characteristic patterns of usage.

A2EP looks forward to receiving feedback on the information contained in this Report, in particular the implementation guides to Industry 4.0 and process heat innovation.

Contents

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1 Purpose and scope of this report

This project was conducted by the Australian Alliance for Energy Productivity (A2EP), an independent, not-for-profit coalition supporting the achievement of a more energy productive economy. This report examines optimal ways to improve energy productivity in manufacturing, focusing on two streams of transformation:

- Deployment of Industry 4.0 technologies (utilising the Internet of Things, data analytics, 'big data', cloud computing, flexible smart equipment, artificial intelligence) in manufacturing activities – across all sectors, not just within the traditional manufacturing sector.
- Replacement of central energy services, with a focus on boilers/steam systems, with digitally controlled electricity technologies to deliver point of end use services with much higher energy productivity and improved compatibility with Industry 4.0 approaches.

What is energy productivity?

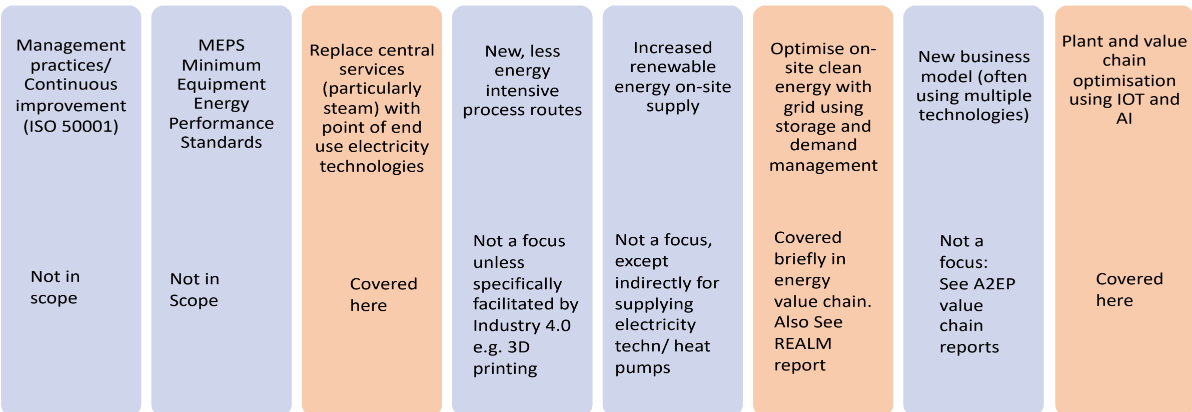
Energy productivity (EP) refers to the value created from using a unit of energy. To improve EP, we can increase economic value added by using energy more effectively, or use less energy – in short, do more with less energy.

EP = Value added ($)/Energy (primary, GJ)

Scope of work

The diagram below summarises the ways that energy productivity can be transformed in manufacturing activity, and which aspects fall within the scope of this project. This report is focused on the application of Industry 4.0 technologies and approaches, including the replacement of centralised energy services with distributed electricity technologies. It does not seek to address incremental improvements in energy management or continuous improvement. While increasing the application of renewable energy is not a focus, the electrification of process heating, which is covered here, is intimately linked with increased renewable generation, storage and demand management at site and centrally, in the drive to reduce carbon emissions and energy-related costs while capturing maximum business benefit.

Figure 1 – Activities to transform energy use in manufacturing



Source: A2EP

2 Process for developing the report

This report was prepared using the following approach. The project team:

1. Established a broad stakeholder group and information exchange:

- Categories of stakeholders identified included food processors, industry associations, research institutions, equipment suppliers, IoT/IT suppliers, government, and Industry 4.0 experts.
- Stakeholder consultation process, including attending specialist events, networking and running two telephone workshops to discuss findings of work completed and to obtain input and feedback from stakeholders. A list of stakeholders consulted can be found in Appendix C: Stakeholders.

2. Prepared an overview of Industry 4.0 including:

- An explanation of Industry 4.0 and how implementation is being supported in Australia.
- A review of existing literature and international activities focused on Industry 4.0 for energy productivity benefits.
- Analysis of the potential impact of Industry 4.0 technologies on energy use productivity, and analysis of how active consideration of how energy use productivity can amplify the benefits of applying Industry 4.0.
- Reviewed technologies to replace process heating by central energy systems (with an emphasis on boiler/steam systems). Assessed practical issues and economics of steam replacement.

3. Prepared a brief step-by-step guide for Australian industry to assist business to realise energy productivity benefits from applying Industry 4.0 and prepared a guide for Australian industry to replace fossil fuel fired central energy systems with distributed efficient electricity technologies.

4. Identified potential demonstration sites to pilot steam replacement with electricity technologies.

3 Industry 4.0 and its potential to enhance energy productivity

This section provides background to Industry 4.0, a brief review of the implementation of Smart Manufacturing in Australian manufacturing and identifies how Industry 4.0 can be used to improve energy productivity.

3.1 Industry 4.0

3.1.1 What is Industry 4.0?

Industry 4.0 is a term coined by the German National Academy of Science and Technology and introduced by the German government. It is shorthand for the Fourth Industrial Revolution. The Fourth Industrial Revolution is increasingly disrupting business practices in many industries and business sectors throughout the world. Klaus Schwab, Founder and Executive Chairman, World Economic Forum Geneva, summarises the transition from the First to the Fourth Industrial Revolution as follows[3]:

- The First Industrial Revolution was a result of using water and steam to mechanise manufacturing tasks, leading to a tremendous increase in productivity.
- The Second Revolution occurred with the adoption of decentralised electric motors in continuous assembly lines to create mass production and further improve productivity.
- The Third Revolution resulted from the application of electronics and information technology to digitalise processes and equipment as well as automating production with the capability to generate large amounts of data leading to accurate, optimised and efficient production systems.
- The Fourth (Industry 4.0) builds upon the Third, by incorporating advanced data collection, communication, and analysis technologies in industrial equipment. This is feasible due to the development of a new set of tools such as advanced robotics, sensors and improved low cost communications and broadband networks (the Internet of Things (IoT)), and cognitive technologies (artificial intelligence (AI)/machine learning).

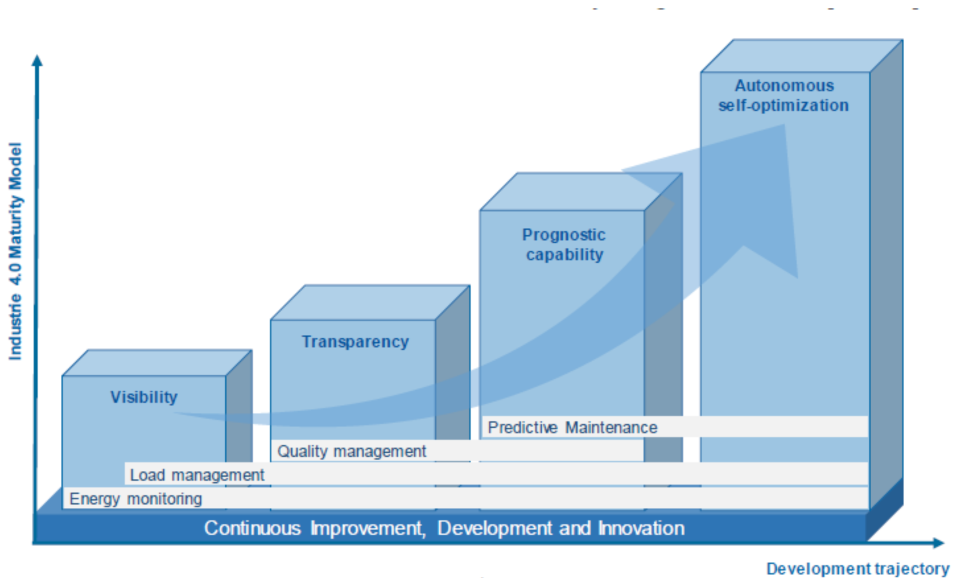
Production flexibility was high when manufacturing was labour intensive. Production flexibility was sacrificed by automation in the Third Industrial Revolution in exchange for mass production. Industry 4.0 re-introduces a superior form of flexibility and a new wave of productivity improvements to industrial plants and processes, as well as a connectivity revolution that crosses traditional business and sectoral boundaries. This is accomplished by engineering advanced production devices, such as 3D printers and robots, that are versatile and can communicate with each other locally or over long distances. In addition, more detailed real-time information supports optimal operation of processes, and transformation from physical products, travel and services to virtual solutions. Note that there is even talk of 'Industry 5.0' which envisions the optimal marrying up of the high speed and accuracy of industrial automation with cognitive critical thinking skills of human staff.

Computerisation was essential to deliver Industry 3.0. The progress towards Industry 4.0 is based on enhanced visibility of data, as well as input of data from a wider range of sources, which is then

[3]https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond

analysed and communicated to a broader range of stakeholders, in a timelier manner, for further management and optimisation in a wider scope. The application of artificial intelligence married with the information from these smart sensors allows machines and systems to learn and self-optimise, as depicted in the right-hand column of Figure 2 below, showing the evolution of Industry 4.0. The vast amount of data collected and analysed over time can be utilised by an intelligent machine brain that makes decisions according to changing external and internal conditions without human intervention (autonomous self-optimisation).

Figure 2 – Industry 4.0 maturity model



Source: S. Nienke, et al., Energy-Management 4.0: Roadmap towards the self-optimising production of the future, Proceedings of the 6th International Conference on Informatics, Environment, Energy and Applications. ACM, 2017

Figure 3, reproduced from the International Energy Agency's (IEA) 2017 report *Digitalization and Energy*[4], shows the relative level of development of digital technologies for use in industry as Industry 4.0 continues to evolve.

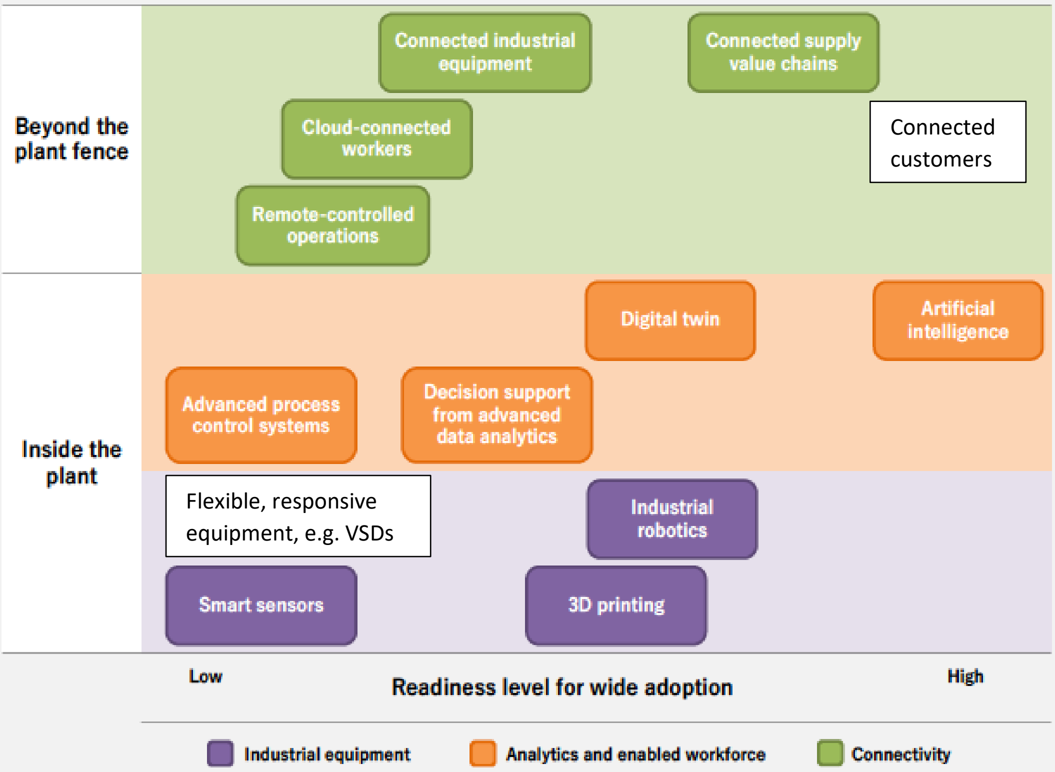
The ability to use Internet of Things (IOT) and cloud computing to provide a view of key parameters across an entire plant, and in fact extended to an entire supply chain, and also down to a micro-level within a process, provides new and powerful opportunities for optimising energy productivity. Integration of information from multiple sources and improved interfaces shifts the focus to 'actionable advice' based on more data and improved analysis.

The application of Industry 4.0 is dependent on, and facilitates, transformative changes in business models. For example, in A2EP's work on the refrigerated food cold chain[5], we identified provision and visibility of real-time information on the temperature and location of food across the value chain, fed back to operators and end consumers, as a potential game changer for energy productivity. With this level of processed information available in a simple graphic format, failures in handling practices, technologies and infrastructure may be identified before they add to costs and food waste. Through this, it is possible to identify the real value of innovations, to support business

[4] http://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf
[5] Accessible from: www.a2ep.org.au/files/Reports/A2EP_Cold_Chain_Report_OEH_v2.pdf

cases for change, identify areas where R&D would be most useful, and help equipment manufacturers to improve their products. And, it provides valuable tools to optimise energy use.

Figure 3 – Application of digital technologies and strategies in industry



Key message: Digitalization in industry can take diverse forms, ranging from automated equipment to connecting industrial operations based in different locations.

Notes: A digital twin results from virtually replicating a real industrial plant; enabled workforce refers to the enhancement of workers' skills through the use of digital technologies.

Sources: Based on World Economic Forum (2017a), *Digital Transformation Initiative: Chemistry and Advanced Materials Industry*, and World Economic Forum (2017b), *Digital Transformation Initiative: Mining and Metals Industry*.

Source: IEA, 2017. Digitalization and Energy adapted by A2EP (white boxes added by A2EP)

'Smart Manufacturing' for energy productivity

"Smart Manufacturing" is a US term used to describe the uptake of Industry 4.0 technologies and practices in manufacturing.

> Smart Manufacturing "is the right data in the right form, the right people with the right knowledge, the right technology, and the right operations, whenever and wherever needed throughout the manufacturing enterprise … it … describes an unprecedented exploitation of data that changes the manufacturing approach with ever-advancing information, modelling, control, automation, and optimisation technologies".[6]

[6] Davis, J., 2017. Smart Manufacturing. In: Abraham M.A. (Ed.), Encyclopedia of Sustainable Technologies. Elsevier, pp. 417-427.

While Smart Manufacturing has the potential to impact (and is already impacting to some degree) most industries to improve overall production value, the specific focus of this report is on the potential for Industry 4.0 technologies to bring about transformative **energy productivity** improvements in manufacturing.

The US-based Clean Energy Smart Manufacturing Innovation Institute[7] (CESMII) promotes the use of clean technology in manufacturing and is particularly focused on improving energy productivity by using Industry 4.0 technologies and approaches including advanced sensing, controls, platforms and modelling in manufacturing. CESMII describes the defining characteristic of Smart Manufacturing as unlocking "real-time data currently inaccessible or unused through new technology tools that realise benefits faster across the manufacturing enterprise". These new tools, such as advanced sensors and controls, are enabled by emerging IoT and Cloud technologies and allow optimisation of production and supply networks. CESMII is promoting the rapid development and adoption of Smart Manufacturing technologies for US manufacturing and the development of an open IT platform and marketplace to address the barriers of bringing data, software, systems, infrastructure and security together to enable real-time data analytics, industrial applications and manufacturing solutions that all participants in the Smart Manufacturing supply chain can access. They have recognised that IoT tools allow for remote data collection from devices as well as remotely controlling them. Cloud computing platforms enable companies to have access to powerful computational capabilities to process all this data without prohibitive upfront IT system setup costs. Cloud systems also provide manufacturers with flexible and low cost means to share the data and collaborate with appropriate stakeholders throughout the production line and the supply chain.

One of the key findings of CESMII is that energy benefits (and other savings) through utilising these technologies and approaches are gained across supply chains and across organisations. They have found that the greatest savings often occur at what they call 'seams', or boundaries/interfaces in the chain or plant where there are information discontinuities that can be resolved through using the IoT and cloud computing.

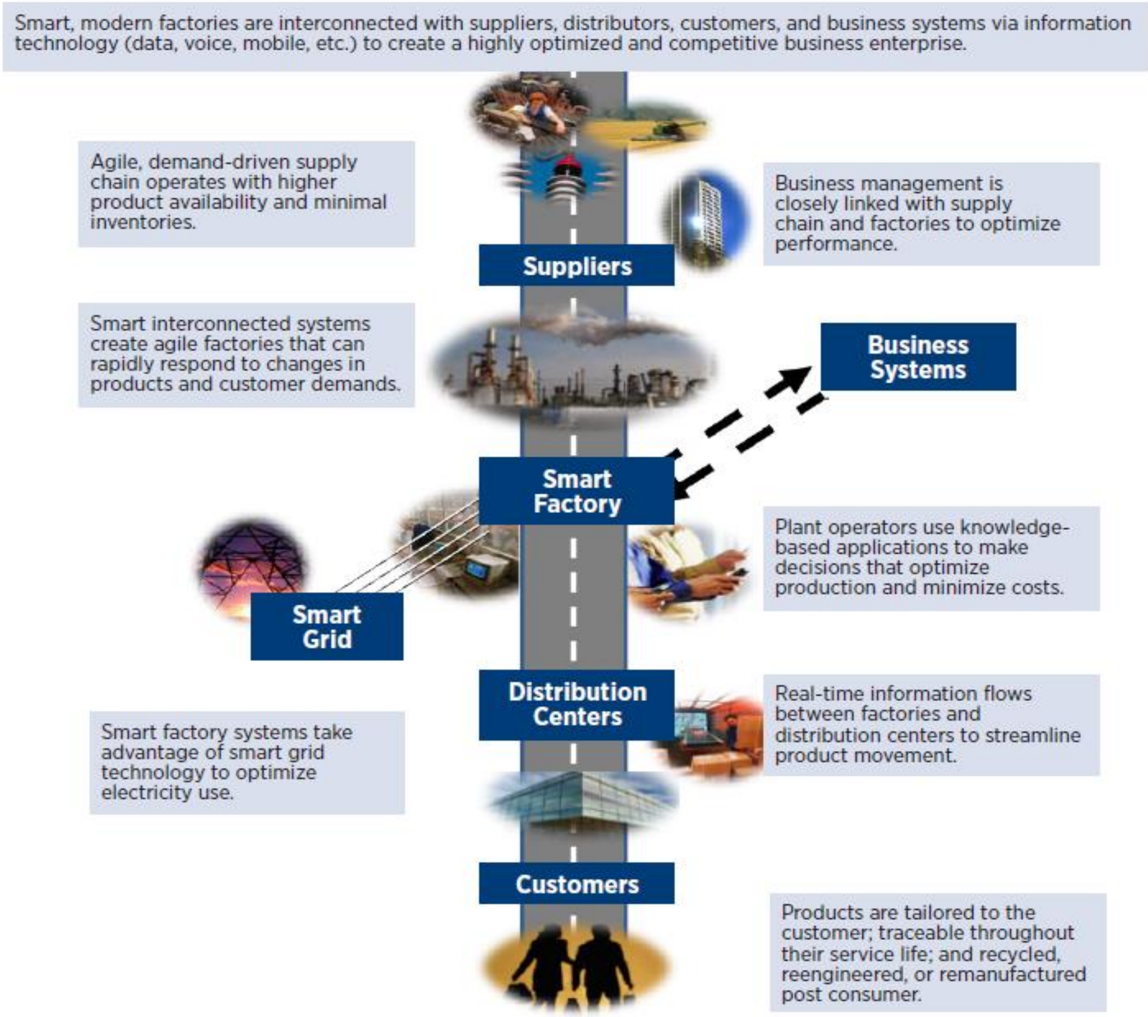
Figure 5 illustrates how Smart Manufacturing is interconnected with suppliers, distributors, customers and business systems using information technology. Note that this also identifies the potential benefits through optimising the energy supply chain to plants, with the energy user as an integral part of the energy chain.

Research conducted by the American Council for an Energy-Efficiency Economy (ACEEE)[8] concluded Smart Manufacturing will transform the manufacturing environment, enabling: mass customisation; reductions in waste, energy and water use; and, improved accuracy and speed. Together with CESMII, the ACEEE supports open-access Smart Manufacturing platforms with common protocols and standards to rapidly transition the US manufacturing sector.

This revolution also supports decentralised manufacturing, as firms such as Boeing are already doing. This has potential application in revitalising Australian rural and regional economies and allowing smaller businesses to engage with national and global production systems.

[7]https://www.cesmii.org/what-is-smart-manufacturing/
[8]https://aceee.org/sites/default/files/publications/researchreports/ie1403.pdf

Figure 4 – Smart Manufacturing



Source: Smart Manufacturing Coalition[9]

Further information on the components of smart manufacturing can be found in Appendix D.

Smart Manufacturing Challenges

Jim Davis[10], Vice Provost – Information Technology, UCLA and Co-founder of the Smart Manufacturing Leadership Coalition, identifies conditions that have to be met for the Smart Manufacturing vision to become a reality as follows:

- ***Good data*** - machine learning, AI, actuation and decision-making depend on good data and data that have been contextualised for objectives, as opposed to big data.
- ***Agnostic interconnectivity*** - better, faster, and lower cost interconnectivity of networks, software, products, infrastructure and companies is required. We note compatibility with

[9]https://smartmanufacturingcoalition.org/sites/default/files/implementing_21st_century_smart_manufacturing_report_2011_0.pdf
[10]https://xplorexit.com/clean-energy-smart-manufacturing-innovation-institute/

widely available software such as Excel is important, so it can be utilised across an organisation and independent analysts, as is capacity to transfer data in standard formats.

- ***DevOps (development and operations)*** - there is a need to work with new insights from the data, new vendor products and configuration of these products to increase capability and benefit in small steps without having to rebuild infrastructure.

- ***Reusability of operational data, software and hardware -*** to avoid building one-off systems, lowering complexity and barriers to access.

- ***Smart workers*** - interoperability of humans and machines such that the capabilities of humans and machines are both extended.

- ***Enterprise security, trust and situational resilience*** - localised diagnostics are important but an enterprise approach needs a broader kind of resilience with situational response and the ability to predict and self-interrogate.

Please note the importance of having flexible process equipment to make use of the data. For example, a fixed speed pump cannot vary its output efficiently in response to any amount of improved information.

Strategies to optimise manufacturing

CESMII[11] categorised four primary elements of an integrated Smart Manufacturing strategy that increase energy productivity and also address challenges of realising the Smart Manufacturing vision. Such a strategy can be led by business organisations, governments, leading edge businesses, financiers or combinations of them. These elements are:

1. ***Enabling technologies*** - through collaborative R&D on advanced key Smart Manufacturing technologies including advanced sensors, data analytics tools, process controls, models, and computational platforms for integration into robust, secure and easy-to-configure Smart Manufacturing systems.
2. ***Smart Manufacturing platform infrastructure*** - build a unified Smart Manufacturing platform, marketplace and ecosystem that enables efficient and cost-effective reuse of enterprise data, technologies, and secure cyber-physical systems to reduce the cost and time to build and deploy functional systems.
3. ***Workforce development*** - to build and sustain a skilled and innovative Smart Manufacturing workforce with expertise in these technologies and practices, develop and continuously update, and deploy customisable, interdisciplinary training resources and programs.
4. ***Businesses practices*** - to facilitate widespread Smart Manufacturing integration, develop a clear and compelling value proposition for Smart Manufacturing; address and mitigate business risks; and provide strategies, tools and best practice for Smart Manufacturing integration and cyber security.

[11] https://static1.squarespace.com/static/586544c544024334881aa773/t/59b1b519f43b5595acc6a587/1504818463107/final+fact+sheet.pdf

Transition: Getting started

There is a major change management challenge associated with the introduction of Smart Manufacturing. Most businesses will need to 'walk before they run'. The transition may start with the addition of low cost sensors and analysis of the new data, leading to introduction of more flexible process equipment and controls. The addition of features to existing process equipment can transform energy use. For example, replacing use of a damper or valve to manage fluid flows with a variable speed motor, and controlling it to match demand can deliver large percentage savings.

Investing in low thermal inertia processing equipment can also be important once you start using variable technologies, so that it is more responsive. Adaptive manufacturing is very likely to possess transient processes that are continuously adjusted to meet variable production schedules. Hence, the equipment for supplying process heat to this emerging type of production line needs to have low thermal inertia to quickly respond to variable thermal energy requests ***efficiently*** and ***cost effectively***. It should also have low standby energy use. Otherwise, the production line is not agile and flexible enough to quickly respond to instructions, obstructing production scheduling and planning. The heating stage in the chain of processes often becomes a production bottleneck leading to high cost of running complex processes, and energy productivity is affected due to the fact that significant energy can be wasted during start up and shut down stages.

An example of such fast response technology is LED lighting. A key benefit of LED lights is that they can dim very quickly to offer responsive dimming linked to real-time intermittent cloud effects. Most chillers, air compressors and motors have a limited range of high efficiency operation and routinely run outside optimum performance because they have been oversized. Better information provides feedback on real-time efficiency, while assisting in appropriate sizing and improving staged management.

Businesses need a specific energy productivity element in their Industry 4.0 strategy to gain the best benefits from this transition. It is important for businesses to consider the timeframe and process for implementing Industry 4.0 to drive energy benefits. Even the introduction of variable speed drives is a major change in a manufacturing process, requiring downtime and commissioning.

A review of how Industry 4.0 technologies can be utilised to improve energy productivity in manufacturing is discussed in Section 3.3. Please see the practical implementation suggestions in Appendix A: Guide for business to implement Industry 4.0 to boost energy productivity.

3.1.2 How is Industry 4.0 playing out in Australia?

Manufacturing contributes 6% of Australia's GDP[12], and manufacturing's share of the economy continues to shrink, at least in part driven in the last seven years by escalating energy prices and low energy productivity of the sector. However, manufacturing is Australia's second largest exporter after mining, representing 32% of the value of Australia's exports. The biggest manufacturing exporters by value in 2015-16 were 'primary metal' and 'metal product manufacturing' at $34 billion, followed by food product manufacturing, with $24 billion of exports. But the statistics on

[12] https://industry.gov.au/Office-of-the-Chief-Economist/Publications/AustralianIndustryReport/assets/Australian-Industry-Report-2016.pdf

manufacturing output are misleading as manufacturing activity is spilling out of the traditional sector which is tracked by Australian Bureau of Statistics (ABS), both upstream and downstream. Value adding on farms and vineyards, micro-breweries, hot bread shops and commercial 3D printing are examples of manufacturing increasingly being undertaken outside the traditional manufacturing sector.

Smart, modular, Industry 4.0 technologies support this transition, as do automated electric technologies. These approaches could re-invigorate rural and regional economies by facilitating automated manufacturing on farms using on-site solar energy and batteries for increasingly competitive regional energy supply. The greatest economic impact of Industry 4.0 technologies may be in fact in the commercial and agricultural sectors because big industrial sites capture economies of scale and consistency of production and pay lower unit energy prices than small scale manufacturing in these other sectors. Smaller sites value equipment flexibility and modularity, so they can efficiently respond to diverse customer expectations and charge higher prices for increased perceived value.

The Australian government recognises the opportunity that Industry 4.0 presents to Australian businesses to improve their competitiveness and increase production, employment and exports, with the Prime Minister's Industry 4.0 Taskforce[13] being formed in 2015. The purpose of the Taskforce is co-operation and information sharing with the German Plattform Industrie 4.0 group in relation to digital transformation and the linking of manufacturing processes along the global value chain via the internet. The Department of Industry, Innovation and Science[14]describes Industry 4.0 as being "the current trend of improved automation, machine-to-machine and human-to-machine communication, artificial intelligence, continued technologies improvements and digitalisation in manufacturing".

The Department identifies the four key drivers of this trend as:

1. Rising data volumes, computational power and connectivity [while also noting the declining cost of elements of the system].
2. Emergence of analytics and business-intelligence capabilities.
3. New forms of human-machine interaction such as touch interfaces and augmented reality systems.
4. Improvements in transferring digital instructions to the physical world, such as robotics and 3D printing.

Organisations that have been key to the promotion of Industry 4.0, particularly in the Australian manufacturing context, are listed in Appendix E of this report as a reference for businesses wanting to implement Industry 4.0.

[13]https://industry.gov.au/industry/Industry-4-0/Pages/PMs-Industry-4-0-Taskforce.aspx
[14]https://industry.gov.au/industry/Industry-4-0/Pages/default.aspx

Australian example of Industry 4.0: Dulux Merrifield paint manufacturing plant

Dulux recently opened a new paint manufacturing plant in Merrifield, Victoria. This plant provides an example of Australian industry embracing and benefiting from Industry 4.0 technology, with the entire production process integrated horizontally and vertically, allowing for the end-to-end digitalisation of the plant. Siemens' simulation platform Simit enables comprehensive tests and virtual commissioning of automation applications, and provided a realistic training environment for operators even before the real start-up.

The plant has been designed for a high degree of automation allowing Dulux to very efficiently produce specialty paint according to specific customer requirements, of a higher quality and in a shorter time, than was possible in the past. In other words, the plant has been designed to facilitate "mass customisation".

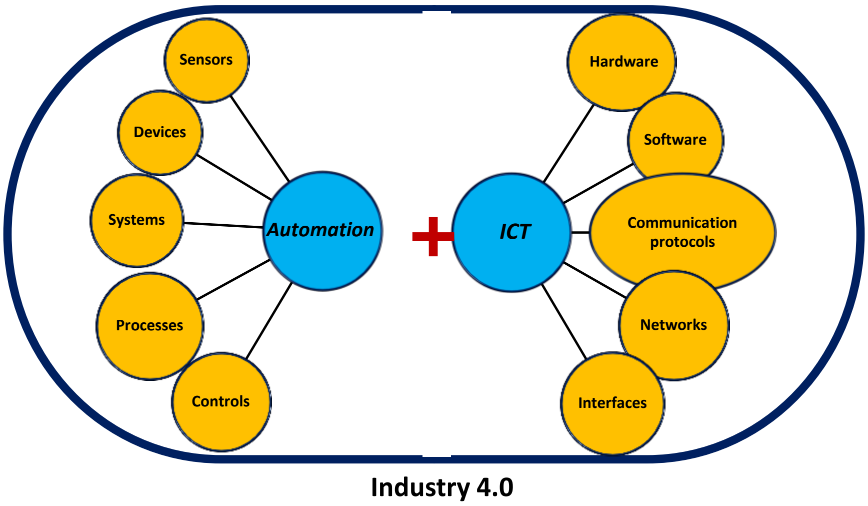
The plant has the flexibility to vary batch sizes between 100 litres and 30,000 litres. Specialty batches can be produced in volumes of 1/50th of the size and about eight times faster than was previously possible. Higher accuracy for specialty paint recipes has led to a large reduction in raw material waste and a 25% reduction in energy consumption over the design.[15]

[15] www.siemens.com/customer-magazine/en/home/industry/process-industry/any-color-desired.html

3.2 Industry 4.0 technologies

Industry 4.0 results from linking conventional automation to information and communication technologies (ICT). In this realm, a range of technologies are used to create a reliable flow of data and transform it into actionable information. Some of the key technologies involved in this transformation are show in Figure 5 and discussed below.

Figure 5 – Technologies employed in Industry 4.0



Source: A2EP

IoT

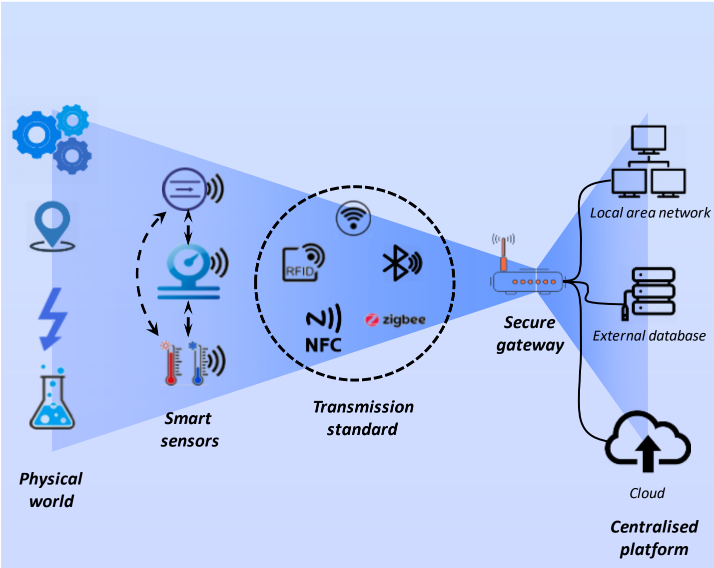
The Internet of Things (IoT) technology refers to data collection and communication devices, hardware and software, that can be deployed across plants, systems, subsystems, and equipment to monitor certain physical variables. IoT technology includes advanced sensors with a capability to upload digital information onto a database via a data communication network/protocol. Sensors are becoming smaller, cheaper, more efficient, battery/solar powered and capable of monitoring multiple variables and communicating via emerging Low Power Wide Area Networks.

The connectivity of the sensor can be realised with the help of different technologies. Some of these technologies allow for connecting hundreds of sensors to a single communication gateway. Figure 6 depicts this relationship.

IoT communications technology

NB-IoT (narrow band Internet of Things), Sigfox and LoRaWAN (long range wide area network) are low cost, low power IoT connectivity technologies with a long battery life time and extended coverage. Sigfox is well advanced in achieving 90% national coverage. Telstra and Vodafone are well underway with providing NB-IoT connectivity using their existing infrastructure.

Figure 6 - Data collection, aggregation, and communication in a smart platform



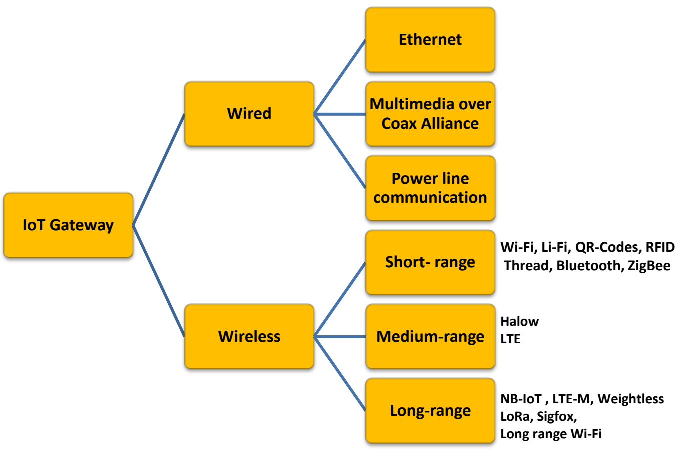
Source: A2EP

Example: Vodafone recently launched a commercial NB-IoT service and has deployed it across Victoria. With Optus, it is extending its reach in the eastern states. The field deployment in the Melbourne CBD showed ability to penetrate two double brick walls, enabling connectivity of objects in underground car parks and basements. Testing in suburban Melbourne area showed up to 30 km of connectivity range. These devices are currently available for operation in harsh conditions, that is in general, the case for industrial plants.

Telstra has deployed their NB-IoT network in major Australian cities and many regional towns. They are expected to complete their roll out across Australia during 2018.

Figure 7 depicts the available communication technologies in the market.

Figure 7 – Available IoT communication technologies



Source: A2EP

Sensors and energy monitoring

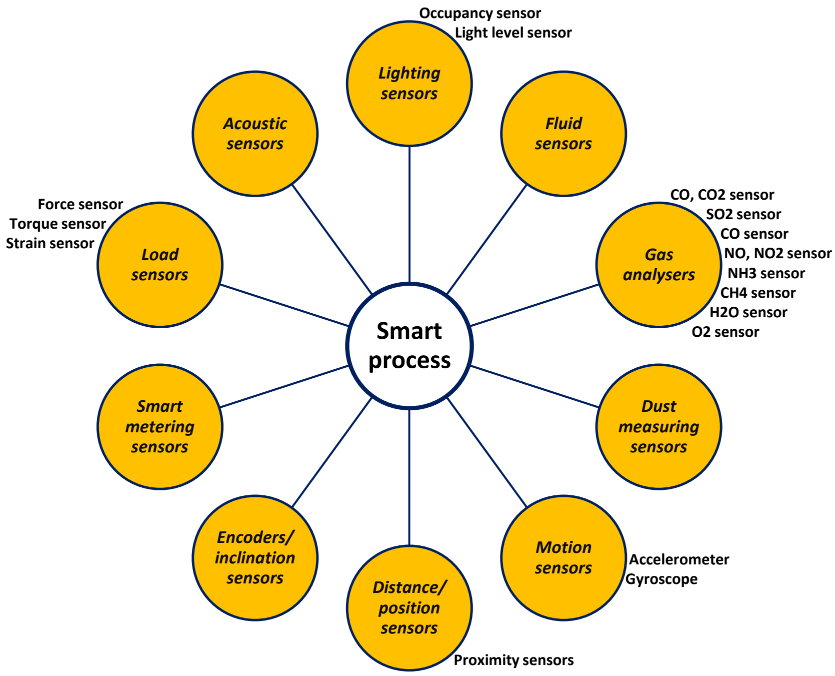
Data in smart enterprises originate from sensors. Sensor technology is continuously improving and costs are declining. Smart Manufacturing requires smart sensors. Sensors and AI/machine learning are two partners in manufacturing improvement. Machine learning relies on having sufficient volume and quality of specific data to learn and make intelligent operating decisions. For example, the development of smart sensors that can 'hear' a machine part being forged have allowed immediate correction of forging settings from part to part, and the ability to 'see' the combustion process (using multiple thermal imaging cameras) has allowed combustion systems to be optimised.

These sensors are more than just a conventional sensing device that transforms a physical variable into an electrical signal. Smart sensors aim to:

- Be low cost to be deployable in large numbers across the enterprise,
- Be physically small, have wireless connectivity (wired connection is not possible in many applications),
- Possess self-identification and self-validation capabilities,
- Use very low power to last long without the need for maintenance and battery replacement,
- Be self-calibrating or accept calibration instruction remotely, and
- Possess data processing ability to reduce the load on the gateway and cloud resources.

Figure 8 provides examples of types of smart sensors that may be deployed in a Smart Manufacturing facility.

Figure 8 – Sensors for smart enterprises



Source: A2EP

Challenge: Metering energy use

The old adage that 'if you can't measure, you can't manage' extends powerfully in the Industry 4.0 age. As measuring is the basis for optimisation and enhancement of processes using Industry 4.0 technologies, the relative lack of energy metering down to equipment level existing in most manufacturing facilities becomes a key barrier for gaining the full energy productivity benefits from Industry 4.0.

The first questions you should ask yourself when planning to implement Industry 4.0 is:

- Do we have adequate energy metering?
- Can we relate the consumption of energy (in core processes as well as ancillary energy using plant like air compressors) to the key operating variables which impact throughput and quality?

If the answer to these questions is 'no', then it is important to develop a plan to rectify this problem. Suggested steps to doing this follow:

- Define what additional metered data is needed, and who will use it, in what format.
- Define the key energy uses which have the greatest impact on throughput and quality and meter those first. Aim to meter the largest energy consuming equipment, noting that typically the largest 10-20% of uses will consume 80-90% of the energy.

See the Industry 4.0 Implementation Guide in Appendix A for more information.

Artificial intelligence and machine learning are keys to the delivering benefits of Industry 4.0

Artificial Intelligence (AI) involves machines that can perform tasks that are characteristic of human intelligence like planning, understanding language, recognising objects and sounds, learning, and problem solving.

At its core, machine learning is a way of achieving AI. Arthur Samuel coined the phrase, defining it as, "the ability to learn without being explicitly programmed". So instead of coding software routines with specific instructions to accomplish a particular task, machine learning is a way of "training" an algorithm so that it can learn how. "Training" involves feeding huge amounts of data to the algorithm and allowing the algorithm to adjust itself and improve, e.g. machine learning has been used to make drastic improvements to computer 'vision'. For example, the approach taken to apply machine learning to tag pictures that have a cat in them versus those that do not could be as follows: use humans to tag hundreds of thousands of pictures - then the algorithm tries to build a model that can accurately tag a picture as containing a cat or not as well as a human, and once the accuracy level is high enough, the machine has now "learned" what a cat looks like.

AI and IoT are inextricably intertwined. The relationship between AI and IoT is much like the relationship between the human brain and body. Our bodies collect sensory input such as sight, sound, and touch. Our brains take that data and make sense of it, turning light into recognisable objects and sounds into understandable speech. Our brains then make decisions, sending signals back out to the body to command movements like picking up an object or speaking. All of the connected sensors that make up the Internet of Things are like our bodies, as they provide the raw data of what's going on in the world. Artificial intelligence is like our brain, making sense of that data and deciding what actions to perform. And the connected devices of IoT are again like our bodies, carrying out physical actions or communicating to others.

The value and the promises of both AI and IoT are being realised because of each other. Machine learning has led to huge leaps for AI in recent years. Machine learning requires massive amounts of data to work, and now this data is being collected by the billions of sensors that are continuing to come online in the Internet of Things. IoT makes better AI. Improving AI will also drive adoption of the Internet of Things, creating a virtuous cycle in which both areas will accelerate drastically. That's because AI makes IoT useful. AI can be applied to predict when machines will need maintenance or analyse manufacturing processes to make big efficiency gains, saving millions of dollars.

Further discussion of Industry 4.0 technologies can be found in Appendix F.

3.3 Industry 4.0 and energy productivity

Energy intensive industries tend to seek better energy management and saving opportunities, as they see it as core business. Until energy became much more expensive in the last decade, other businesses often treated energy as an overhead cost, and did not prioritise managing energy costs.

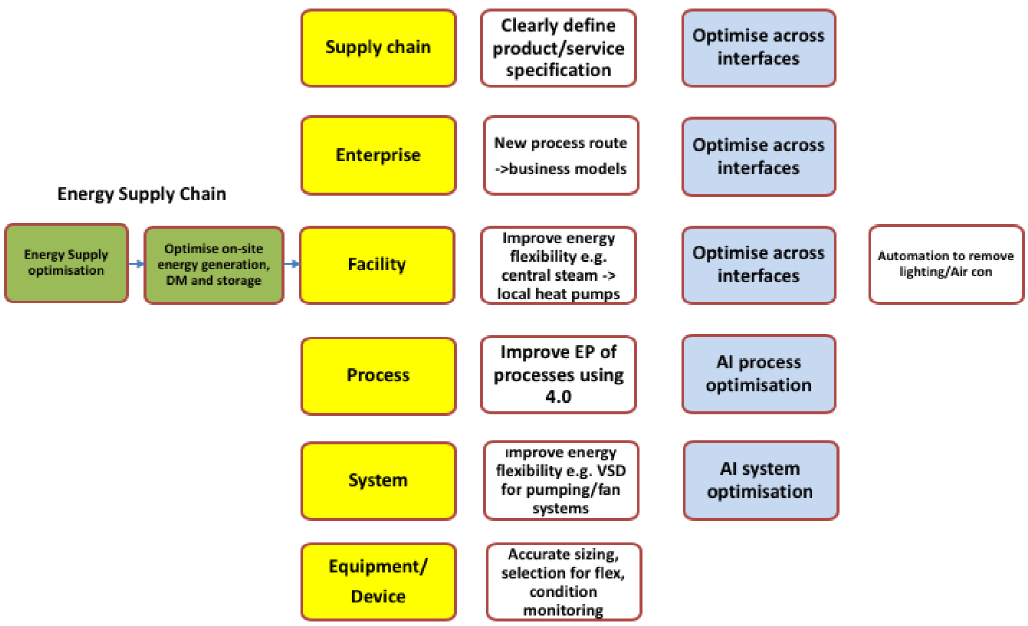
Industry 4.0 technologies and the Smart Manufacturing approach can facilitate substantial energy productivity gains – through energy being applied better to create more value, and often also through energy consumption being reduced at the same time.

But, as we explain in *Appendix A: Guide for business to implement Industry 4.0 to boost energy productivity*, applying these technologies and approaches does not necessarily lead to optimal energy productivity outcomes. To achieve this, it is important to understand how energy is applied in the business and take a focused approach to integrating energy productivity improvement into the Industry projects.

Figure 9 summarises primary sources of energy productivity benefits which may result from the deployment of Industry 4.0 as they provide greater visibility across the information interfaces/boundaries between levels in a manufacturing ecosystem. Strategies to realise the energy productivity benefits of deploying Industry 4.0 technologies for each level can be seen by looking horizontally across the diagram. Optimisation of energy supply to the facility is shown on the far left.

Savings available at each level of the manufacturing ecosystem are discussed in further detail in section 3.3.1 below.

Figure 9 – Sources of energy productivity benefits from Industry 4.0



Source: A2EP

This diagram summarises the types of energy productivity benefits that we have identified as being available through applying Industry 4.0. These basically fall into four categories which are discussed in more detail in this report and the guide in Appendix A:

- Benefits gained through having information available across traditional information boundaries at the different levels in a supply chain (yellow boxes), which are summaries in the grey boxes.
- The benefits from optimisation within each of the levels (white boxes).
- Use of Industry 4.0 to optimise the supply of electricity to/from facilities and increasingly integrate the facility into the energy supply chain (green boxes)
- The ability to operate fully automated lines in buildings without lighting or space conditioning (orphan white box on right).

3.3.1 Energy savings available across the value chain

The "Energy Savings Potential of Smart Manufacturing" report produced by the American Council for an Energy-Efficient Economy (ACEEE)[16] argues that most energy efficiency savings resulting from Smart Manufacturing investments are supplementary benefits to other, higher-priority performance metrics for manufacturers in their quest to improve overall business productivity. That is, when an investment improves the productivity of a process, workforce, facility or company, it generally also results in energy savings. Importantly, capturing the full energy productivity improvement needs additional specific focus. Furthermore, the data collection abilities that enable optimisation of Smart Manufacturing systems make real-time measurement, monitoring and management of energy

[16] https://aceee.org/sites/default/files/publications/researchreports/ie1403.pdf

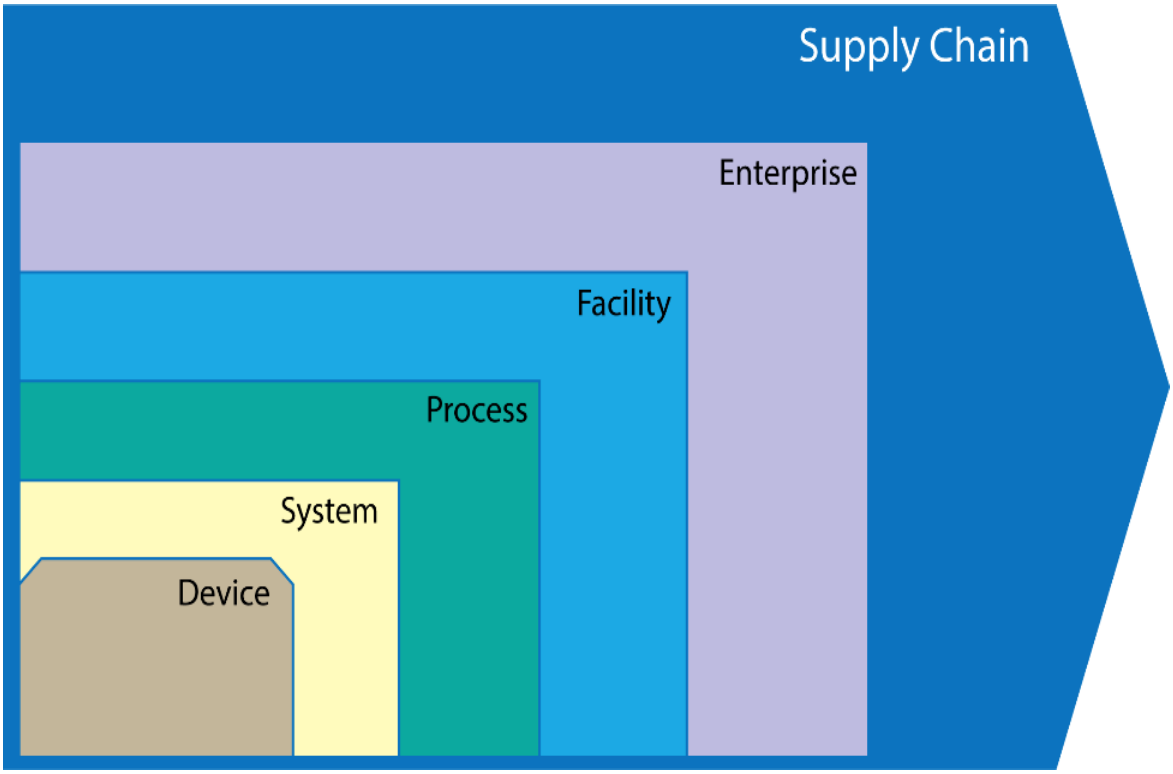
easier. That is why A2EP's focus on improving energy productivity i.e. increasing total production value created as well as improving energy efficiency fits so well with the objectives of Industry 4.0 implementation.

By actively applying an energy productivity lens to a situation, using smart technologies and approaches, we gain greater insights into the underlying physics and chemistry of the process, and better understand the fundamental services being provided, so we can pick up many productivity and other valuable benefits. This works because energy is so deeply interwoven with all business activities and delivery of goods and services as a basic enabler of manufacturing.

The ACEEE report considers energy savings achievable in each level of a manufacturing ecosystem, as depicted in
Figure 10. (Note, the levels are the same ones shown in

Figure 9.)

Figure 10 – Order of energy savings in manufacturing



Source: ACEEE, Energy Savings Potential of Smart Manufacturing.

There are always tensions between 'bottom up' approaches that consider 'manageable' actions that involve low risk and build confidence through 'learning by doing' and 'big picture' approaches that provide a broader context. Later in this report we outline ways of pursuing the former approach, but here we frame the context, which involves looking wide first and then narrowing down to ensure the most effective route is found to achieve potential energy productivity benefits. Full integration of the manufacturing process will include a design process that takes into consideration all raw materials to be used in production, production wastes, wastes, generated by product use and issues related to recycling the product at end of life. This results in reduced energy use at each step of the process. Ideally production runs at the speed of customer demand (as opposed to projections) so no energy is wasted producing products that will not sell and transporting unneeded materials.

Supply chain energy savings

Procurement and supplier relations, customer order processing and client management software programs can be integrated to inform the production system of existing and pending orders. This results in customer demand, production and supplier data being more accessible, better contextualised and available more quickly, improving production efficiency. When the supply chain operates more efficiently less waste is generated and as a result energy is saved. One example of this is a project A2EP is involved with on the real-time tracking of temperature and location of food from farm to retailer shelf. The tracking technology identified major opportunities for food quality benefits through providing visibility of poor temperature control across the chain including multiple organisations and locations.

Enterprise level energy savings

Integration of multiple production facilities can allow corporate management to dynamically determine the optimal production levels for a mix of products across a fleet of manufacturing facilities. Factories are most efficient when operating at capacity, so integration that improves decision-making about how to best allocate resources will result in less waste.

Facility level energy savings

At the facility level, Smart Manufacturing involves both vertical integration within production processes, and horizontal integration across systems. The next level of integration is for the production process to communicate with business management systems such as accounting, payroll and enterprise resource planning. This will simplify the transfer and analysis of information, such as raw-material delivery times and labour hours per product shipped. A business automation system can take all variables across a facility into consideration and recommend options to reduce energy use and overall costs.

System and process level energy savings

Below the facility level are core processes and systems. Systems are groupings of equipment that fulfil a specific function e.g. a pumping system, or a refrigeration system. A water pumping system, for example, may be part of a larger manufacturing process. A network that enables the pump to schedule its load for the day may also allow each system in the production line to optimise its use of energy. When each of these systems communicates with other systems the operating scenario can be optimised. This process level efficiency adds to the savings that may be realised at the systems level. For new facilities, or when replacement equipment is required, capital investment may also be reduced through reduction in equipment capacity, based on better information and smarter management resulting from improved information.

Device level energy savings

Device efficiency is tied to the ability of the device to convert one form of energy to another. For example, the ability of a motor to convert electricity into mechanical motion. Improving device efficiency results in energy savings. Modern equipment is often significantly more efficient, due to improved design, manufacturing techniques and materials. Device efficiency is also impacted by selection. For example, if an electric motor is 100% oversized, then it is likely to be often operating at a point well below its efficient operating range.

3.3.2 Scale of energy savings from optimising data use

The Clean Energy Smart Manufacturing Innovation Institute[17] (CESMII) has estimated the scale of energy savings that can be achieved in the US from Smart Manufacturing at about US$200 billion over a 10 year horizon. CESMII used public data on baseline energy consumption for five energy intensive industry sectors in the US to create a 10-year projection of a Smart Manufacturing journey.

CESMII assumed conservatively that an average energy reachability would be between 10% and 15% for the first five years (where energy reachability means the potential economic/energy productivity improvement that is immediately foreseeable). CESMII combined this with a low estimate of market penetration for Smart Manufacturing technology practices at less than 5%. For the second five years CESMII then applied their 'journey' data to estimate an average increased energy savings (largely based on the upper ends of the bracketed reachability). CESMII also conservatively increased market penetration for the second five years.

Note: These savings estimates do **not** include benefits gained by changing process route. Another US Department of Energy institute - The RAPID Manufacturing Institute[18], has as its focus the transformation of industrial processes. The Institute is leading efforts in the US to improve energy productivity in manufacturing processes by engaging in research and development activities related to process improvement and intensification.

Appendix G contains a table referencing literature that discusses the effects of Industry 4.0 technologies on energy use.

3.4 Conclusions

1. Industry 4.0 technologies and business approaches, and new electricity technologies such as high temperature heat pumps, if effectively deployed, could very substantially increase energy productivity in the manufacturing sector through:

    - Enhancing visibility of energy use, and key product parameters that impact energy use, across the information boundaries that traditionally have limited information flows across systems, plants, enterprises, and entire supply chains.
    - Application of IoT and AI/machine learning to optimise energy using systems and processes. International case studies demonstrate up to 20-30% improvement in operation of energy intensive processes using these tools, and IT models developed and refined in one location can be readily replicated in other similar operations.
    - Application of high energy productivity distributed electricity technologies to displace fossil fuel use in process heating. These technologies include highly energy productive technologies like heat pumps, as well as non-thermal processes like membrane dewatering and high-pressure processing. If a steam system with 50% overall efficiency was replaced with heat pumps with a COP_h of 5, this would provide an energy efficiency improvement of

[17] www.cesmii.org
[18] www.aiche.org/rapid/

10X. Better reliability, improved working conditions, and digital control from this change can deliver an even larger energy productivity dividend.

- Electrification of plants, supplied by increasing levels of on-site renewable energy (and/or off-site Power Purchase Agreements), which is becoming increasingly financially attractive.
- Optimisation of the electricity supply chain to facilities, and particularly optimising the timing of electricity purchases to reduce average electricity prices, facilitated by Industry 4.0 technologies. Increased information availability along the chain facilitates industry load flexibility which can be attained by optimising energy storage (thermal/material/ batteries), demand management and on-site generation. This flexibility can allow energy consumers to make real-time decisions to maximise production in low energy price periods.
- The combination of modular, highly automated and ultimately self-optimising electricity technologies, with energy from solar and batteries, and material supply chain visibility, can facilitate manufacturing activity earlier or later in the supply chain (and provide extra energy productivity benefits by potentially reducing the transport task and optimising activity to better match customer requirements).

2. It is important for businesses and governments to consider the timeframe and process for implementing Industry 4.0 to drive energy benefits. Even the introduction of variable speed drives, through retrofitting in existing facilities, has meant a significant change in a manufacturing process, requiring downtime and commissioning. Achieving incremental improvements of energy efficiency within existing facilities will continue to be difficult, requiring change management and time. New facilities (and new market entrants) can by-pass many of these legacy challenges by implementing these technologies from scratch.

3.5 Recommendations

1. Implement information and training related to the application of Industry 4.0 and new electricity technologies for improving energy productivity. A2EP and the project sponsors have attempted to take a first step down this path with the development of this material, but this job has just started. There is very limited business knowledge and understanding of energy productivity transformation opportunities through these initiatives. This extends right through from the businesses that could benefit to the Australian technology and services supply industry, including specifiers and consultants.
2. Assist companies who are piloting Industry 4.0 initiatives to incorporate energy in their programs, so that the pilot projects can also demonstrate the ability of these technologies and business models to drive energy transformation. These projects may incorporate modernisation/replacement of central energy services.
3. Increase cooperation between industry and energy/environment government departments, and between university faculties addressing IT, manufacturing technology and energy/environment. The application of Industry 4.0 to energy requires a broad vision and a multi-disciplinary approach.

4 Facilitating digitalisation and boosting energy productivity by addressing process heating

The application of Industry 4.0 approaches and technologies relies on being able to address energy using processes and systems which are flexible to changes in product and throughput, and whose energy use can dial up and down closely in line with process demands.

But the area of process heating is one where often antiquated processes are linked with antiquated energy distribution systems, which use gas and steam which is hard to measure, are not flexible with throughput and product changes, and are not suited to digitalisation. Further, these systems typically have very low energy productivity. The good news is that there is the opportunity to displace them by using electricity technologies like heat pumps, with exceptionally high energy productivity, that are well suited to Industry 4.0.

This section provides an overview of process heating in manufacturing, shows why steam age processes need to be replaced, showcases the technologies which could displace steam, and looks as the ways we can address key barriers to making this important change. Appendix B: Guide for business: Process heating innovation to boost energy productivity is designed as an aid for businesses wishing to replace their boiler systems with more energy productive, innovative technologies.

4.1 Purpose of process heating and associated energy use in Australian manufacturing

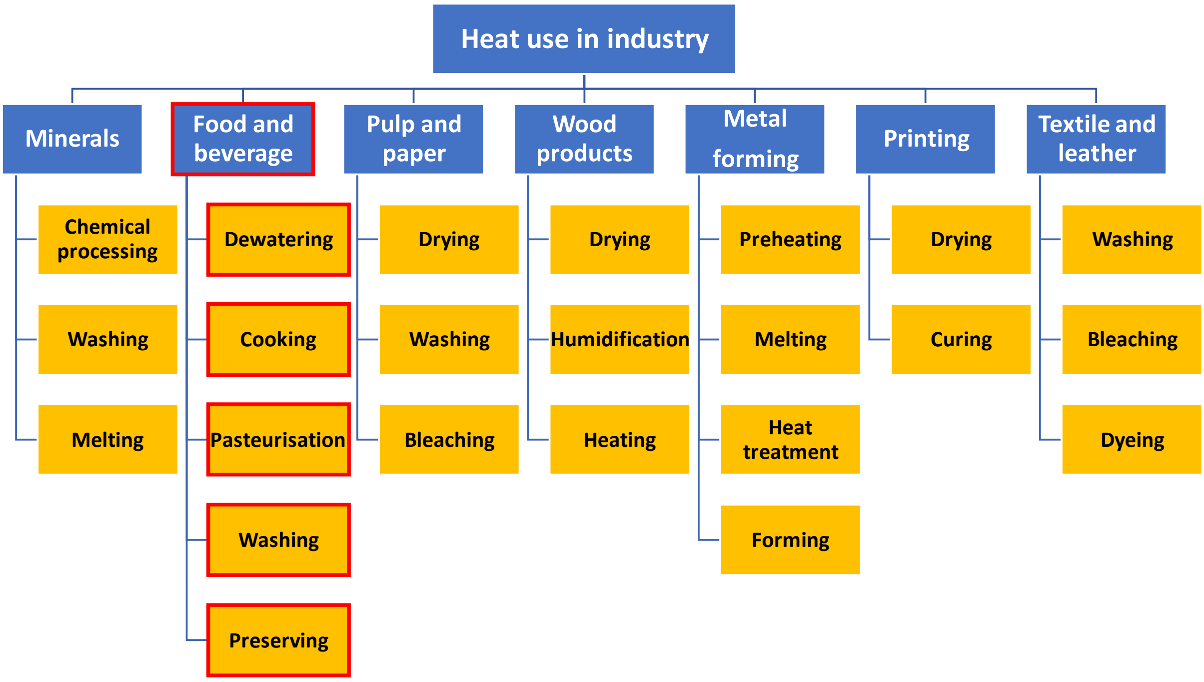
Process heating is typically used in:

- Food processing for removing water (concentrating, crystalising, drying), preserving, cleaning and cooking.
- Other industries for heating for forming, melting for casting and heating to promote chemical reactions.

Figure 11 depicts uses for heat in industry. This report is interested in the uses of heat in the food and beverage sector in particular.

Note: To improve energy productivity in process heating it is very important to examine in detail the purpose of the process heating – and this means, why exactly are we heating the product? For example, is it for killing particular bacteria? If so, have we done tests to determine the specific conditions that are required to achieve acceptable outcomes? And are there alternative ways of achieving the same outcome? Do not assume that a process heating application using steam needs to be replaced by another heating source with the same delivery temperature as the steam. And further, there may be non-thermal alternative ways to get to the same (or in some cases better) overall product specification.

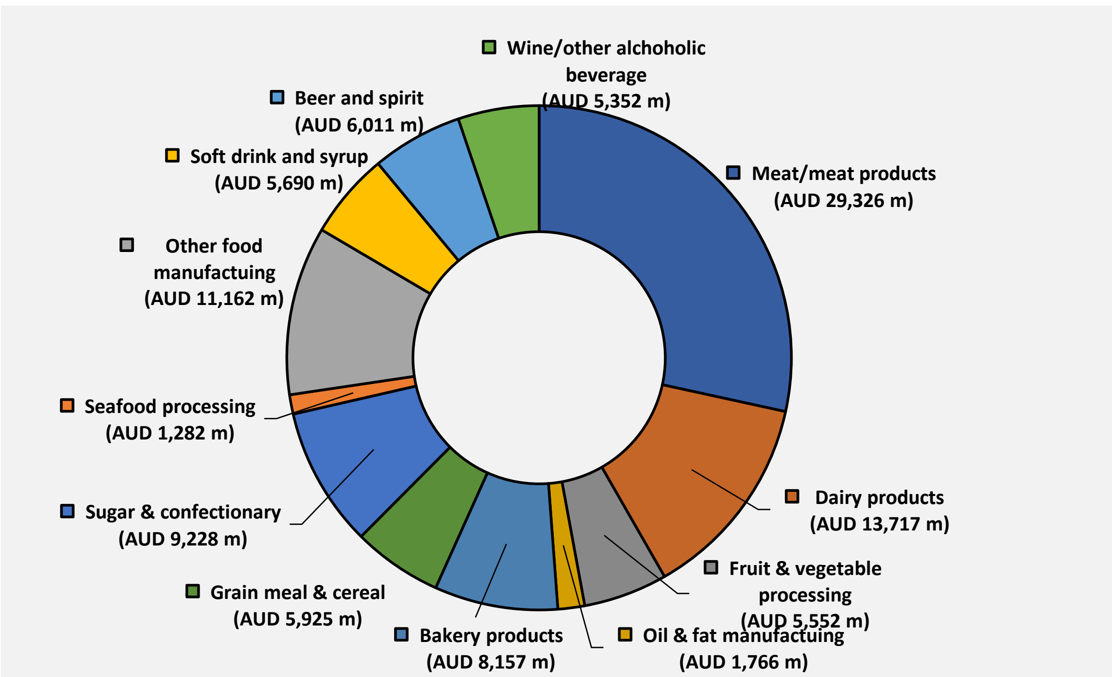
Figure 11 – Heat use in industry



Source: A2EP

Figure 12 shows the turnover of different sectors of the food and beverage industry in Australia. This accounts for 33% of all turnover in the Australian manufacturing sector. For the 10-year period ending 2016, energy consumption in the food and beverage sector has been growing by an average rate of 4.8% per year, while the total energy consumption in manufacturing sector overall declined by 1.3% per year during the same period.

Figure 12 – Turnover of food and beverage product categories in the Australian food and beverage manufacturing sector in 2014-15



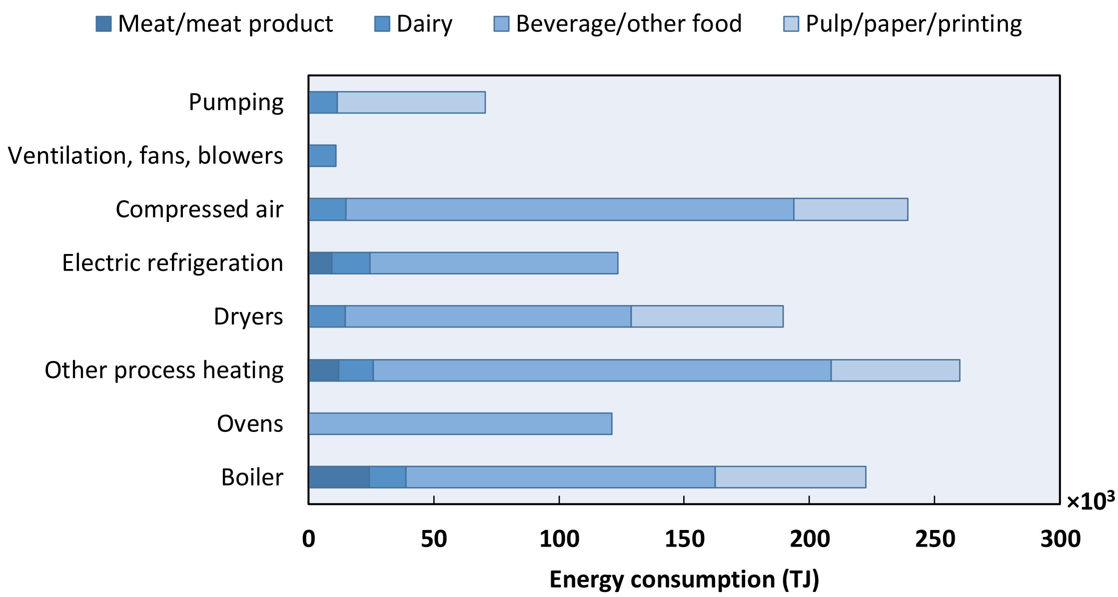
Source: Reproduced from "State of the industry, 2016", Australian Food and Grocery Council, 2016

The rising cost of energy has been identified as one of the major concerns for the sector[19]. A 20% improvement in the energy productivity of the food and beverage sector translates to a 7% improvement in the energy productivity of Australian manufacturing.

There is no data available in Australia on the breakdown of energy consumption for different processes such as dewatering and cooking in the food industry. There are only rough estimates available (such as from ClimateWorks Australia[20]).

The food industry currently uses electricity and gas to meet the thermal energy demand of production processes. Some of the applications consuming energy in the Australian food Industry[21] are shown in Figure 13. Note that the actual total energy consumption is expected to be significantly higher. This graph is based on incomplete data, so total energy use would be higher.

Figure 13 -Estimates of energy consuming processes in industry (food and paper) – identified cases only (actual total consumption is higher)



Source: Climateworks

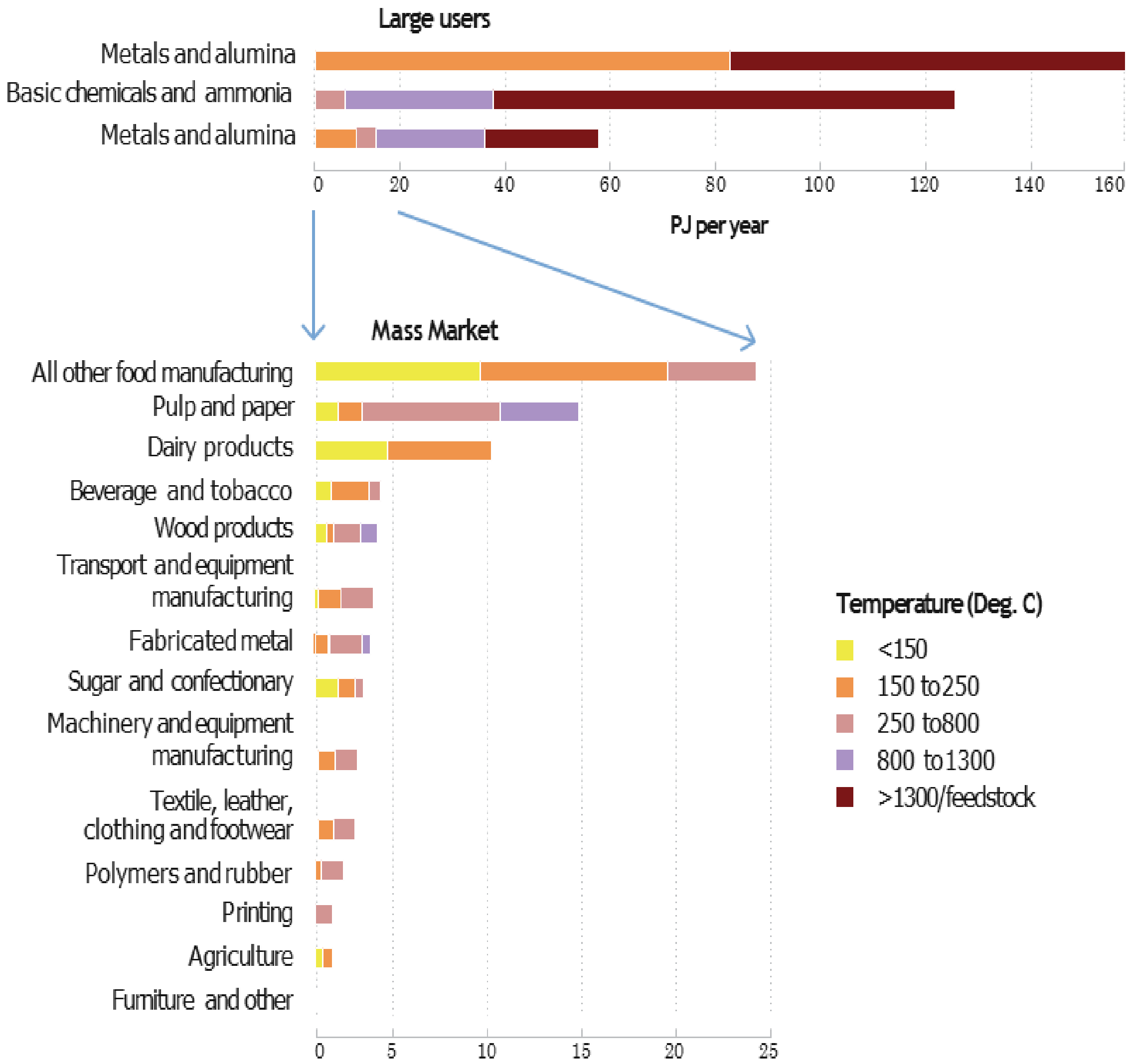
Thermal processes, including heating and refrigeration, are the most energy intensive process in this sector. Currently boilers/steam reticulation is the most common heating system used.

Thermal energy is used at a large range of temperatures. This includes very high temperatures for metal forming and minerals to relatively low temperatures in the food industry. Most of this energy is currently produced from burning fossil fuels. Natural gas accounts for 70% of all energy consumed in industry. This report is focused on displacing steam and hot water from central boilers/reticulation systems below 95°C.

[19]https://www.afgc.org.au/wp-content/uploads/AFGC_State-of-the-Industry-2016.pdf
[20] Industrial energy efficiency data analysis project, other manufacturing, construction and services, ClimateWorks Australia, May 2013
[21]https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_dret_ieeda_factsheet_other_20130502.pdf

Figure 14 below shows process heat temperature provided, but this is often far higher than the temperature required. As discussed earlier, it is essential to understand the underlying process temperature required, and to explore non-thermal ways of achieving the chemical reactions or required outcomes. It is also important to identify potential sources of 'waste' heat that can be utilised within the process or by other processes.

Figure 14 - Process heat temperature provided to industrial applications mainly from gas[22]



Source: ITP Renewables

[22] Report on renewable energy options for Australian industrial gas users, ITP Renewables, 2015

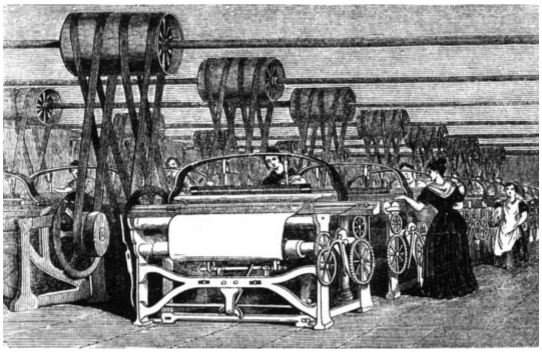
4.2 From Industry 1.0 to Industry 4.0: The mismatch of boilers and steam systems within an Industry 4.0 world – and Industry 4.0 alternatives

The global manufacturing paradigm is shifting from automated production lines (Industry 3.0) to demand driven, flexible enterprises (Industry 4.0). The shift towards Industry 4.0 will lead to production lines that:

- Have variable production schedules with changing energy/power demands.
- Can respond to varying real time energy prices to minimise costs.
- Are more environmentally friendly and designed to increase the use of renewable energy.
- Can be integrated with the whole plant, and continuously (self-) optimise.
- Are digitalised, monitored, connected and controlled intelligently.

Boilers and central steam systems (and compressed air systems) are poorly suited to the emerging industrial environment because they:

- Have low energy productivity due to significant losses, particularly at reduced load levels and on standby.
- Are very difficult/expensive to monitor.
- Are slow to respond and thus have poor flexibility and controllability.



Scientific American (1991):

"...At the turn of the century, a typical workshop or factory contained a single engine that drove dozens or hundreds of different machines through a system of shafts and pulleys. Cheap, small, efficient electric motors made it possible first to give each tool its own source of motive force, then to put many motors into a single machine."

Reducing the use of central steam systems and ultimately eliminating them by replacing them with alternative technologies will be part of the Industry 4.0 transformation. These alternative approaches can be:

- Improved processes that need less thermal energy/lower temperatures.
- Local heating systems near the process heat application, leading to reduced energy losses, and higher modularity with better controllability and more flexibility.
- Electrification of process heat, leading to more efficient systems, better monitoring of the performance, higher controllability, and higher capacity to uptake renewable energies.
- Replacement of process heating with non-thermal processes.

The following sub-sections introduce these technologies. The choice of technology(ies) to best address a process need requires careful examination of each specific process.

4.2.1 Non-thermal alternative technologies to steam heating

4.2.1.1 Mechanical de-watering

There are a range of mechanical methods for de-watering slurries, including centrifuges, filter presses, belt thickeners and membranes. Membranes separate water from larger product molecules by using a suitable pore size to filter out the product molecules – and the energy consumption is largely from pumps used to pressurise the working fluid to force the water through the membrane. Depending on the pore size the membrane process can be described as microfiltration, ultrafiltration, nanofiltration or reverse osmosis. This method has energy productivity benefits in terms of reducing energy requirements for dewatering the product – as mechanical removal of water can be less energy intensive than drying using natural gas or steam, at least to a specific concentration, above which evaporation may become more cost effective. For example, evaporating one litre of water uses more energy than heating five litres by 100°C.

Case Application

Normally milk is transported with its full water content and dewatered thermally at the processing plant using spray dryers. It has been demonstrated that milk can be economically concentrated to 50% of the original volume using reverse osmosis. Once concentrated, only half the volume of product needs to be stored, refrigerated and transported. A further energy productivity benefit is a much lower energy requirement for drying milk at the processing plant. The water recovered is suitable for use as on farm irrigation water without further treatment and this is a significant economic benefit for some farms. The technology is suitable for on-farm use where a large farm is a substantial distance from the processing plant (noting care must be taken to maintain low bacterial levels in this additional process step), for inter-factory transfers of milk and milk products, and for sales of bulk milk products interstate and internationally.

Example: Yanakie Dairy Farm, Victoria

The feasibility of removing water from milk on-farm was trialled utilising a reverse osmosis system manufactured by Tetra Pak Dairy & Beverage. The equipment for the pilot was leased from New Zealand and retrofitted to suit the needs of the Yanakie Dairy Farm in Gippsland, Victoria. The system produced 400 litres/hour of concentrated milk, and of fresh water.

Figure 15 – Reverse osmosis on a dairy farm

Source: www.clearwater.asn.au

Preliminary assessments identified a payback in less than two years based on benefits to the farmer for an on-farm system which cost $100,000. Reduced transport costs to the processing plant was the greatest source of savings for the farmer, worth about $30/kilolitre.

4.2.1.2 High pressure processing

High pressure processing (HPP) is a non-thermal process that uses very high pressures to kill yeasts, moulds and bacteria, extending the shelf life of chilled perishable products. HPP is an energy productive alternative to conventional food processing using heat and chemical preservatives and is suitable for chilled perishable products such as juices, meat, poultry, seafood, fruit and vegetable products, meal solutions, dips and sauces. HPP extends shelf life and also provides improved taste, texture, quality, fresh-like characteristics and nutritional value compared to thermal processing.

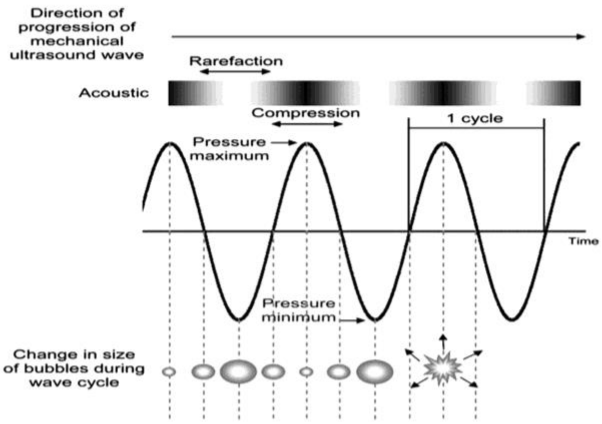
Commercial applications of high pressure processes use 300-700 MPa for 2-30 minutes at room temperature for microbial inactivation and quality retention. The specific energy required to increase water pressure to 600 MPa is estimated to be about 122 kJ/kg[23]. The conventional specific energy input required for thermal sterilisation of cans is about 300 kJ/kg[24]. Adiabatic compression caused by pressurisation creates an almost instantaneous temperature rise of 18°C in pure water. The subsequent depressurisation also leads to rapid cooling of the liquid.

See Appendix B for an example of HPP being used to pasteurise fruit juice.

4.2.1.3 Ultrasonic Processing

Ultrasound refers to sound waves at a frequency above the threshold of human hearing. The common frequency range that is applied in ultra sound technologies is 20 kHz to 500 MHz. Applying ultrasound waves to liquids causes acoustic cavitation that is a phenomenon of generation, growth and collapse of bubbles. The oscillation and collapse of these bubbles cause thermal, mechanical, and chemical effects[25]. Current systems have an energy efficiency of above 85% meaning that 85% of the consumed energy is transferred to the material[26].

Figure 16 – Ultrasonic processing



Source: Ultrasonication and food technology: A review, Majid I, et al, FOOD SCIENCE & TECHNOLOGY, 2015

[23] Energy efficiency and conservation in high pressure food processing, Wang et al. 2008
[24] Innovation strategies in the food industry, Implementation of emerging technologies, Barba et al., 2016
[25] https://www.tandfonline.com/doi/full/10.1080/23311932.2015.1071022
[26] Ultrasonic innovations in the food industry: from the laboratory to commercial production, Patist and Bates

This technology has wide range of applications. Here, we briefly mention those ones that can assist to replace process heat and improve energy productivity[27].

- **Disintegration of cells and extraction** to break cell structure and extract intercellular content such as starch from the cell matrix, this can significantly reduce the need for heating the raw material.
- **Acceleration of fermentation,** for example, in yogurt fermentation by reducing the fermentation duration by up to 40% and improving the quality of the product resulting in higher viscosity.
- **Homogenising** milk using cavitation within the liquid; the collapse of bubbles creates high pressure causing homogenisation with minimal moving parts and heat requirement.
- **Dispersion of dry powder in liquids** ultrasound cavitation generates shear forces to break particle agglomerates and create single particle dispersion with minimal heat requirement.
- **Emulsifying of oil/fat in a liquid stream** emulsifying is the dispersion of two or more immiscible liquids. The mechanism is very similar to homogenization and is applied in cosmetics, paints, lubricants, etc.
- **Degassing,** e.g. in juice, sauce wine to suppress microbial growth and oil and lubricant before pumping.
- **Meat tenderisation** by releasing proteins from muscle cells with minimal heat requirement.

4.2.1.4 Irradiation

Irradiation is used to destroy bacteria and pests to extend the shelf life of food products. To do this, food is irradiated by gamma rays, powerful X-rays, ultraviolet, or high energy electron-beams. These waves penetrate through the material without significant heating effects.

Electrons have a limited penetration depth of 5 cm, while X-rays have a much deeper penetration of 60-400 cm depending on the energy level of the radiation[28]. Electricity driven radiation sources can be quickly switched on and off and can vary level of radiation intensity to match the load level.

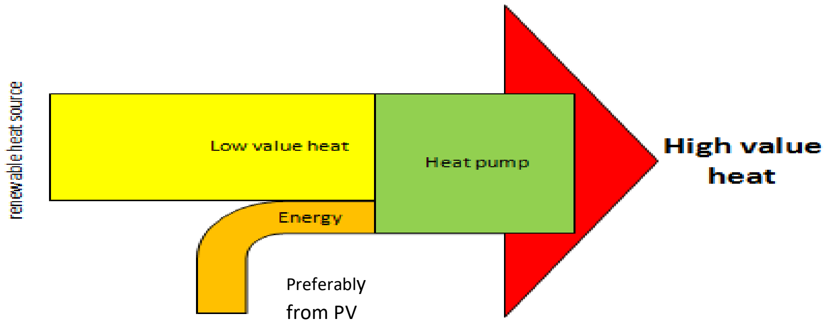
4.2.2 Alternative thermal technologies to steam heating

4.2.2.1 Heat pumps

Industrial heat pumps use a refrigeration cycle to very efficiently transfer and upgrade heat to higher temperatures. They can extract energy from the environment and waste heat streams such as waste water, hot humid air (e.g. from dryers) and condenser heat from refrigeration systems, for utilisation in a range of applications like blanchers, dryers and pasteurisers.

[27] https://www.hielscher.com
[28] Non-thermal processing in food applications: A review, Awsi Jan et al, 2017

Figure 17 – Heat pump leverage: input from lower grade heat streams



Source: Pachai, A C. 2013, Applying a heat pump to an industrial cascade system

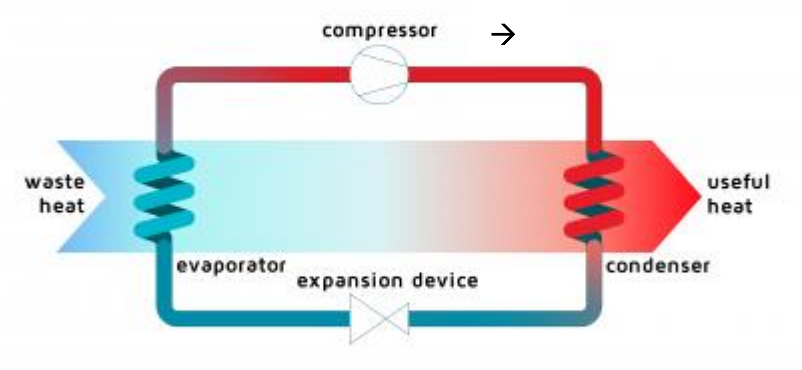
Heat pumps can fulfil a number of functions:

- Raise the temperature of a fluid.
- Simultaneously cool a fluid (which could also be used for dehumidification) while providing heat for another process.
- Recover waste heat from a stream, including latent heat from water vapour.

A mechanical heat pump driven by an electric motor is the most widely used. Its operating principle is based on the compression and expansion of a refrigerant.

A heat pump has four main components: evaporator, compressor, condenser and expansion device, as can be seen in the diagram below. In the evaporator, heat is extracted from a waste heat source by evaporating the refrigerant at low pressure. The gas is compressed and its temperature increases (just like in a bicycle pump). In the condenser, this heat is delivered to the process at a higher temperature as the refrigerant condenses and releases its latent heat. Electric energy drives the compressor and this energy is added to the heat that is available in the condenser.

Figure 18 – Heat pump components



Source: De Kleijn 2017, www.industrialheatpumps.nl

The efficiency of refrigeration systems and heat pumps is denoted by the coefficient of performance (COP). The COP is the ratio between the energy usage of the compressor and the amount of useful cooling at the evaporator (for a refrigeration installation) or useful heat extracted from the condenser (for a heat pump). Most of the electric energy needed to drive the compressor is released to the refrigerant as heat, so more heat is available at the condenser than is extracted at the evaporator of the heat pump. For a heat pump a typical COP of 4 means that the input of 1 kW of electric energy is used to achieve a release of 4 kW of heat at the condenser. At the evaporator side 3.0-3.5 kW of heat is extracted and additional heat from the electricity input to run the motor/compressor is added, so that a total of 4 units of heat is delivered at the condenser when only 1 unit of electricity (or mechanical energy) is used. This system could simultaneously provide 3-3.5 kW of cooling if there was a use for it.

Applications

Typical heat pump applications in the Australian food processing industry are summarised in the table below:

Application type	Features	Typical Industries
Dryers	Capture sensible and latent heat from exhaust streams	Milk, pasta, noodles
Food washing	Capture sensible and latent heat (water vapour) from exhaust streams	Potatoes, vegetables, fruit
Water heating for process and cleaning	Capture waste heat from process or refrigeration (or air) compressors	All food
Pasteurisation	Can be heating and/or cooling role	Milk, juices
Combined process heating and cooling	Ideal applications use the condenser for heating and evaporator for cooling simultaneously	An example is bread - product cooling and proving

Drying

Food dryers generally use air heated with steam, gas or hot water. Warm air picks up moisture from the wet product, and generally this humid warm air is exhausted and wasted. Conventional heat exchangers can only capture a proportion of this waste heat. A heat pump can extract heat from the humid air - both sensible heat and latent heat by condensing the water vapour. The now dry cool air is heated by the heat pump for reuse in the dryer. (Note that the latent heat accounts for most of the available energy in the humid warm air streams).

Heating process water with waste heat from a refrigeration system

Waste heat from a refrigeration system typically has a temperature of 25 to 30°C. With the use of an add-on heat pump, waste heat from the condensing side of the refrigeration system is used to heat water to temperatures up to 80°C, at COP of 4 or higher. Even higher temperatures could be achieved by using options such as cascaded or multi-stage heat pumps.

Pasteurisation

The pasteurisation process requires products to be heated above 70°C, and then cooled. Heat exchange (regeneration) between cold and hot product flows is already implemented but is limited by heat exchanger efficiencies and equipment design. Extra heating to bring the product to pasteurisation temperature is typically provided by steam, and product cooling after heat exchange is provided by externally sourced chilled water. A heat pump can extract heat from the product to be cooled (displacing cooling from chilled water) and supply this heat at a higher temperature to product to reach pasteurization temperature (displacing steam). This is an example of a heat pump simultaneously heating and cooling a process. In these cases, the effective COP can be particularly high, but this benefit needs to be balanced with scheduling challenges.

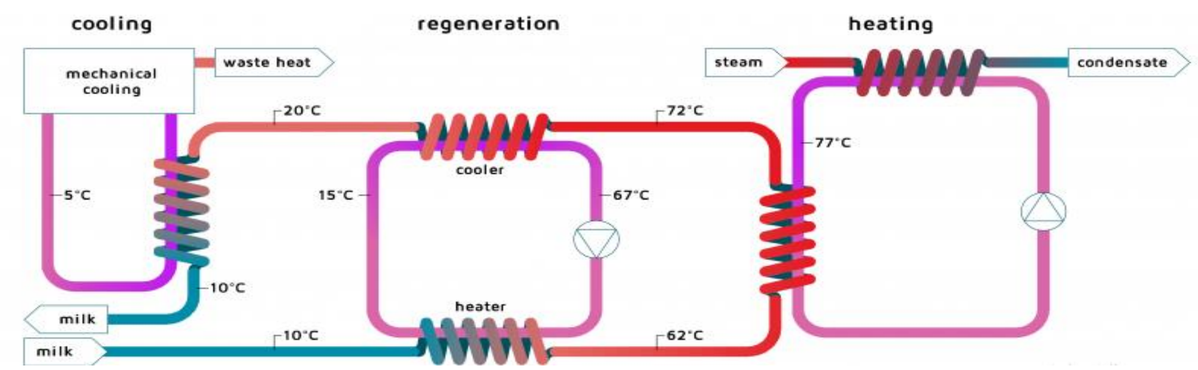
Water heating for process and plant cleaning (including cleaning in place – CIP systems)

Water is needed at elevated temperatures – typically 65°C + for cleaning process plant, including using cleaning in place (CIP systems), as well as for process needs at temperatures up to 80°C +. Heat pumps are well suited to this duty.

Example: Pasteurisation

Figure 19 shows a typical milk pasteuriser. Milk comes in at 10°C and is preheated to 62°C degrees with regenerative heat from milk being cooled after pasteurisation. The milk is then heated to 72°C with hot water, often produced from a steam heater. After this desired pasteurisation temperature is reached, the milk needs to be cooled down back to 10°C. At first cooling is supplied by regeneration with fresh milk to 20°C. To reach the desired milk temperature of 10°C, a cold water circuit is used. This circuit is cooled with the use of a refrigeration system. The cooling circuit releases (potentially useful) waste heat at its condenser site.

Figure 19 – Conventional pasteurisation process

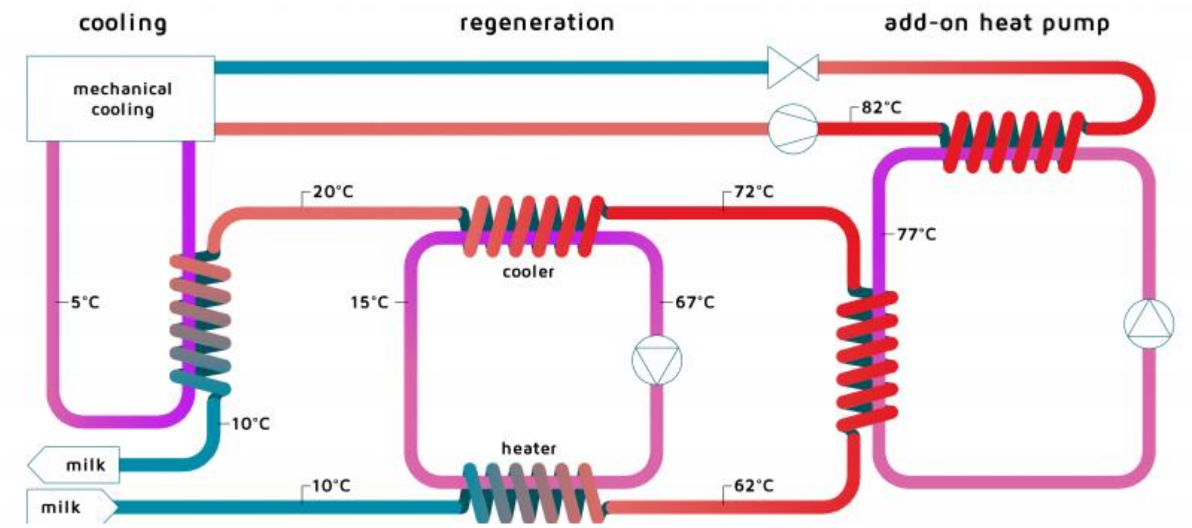


Source: De Kleijn 2017, www.industrialheatpumps.nl

Pasteurisation with the use of an add-on heat pump

Application of a heat pump enables the opportunity to reuse the waste heat from the mechanical cooling system in the pasteurisation process. The add-on heat pump replaces steam for the pasteurisation process. Compressed gases from the refrigeration installation have a condensation temperature of 25 to 30°C. The heat pump compressor increases the pressure of the gaseous refrigerant further so the condensation temperature is over 80°C. Heating for pasteurisation is thus supplied by the heat released at the condenser of the refrigeration system. After condensation of the refrigerant in the refrigeration system, its pressure is reduced inside an expansion element after which the refrigerant is sent back to the original cooling cycle.

Figure 20 – Pasteurisation process with add-on heat pump



Source: De Kleijn 2017, www.industrialheatpumps.nl

See also the A2EP heat pump report here for more information on heat pumps.

Heat Pumps Economics

Heat pump performance and economics depends on the application and site specifics:

- electricity-to-gas price ratio
- real world efficiency of gas heated process
- ambient temperature
- availability of waste heat
- type of heat exchangers in place: water-to-water, air-to-water, etc
- availability of on-site renewable electricity
- possibility of co-using heat and cold, and other factors.

Here, we will provide some indicative costing of heat pump systems for industrial process heat. But each case requires accurate costing and economic analysis based on engineering analysis.

Most process heating applications need a heat delivery temperature of above 65°C, which requires 'high temperature' heat pumps. The capital cost of such heat pumps capable of delivering heat with temperature of up to 90°C is presented in Figure 21. These are estimated installed costs for heating duty only in Australia. As heat pumps are used more widely, economies of scale and 'learning from experience' will reduce capital costs, while renewable electricity and demand management can reduce input electricity costs.

The cold side temperature is the heat source for the heat pump. This can be the ambient air, mains water, or most frequently a waste heat stream. The hot side of the heat pump in the diagram is set at 65°C or 90°C. At 65°C there is a higher COP and lower capital cost.

Other than the extreme case of keeping the cold side at -7°C, the capital cost (in 2018) of the systems is estimated to be around 0.80-1.00 AUD/$W_{heating}$.

Figure 21 - Capital cost of heat pump installed for process heat purposes

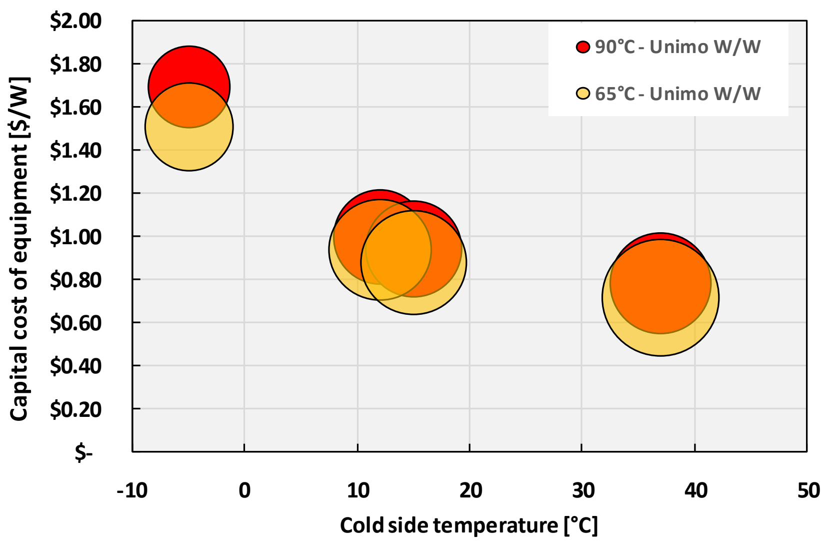
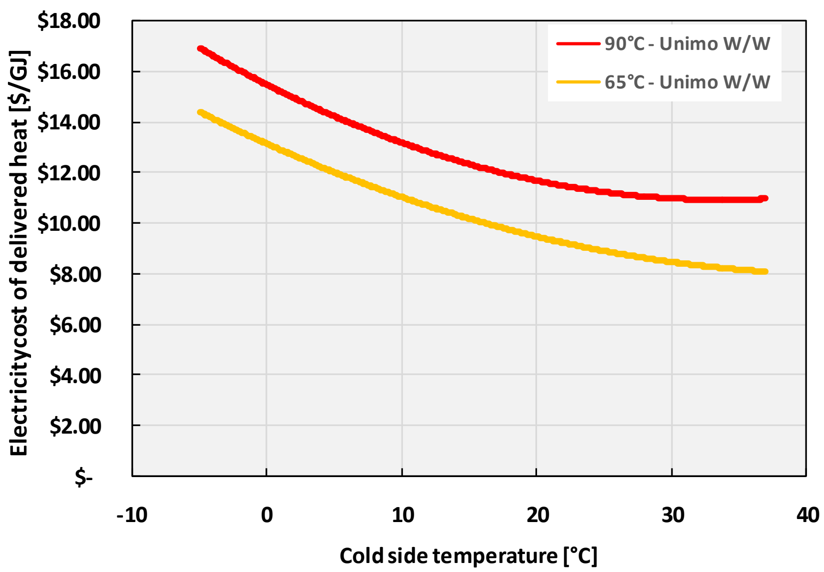


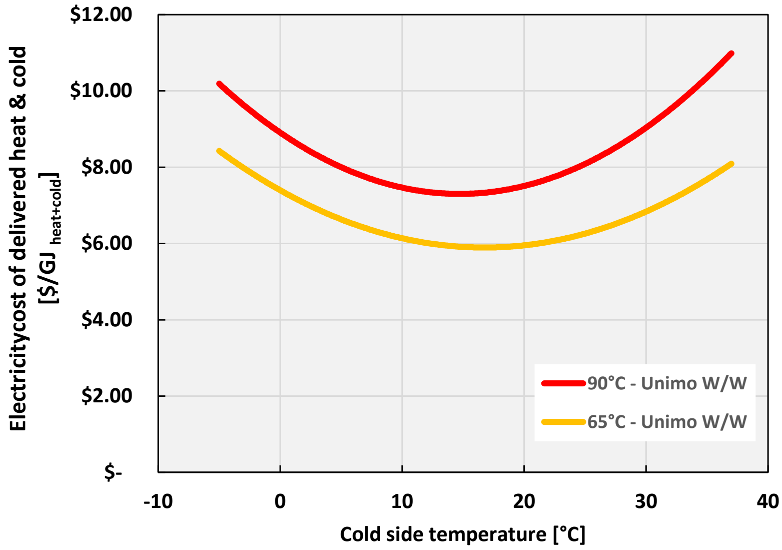
Figure 22 shows the indicative electricity cost of producing 1 GJ of heat at 90°C and 65°C with the same heat pumps. Here we have assumed that electricity can be sourced at 15 c/kWh. With different electricity price, the presented costing can be scaled accordingly. It is important to compare this cost/GJ to the cost of heat *delivered* by a gas-fired system, not the cost/GJ of gas or the cost/GJ of steam produced.

Figure 22 - Cost of electricity for producing a unit of heat using heat pumps



The cold side temperatures of the above heat pumps mean that they can be used for refrigeration duties by another process (ideally adjacent to the heating process). If the heat pump can be used for simultaneous heating and cooling, the economics of the heat pumps improves further. Figure 24 assumes full use of these cold streams. The indicative energy price on the vertical axis shows the average cost of producing a unit of thermal energy (heat or cold). For example, the heat pump system can co-produce about 0.3 GJ of chilled water at 0°C and 0.7 GJ of hot water at 65°C consuming only ~$7.50 of electricity. Note that the rate of generating cooling power is always lower than the rate of generating heating power, as explained earlier.

Figure 23 - Electricity cost of co-producing a unit of heat and cold



4.2.2.2 Microwave processing

Microwaves are electromagnetic waves with frequencies between 300 MHz and 300 Ghz. Microwaves with a frequency of 915 MHz are widely used for heating purposes in industry. These waves can penetrate through the bulk of materials and interact with polar water molecules and charged ions. Polar molecules constantly reorient to couple with the oscillating electromagnetic field. The resulting friction generates heat.

Microwave heating can be an advantageous method because it:

- Heats the bulk of material; conventional surface heating suffers from the low thermal conductivity of organic raw material and may risk overheating the surface.
- Can be combined with other heating methods such as convection and infrared or UV radiation. Combining microwave and vacuum can also be used.[29]
- Can be used in a cold space with minimal temperature rise of the ambient temperature.

[29] Useful references: https://www.omicsonline.org/potentials-of-microwave-heating-technology-for-select-food-processing-applications-a-brief-overview-and-update-2157-7110.1000278.php?aid=22002 also https://pdfs.semanticscholar.org/7f43/536e0a116b8031debda9611808ce4a231245.pdf

- Delivers thermal energy directly to areas with more water content, which in many cases is the main purpose of the process.

Applications[30]

Baking and cooking bread, cakes, pastry, etc.: often microwave heating is combined with conventional or infra-red heating for better texture and crust formation. Microwave baking may reduce the baking time significantly by focusing on water rich areas and penetrating though the bulk of the raw material.

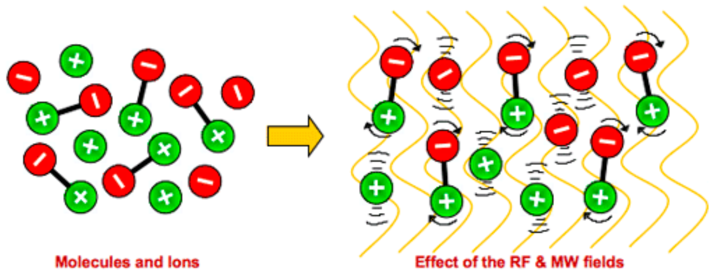
Pre-cooking poultry, meat patties, bacon, etc.: Microwave can produce a valuable byproduct of rendered fat by melting the fat close to the surface.

Tempering of frozen food: Microwave can be used to overcome the low thermal conductivity of frozen food such as large blocks of butter, meat, fish, fruits, etc. This can lead to significant reduction of tempering time from days to minutes or hours with minimal rise of the ambient temperature that helps to suppress microbial growth. The required space is also reduced by an order of magnitude.

Drying: Microwave can accelerate the drying process without hardening due to large moisture gradients. It can be combined with hot air flow or vacuum drying methods such as in pasta drying, or dried onion products.

A study in 2007[31] showed that most magnetrons in microwave ovens can convert electricity to microwave with an efficiency of 50-60%. The rest is wasted mainly as heat. The absorption of microwaves by water content of food is about 86-89%. Hence, the total thermal efficiency of microwave heating is about 44%. However, the accurate delivery of heat to material usually more than compensates for this loss.

Figure 24 - Interaction of polar molecules within the material with alternating electric fields created by microwaves[32]



4.2.2.3 Infrared processing

Infrared refers to electromagnetic wavelengths of 0.78 to 1000 micrometer. With infrared heating, thermal energy travels directly from the emitter/heater to the part without heating an intervening medium such as air. Infrared heating has gained popularity in manufacturing applications due to:

[30] Novel and traditional microwave applications in the food industry, Schubert and Regier, University of Karlsruhe, Germany
[31] Energy consumption in microwave cooking of rice and its comparison with other domestic appliances, Lakshmi, 2007
[32] https://profpeterelia.wordpress.com/category/uncategorized/

- The simplicity of the required equipment
- Its fast heating rate/ response time
- Its capability for localized heating
- Its compatibility with vacuum or controlled environment.

In the food industry, infrared heating is used for:

- Drying and dehydration
- Enzyme inactivation, and pathogen inactivation
- Baking, roasting, frying.

Infrared heating can be combined with other methods such as convective drying to improve the performance of the process. For example, an analysis showed that with this combined method, for some food industry applications, the time and energy consumption for a drying process reduces by about 50% and 60% respectively.

The use of infrared heating in food applications can reduce the processing time and energy loss and extend shelf life of the food product.

Figure 25 – Infrared heating

4.3 Barriers to adoption of heat pumps

The major barriers to adopting energy efficiency measures in industry[33] are the perceived payback period for the investment in these measures, and lack of information, including data on the energy use and efficiency of existing or benchmark of processes due to inadequate metering – see Figure 26 below. The concerns that can be addressed by adopting more accurate metering technologies have been highlighted with green colour.

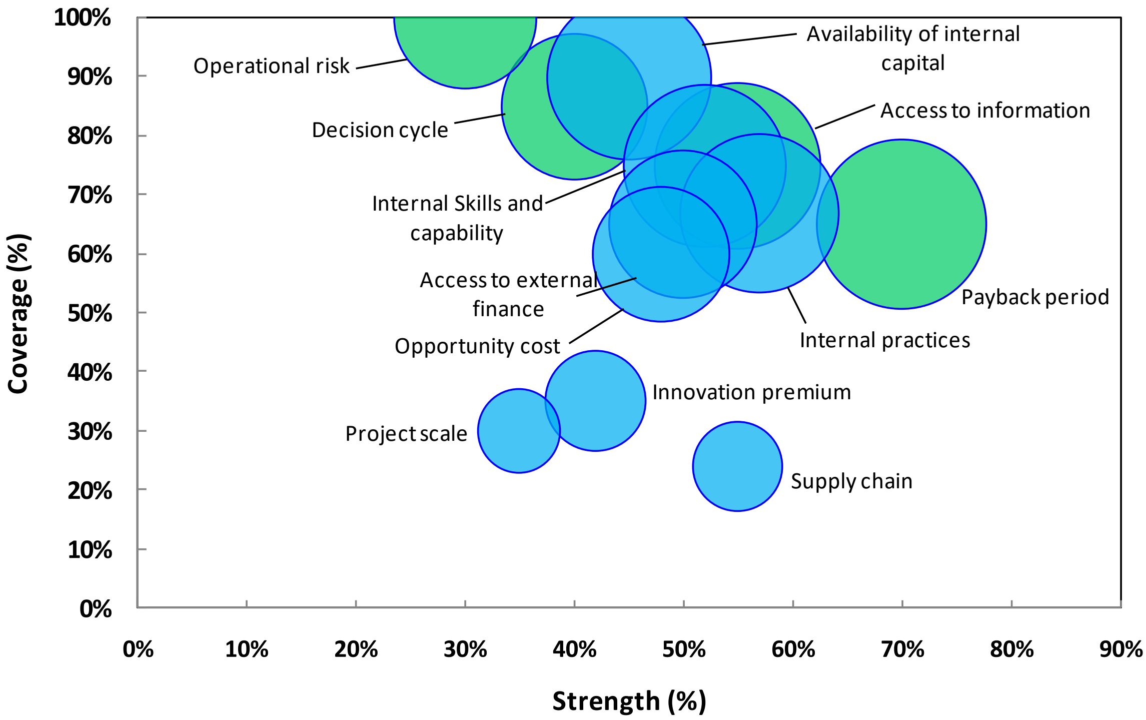
Coverage: The proportion of energy savings identified in industry and affected by the factor (the labels).

Strength: The level of impediment created by the factor.

[33] https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_dret_ieeda_factsheet_other_20130502.pdf

Bubble size: Total percentage of energy savings blocked by the factor, that is, by eliminating the blocking factor associated with bigger bubbles, more energy productivity gains can be unleashed.

Figure 26 -Perceived barriers to adopting energy efficiency measures in industry



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

The following is a discussion on barriers to the uptake of heat pump technology – though the points are also relevant to other technologies discussed in this report as alternatives to boiler systems.

Barriers to adoption of heat pumps

As part of the ATMOsphere Australia 2018 conference[34], which took place in Sydney on 7 May 2018, experts on heat pump technology held roundtable group discussions on the future of Australia's market for natural refrigerant-based heat pumps. The goal of the workshop was to form an action plan to gather industry support for further uptake of water-heating heat pumps using natural refrigerants in Australia. Participants included representatives from globally leading OEM's such as Mayekawa, Johnson Controls, and Mitsubishi Heavy Industries as well as from local industry stakeholders, end users, and contractors. The session was co-chaired by A2EP.

The top three barriers and recommended actions from the workshop were:

Barrier #1: High capital costs, perceived risk & resistance to change

High capital costs for end users for natural refrigerant-based heat pumps came up as the top barrier among participants during the session.

[34] http://www.atmo.org/

On most occasions, less efficient and more environmentally harmful solutions for hot water heating represent lower capital costs than natural refrigerant-based heat pumps in the Australian market, even though their life cycle costs due to high energy consumption would be much higher, and with the current higher gas prices, paybacks of two to five years are typical for simple heat pump applications for water heating.

Action proposed on Barrier #1:

Provide concise and clear documentation targeting end users with three key messages:

- The business case for natural refrigerant-based heat pumps over current technology with simple and easy to understand life cycle cost and return on investment figures.
- Awareness-raising on public funding to overcome capital costs such as the Australian Government's ARENA program which funds projects that advance renewable energy. The parameters of this program are still being resolved at the time of writing.
- Technology advantages (including heat recovery) of heat pumps when used effectively in business operations.

Build and share knowledge of Australia specific heat pump applications through pilot projects and case studies. With the funding of pilot projects, early adopters in the market should begin to build the foundation for sharing knowledge and training with the rest of the market. Pilot projects can also serve to educate the rest of the industry on how to properly install and maintain heat pumps.

Barrier #2: Lack of education across supply chain & lack of skilled technicians

Participants found that the lack of awareness of heat pump technology across the entire supply chain (technicians, consultants, engineers, contractors, and end users) is a significant barrier to natural refrigerant-based heat pump adoption in Australia.

Actions proposed on Barrier #2:

- Obtain support for training programmes for technicians. Training programmes from public institutions such as the Department of the Environment and Energy, etc. as well as private initiatives should be more widely available. ATMOsphere conference participants should have a specific call for public funding for training.

Barrier #3: Lack of expertise and experience of specifiers and consultants

Action proposed on Barrier #3:

- Improved training for specifiers and consultants.

  Encourage more proactive sales and marketing by manufacturers, specifiers and consultants. Manufacturers have an opportunity to help spread awareness of the technology through more direct and proactive communication of heat pumps as a heating solution at tradeshows, exhibitions and other events. In addition, consultants and contractors should differentiate themselves in the market by actively communicating the benefits of heat pump technology to their customers.

4.4 Potential technology demonstration sites

In the course of this project 10 sites were identified as locations to evaluate the technical and economic feasibility of replacing centralised boiler systems with heat pumps and conduct technology demonstrations for sites with high potential.

Typical characteristics of the identified sites include:

- The site has an existing boiler/steam system, and the boiler is oversized and/or old and due for replacement.
- The main use of the boiler is producing hot water, ideally less than 90°C.
- Waste heat is available (for example from an existing refrigeration plant).
- Site and company management are innovative and proactive in their approach.

4.5 Conclusions

1. The uptake of Industry 4.0 technologies and business approaches for overall productivity and quality benefits will not automatically drive these substantial energy productivity gains. Businesses must understand their current energy use and the services being delivered, and plan to specifically address energy productivity in their implementation of Industry 4.0. Otherwise their energy benefits, and broader business benefits gained will be limited by:
    - Lack of energy metering, monitoring and information tools.
    - Inflexibility and high standing energy losses of existing central energy distribution services e.g. steam and compressed air.
    - Lack of knowledge of the scope for alternative production approaches to capture energy productivity benefits.
    - Inadequate energy management know-how in many businesses and the equipment and services companies supplying them. This becomes critical when addressing more technically challenging issues like process optimisation, or determining the optimal use of heat pumps for heating and cooling, which requires the ability to apply heat balances, and pinch studies in more complex facilities.
2. Application of these approaches can capture multiple business benefits through improved product and service quality, higher productivity, improved matching of product to consumer preferences, and reputational benefits.

4.6 Recommendations

1. Accelerate development and deployment of energy metering. The lack of real-time measurement and reporting on energy use needs to be addressed to support the ability of

companies to gain the maximum energy productivity benefits from Industry 4.0 implementation. This should include incentives to encourage companies to implement more comprehensive sub-metering, and also support for start-up companies to develop and demonstrate non-invasive monitoring processes e.g. using AI to infer energy use of plant and equipment through recognition of their characteristic patterns of usage.

2. Conduct pilot studies and demonstration implementations of heat pumps and other electricity technologies to demonstrate the application of these technologies for fossil fuel steam system displacement, and the business benefits of their implementation.

3. Establish an electricity technology centre to accelerate introduction and demonstration of these technologies in Australia. This could be part of a broader research centre aimed at ensuring co-ordinated and consistent efforts to harness innovation to drive forward Australia's energy productivity and improve business competitiveness.

Appendix A: Guide for business to implement Industry 4.0 to boost energy productivity

Why improve your energy productivity?

Energy is a key enabler for business, but most organisations treat it as a fixed overhead and do not get full value from its application.

Energy price escalation – electricity, gas (and recently oil again) is impacting business competitiveness, particularly because Australian companies generally create significantly less value from every dollar of energy they use than their overseas competitors.

Energy productivity (EP) measures the value created from using each unit of energy. To improve EP, you increase value added by using energy more effectively, and by using less energy.

This guide aims to help companies to improve energy productivity (and reduce average electricity costs through demand management and on-site PV generation) as an integral part of implementing Industry 4.0.

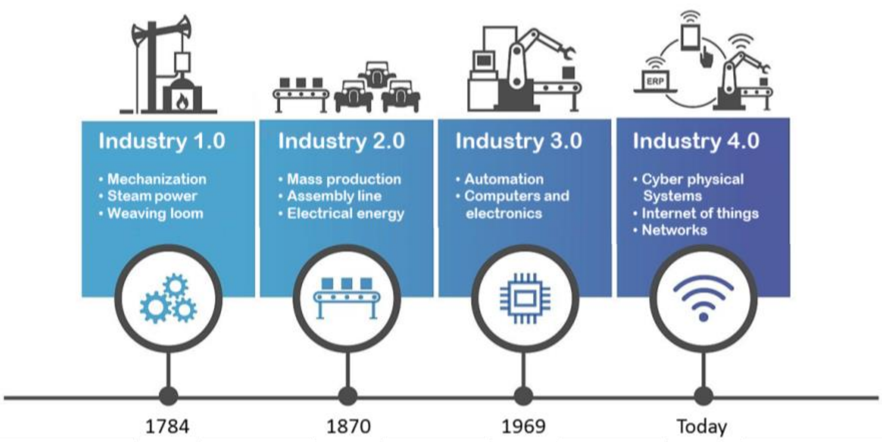
Adaptive, intelligent, connected manufacturing

Industry is undergoing a technological transformation, which is sometimes called the fourth industrial revolution or Industry 4.0.

Industry 4.0 emerged in Germany. A similar approach in the US is called 'Smart Manufacturing', and 'smart factory' is also a term used in Germany. Other countries have their versions (e.g. 'Made in China 2025'). This revolution promises not just improved manufacturing productivity, but also the ability to exchange information with suppliers and customers, facilitating more responsive manufacturing.

The transition to smart, connected industry also allows businesses to better control energy costs, and capture broader business benefits from applying energy better, including increased throughput, improved plant reliability, better product quality and reduced maintenance costs.

Fourth industrial revolution: adaptive, intelligent, connected manufacturing



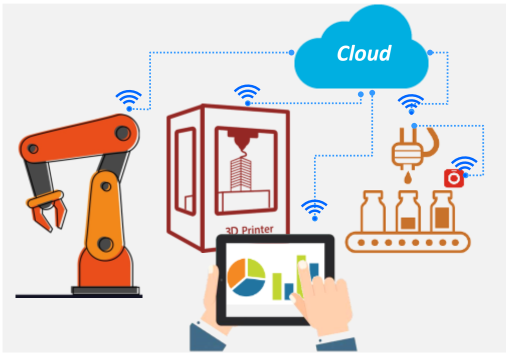
Source of Industrial Revolution images: http://www.btelligent.com/en/portfolio/industry-40/

However, the change to smart, connected industry will not happen automatically. Energy needs to be actively addressed and managed in an Industry 4.0 environment as much as it did in Industry 3.0 or 2.0.

Key elements in the Industry 4.0 transformation are:

- **Flexible equipment and processes** that can respond to information from across the business and beyond, changing product specifications and optimising performance in response to customer needs. To ensure this flexibility converts to high energy productivity, energy using equipment must be able to flexibly adjust to production changes.
- **Access to data streams** from other parts of the business, the supply chain, delivery system, customers – and their customers, as well as from external sources like public agencies (e.g. weather bureau, traffic management authorities, sources of statistical data). To convert these data streams to high energy productivity, we need to be able to measure energy use and understand how this impacts on key production variables.
- **Communication systems and platforms** that are secure and reliable, including for energy use**.**
- **Data analytics** that manage, analyse and convert data into actionable and useful information. Energy productivity metrics should be included in outputs.
- **Organisational capacity**, including change management, and specific Industry 4.0 and energy management skills/knowhow. Do not underestimate the importance of managing the people side of this transformation. Specialist energy competency may need to be built in-house and supplemented with consulting/technology vendor assistance during the implementation of these changes.

Key elements of Industry 4.0



Industry 4.0 Technologies

A range of technologies underpin the Industry 4.0 transformation. Key technologies include: Internet of Things (IoT), enhanced data analytics, cloud computing, more flexible plant, artificial intelligence (AI)/machine learning, and augmented and virtual reality.

Refer to the Glossary of Terms at the end of this Guide for an explanation of Industry 4.0 enabling technologies.

Including energy productivity in your Industry 4.0 program

To successfully transform a manufacturing enterprise, Industry 4.0 enabled technologies need to be applied to monitor energy use and optimise energy use for variable production.

You will need a clear plan to optimise energy use and achieve high energy productivity through this transition. Digitalisation offers lower cost advanced energy management tools to help optimise energy use. However, most companies have inadequate metering of their energy use to even understand the scale of the opportunity.

Energy using plant and systems may need to be modified/designed so they have very low standing energy losses (i.e. energy use at zero throughput) and thus good turndown response, and energy using services like compressed air need to be able to be isolated from plant when not in use.

This guide provides guidelines on how to transform the way you apply energy as you go through the Industry 4.0 journey.

There are many energy productivity opportunities in every business, and we have characterised them below, starting from helicopter level down to equipment level, to assist you to systematically approach this task.

The biggest insights often come where traditionally there has not been free information flow – where there are information boundaries between systems/divisions in plants and between organisations in supply chains. So, it is worth looking briefly at least at the big picture before diving too far into the weeds. Here is the way we have approached the opportunities:

1. **Savings from improving information flow across interfaces between organisations and production lines**
2. **Improving plant energy flexibility**
3. **Optimisation of energy intensive processes and systems**
4. **Improving the energy productivity of equipment**

There is also potential to reduce your average energy cost through the use of renewable energy procurement, integrated with load management and storage, and this is covered in a separate section.

1. Improve information flow across interfaces between organisations and production lines

Opportunities often exist to achieve substantial energy productivity gains by improving the visibility of information across multiple businesses in supply chains, and across multiple operations on a site.

Industry 4.0 technologies can provide real time visibility of key material variables (e.g. size, temperature, moisture content, location) across interfaces in the chain. This information, accessible from cloud-based applications, can provide a selectively shared view of key product variables, and facilitate a shared understanding of final customer needs, to allow players along the chain with the right incentives to optimise material specification to boost overall energy productivity.

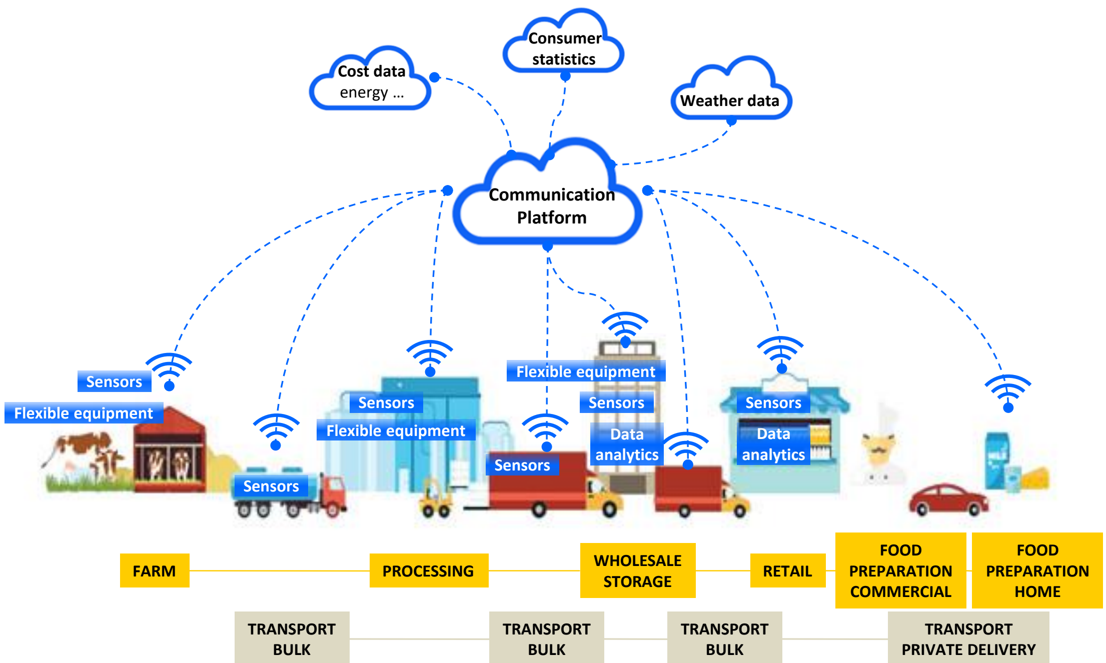
Energy performance benefits across value chains come from:

1. Availability of securely and selectively shared information across the chain, which facilitates changes in operations upstream and leads to reduced demand for energy at the processing stage. For example, where it is feasible to reduce water content of a product earlier in the chain.

   Example: Real-time temperature and location monitoring in the cold chain.

   Companies are starting to improve control of the quality of perishable food by monitoring the temperature and location of these products through the cold chain from farm to shelf, using low cost sensor devices/ transmitters, communication networks and cloud-based applications to collect, report and respond to variances from target temperatures in real time.

Inter and intra-organisation information flow across interfaces using I4.0 technologies in the food value chain



2. The control of key product variables in energy-using processes along the chain (including in processing) that results in greater product value/reduced product losses.

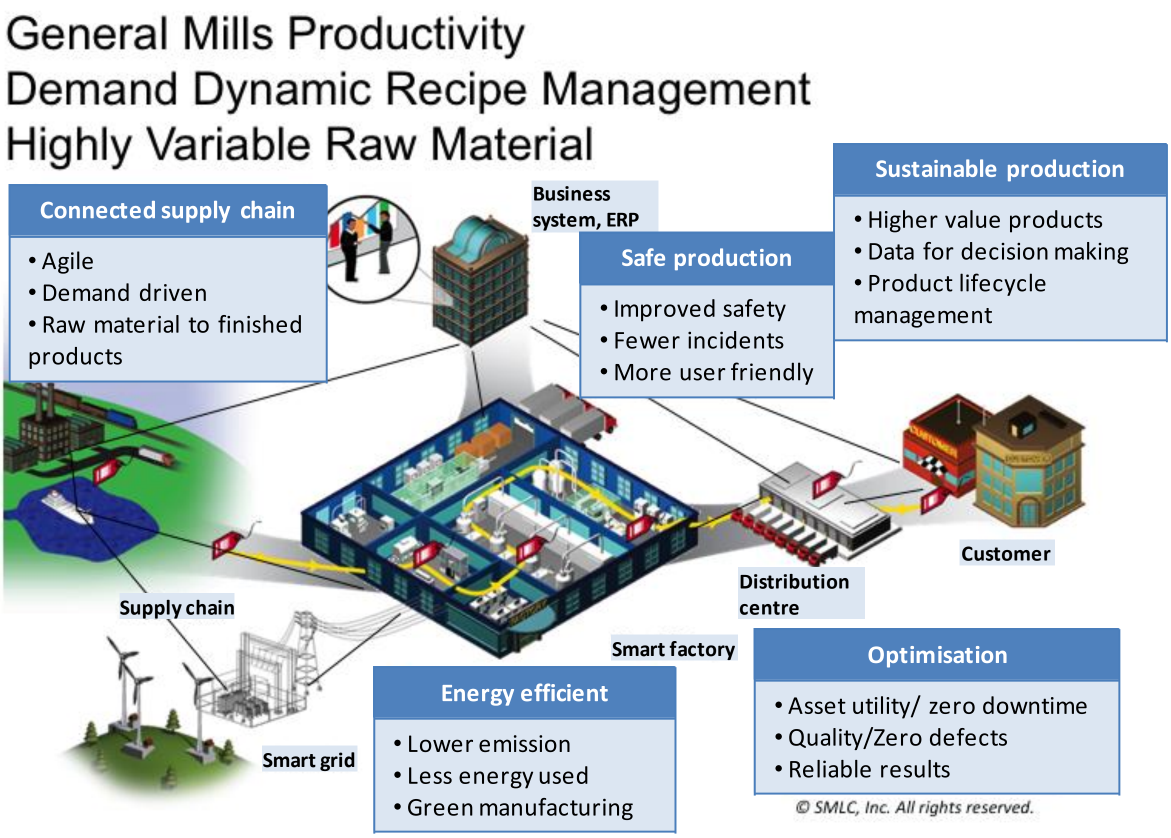
   Example: Oat properties and composition content for manufacturing breakfast cereal.

   Cereal manufacturing depends on an oat supply chain that needs to ensure growing conditions (GMO-free), safety (contamination free), properties (oat quality) and composition (oat and moisture). Increasing the visibility of the feed product specification from the many suppliers opens the door to focus on oat composition relative to product demands, dynamic recipe management and managing energy consumption as a result of transporting, mixing, storing and dealing with the properties and the moisture content of the product (see diagram below).

Checklist questions to find savings

- Are there key product parameters in the raw materials supplied to your plant that particularly impact on energy use? Examples might be product moisture content, size specifications and temperature.
- Would there be value to you if you could see those variables in real time for these materials before they were delivered?
- Are there changes in the material specification supplied that could improve your energy productivity (and potentially save cost for the supplier)?

These same questions can be applied within a plant between different lines/departments where there have traditionally been information boundaries.



2. Improve plant energy flexibility

Industry 4.0 plants are flexible and responsive to customer demands. This flexibility will not necessarily result in energy benefits unless efforts are made to measure and understand the relationship between throughput and energy use.

Much energy using plant and systems are inflexible in their use of energy due to high energy losses even at low throughput, so their turndown efficiency is very poor.

For example, boilers/steam systems and compressed air systems often have very high standing energy losses. Pumping and fan systems also have poor efficiency at turndown if they are controlled with throttling valves/dampers, but variable speed drives are rapidly being adopted to control these systems.

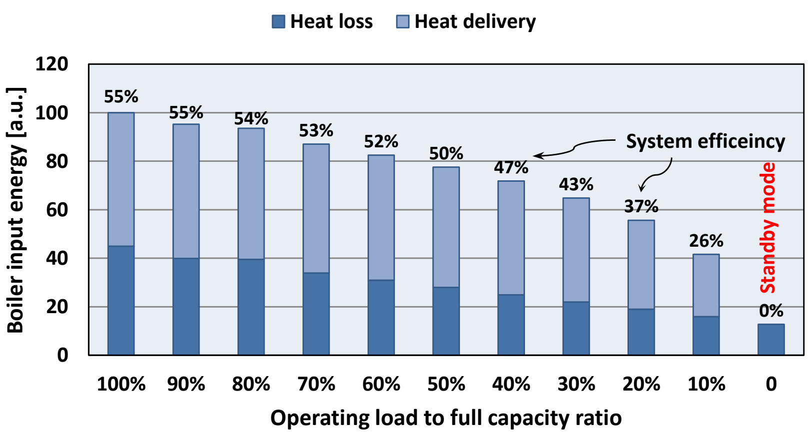
It is possible to determine standing losses by measuring energy consumption at different throughputs and plotting the data. When the energy consumption does not vary much with throughput, standing losses are high (see figure below).

This inflexibility issue can be addressed partially through improved monitoring and controls facilitated by Industry 4.0, but in some cases will need investment in new digitally controlled technology to provide really flexible energy consumption and cost.

Checklist questions to find savings

- Do you have compressed air or steam systems that are significant energy users?
- Can you turn off the supply of compressed air, steam and electricity to process plant when not needed (ideally at the source)?
- Do you have pumping systems controlled by valves, or blowing systems controlled by dampers?
- Does your steam system supply mainly hot water needs?
- Do you have variable speed drives on all lead compressors for refrigeration and compressed air?

The efficiency and heat loss of a steam system for different operating conditions, the horizontal axis is the actual load to full capacity ratio (part load ratio). The standby mode is when there is no heat delivery. We see that there is still heat consumption due to losses.



Example: Replacing central boiler and steam systems with localised heat pumps

Central boiler and reticulated steam systems typically have high energy losses at reduced throughput. Where the steam is mainly used for generating hot water, they may be replaced with industrial heat pumps that can supply heat to specific processes and thus have low standing losses and have very high inherent energy productivity (as they can deliver up to 5+ units of heat for every unit of power they consume).

See detailed coverage of this topic here.

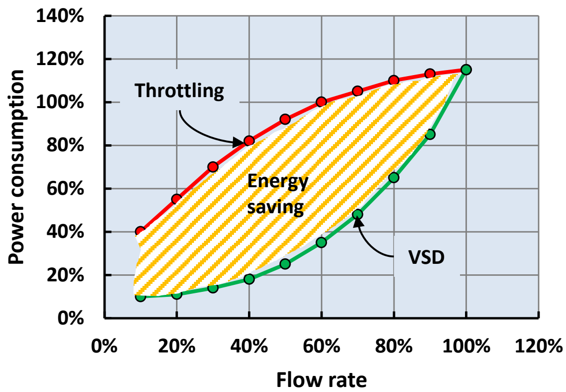
Industrial heat pump

Example: Pumping system with variable speed drive

As can be seen from the graph to the right comparing a pumping system with a throttling (valve) system to an equivalent pumping system with a variable speed drive (VSD) add-on, the system with a VSD is considerably more energy efficient at part load.

For example, at a flow rate of 40% of full load, the energy consumption of the pumping system fitted with a valve is 80% of the energy consumption at full load (100% flow rate). In comparison, at a 40% flow rate, the energy consumption of the pumping system fitted with a VSD is 20% of energy consumption at full load. Note these are indicative and may vary depending on other factors.

Pumping at part load: valve (throttling) versus VSD



Electronically controlled variable speed pumps

Image: www.au.grundfos.com/products/find-product/alpha2.html

3. Optimise energy intensive processes and systems

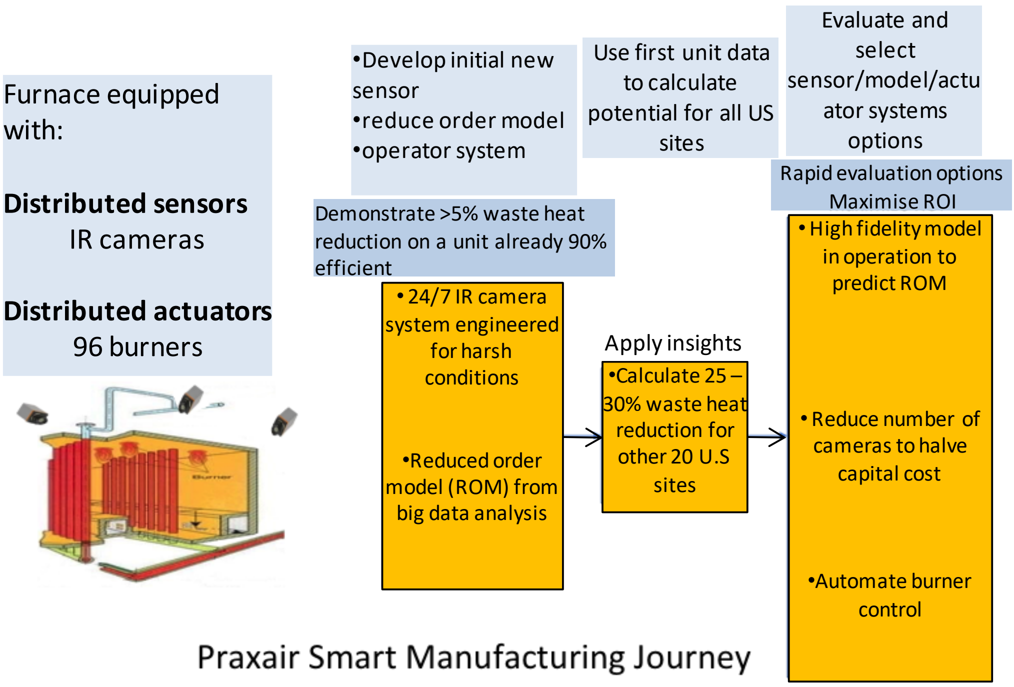
One of the key energy benefits from Industry 4.0 is the potential to optimise existing (and new) energy systems like refrigeration, and core process plant, using enhanced real time monitoring of key variables, and use of artificial intelligence to learn which operational modes deliver the lowest energy outcomes under a range of typical operating conditions.

This includes use of automated visual recognition to identify in real time if a product is being correctly manufactured and making adjustments to keep the product in specification, BEFORE it results in multiple rejects.

Example: Process optimisation at a gas-stream reforming plant[35]

Praxair is a large industrial gas supplier in North America. The company has similar furnace-based manufacturing plants across the U.S. operating with some variation in efficiencies. The Texas branch deployed advanced image sensors for the real time measurement of temperature variations throughout the geometry of the large-scale furnace, variations that relate to optimal product output.

A very large amount of real-time temperature distribution data over time were used to build and optimise a virtual physical model for how temperature, and in particular temperature distribution, relates to the 96 burners. The results of the demonstration were used to project a >25% reduction in waste energy across multiple US sites and the learning resulted in evaluating enhanced approaches.



[35] Final Report, Industrial Scale Demonstration of Smart Manufacturing Achieving Transformational Energy Productivity Gains. Award Number: DE-EE0005763 Project Period: 9/01/2013 – 11/30/2017, PI Thomas Edgar, University of Texas Austin, February 2018.

Example: Intelligent refrigeration monitoring system

The 'Metis' monitoring system involves the installation of a range of sensors on refrigeration systems to track indicators including temperature, pressure, and humidity at various points, and current draw of motors and heaters.

The system is cloud based so data is remotely available 24/7. Each site wirelessly connects to the cloud where data is logged for unit history and trend analysis. Data collected faciliatates remote and auto diagnostics in real-time, enabling preventive maintenance and predictive failure detection.

The monitoring system uses artificial intelligence to learn the operation of a refrigeration system. It recognises and creates an alarm if a fault is identified, including for complex faults such as compressor short-cycling, liquid flood back, excessive suction superheat, blocked condensers and refrigerant loss or overcharge.

Selecting technologies enabled by Industry 4.0

When there is a major investment/refurbishment occurring in your plant, consider alternative processes that have higher energy productivity and are better suited to maximise benefits using Industry 4.0.

Examples include:

- Improved digital processes with lower energy footprints, such as 3D printing (additive manufacturing).
- Modular technologies suited to micro-factories, potentially integrated with upstream activities (e.g. on-farm dewatering) or downstream activities (e.g. micro-breweries).

Intelligent refrigeration monitoring

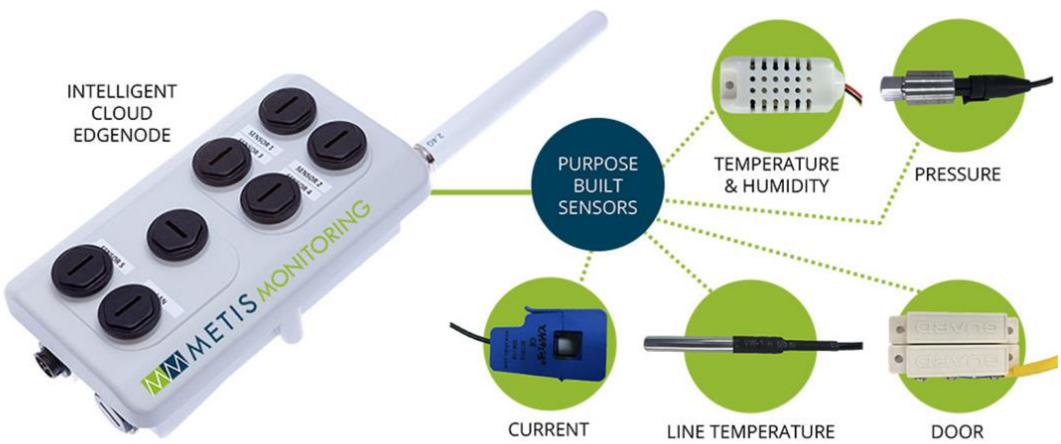


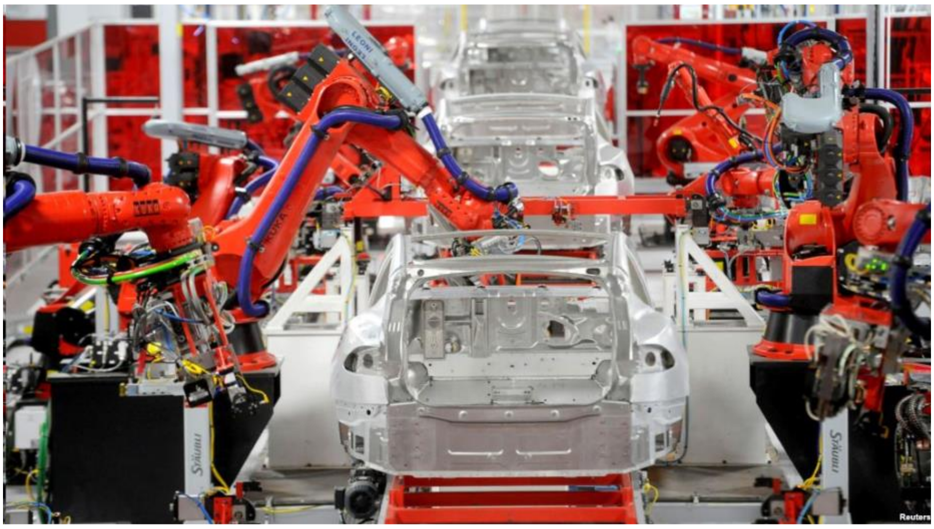
Image: http://metismonitoring.com.au

Automation to remove lighting/air conditioning

The uptake of automated systems and robots reduces the need for human presence in industrial buildings and warehouses, facilitating lower energy consumption to maintain lighting, comfort conditions and air quality.

This energy saving can be significant because maintaining comfort conditions in industrial buildings tends to use more energy than expected because in most manufacturing buildings, infiltration is significant, high ceilings make heating systems less effective, significant ventilation is required in some manufacturing plants to maintain the air quality, and these building tend to have a large footprint.

Comparison of human operated and fully automated production plants



4. Improve the energy productivity of specific equipment

The key issues to consider are:

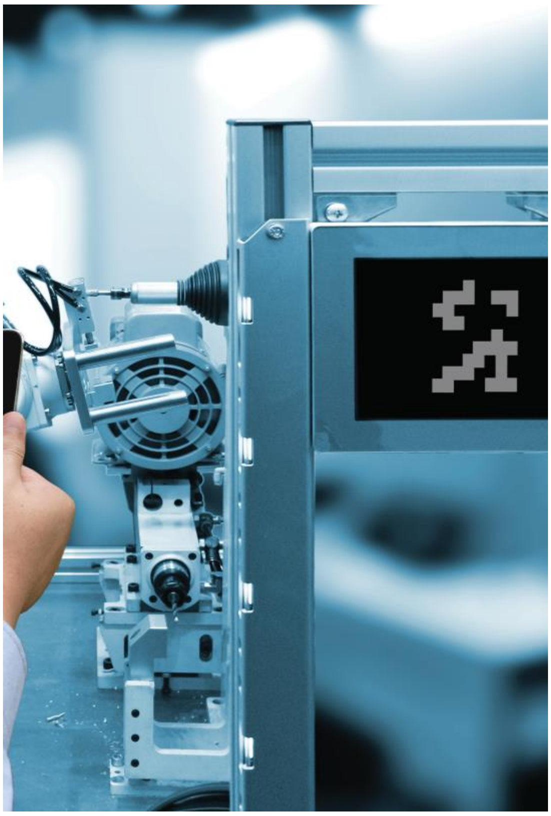
1. Select energy using equipment like motors and compressors to facilitate Industry 4.0 to deliver energy performance benefits.

- Size equipment so that it will normally be controlled to operate between 75 and 90% of rated load. Motors, for example, generally operate at peak efficiency in this range, but efficiency falls away markedly below 50%.
- All equipment should be Industry 4.0 compatible – digitally controlled, well instrumented – including energy metering, with suitable communication interface, with energy efficient turndown and automatic switching when not required.
- Replace motors when damaged with new Industry 4.0 compatible, high efficiency equipment, and do not rewind.

2. Use condition monitoring to ensure ongoing efficient operation of equipment, particularly rotating plant and equipment.

Checklist questions to find savings

- Have you checked to see whether larger motors are running lightly loaded and could be replaced with new smaller, more energy efficient models?
- Do you always replace motors or do you rewind them?
- When you buy new equipment, is it specified to be Industry 4.0 enabled and include energy metering?
- Do you use real-time condition monitoring on rotating equipment to ensure energy efficient operations and reduce downtime?



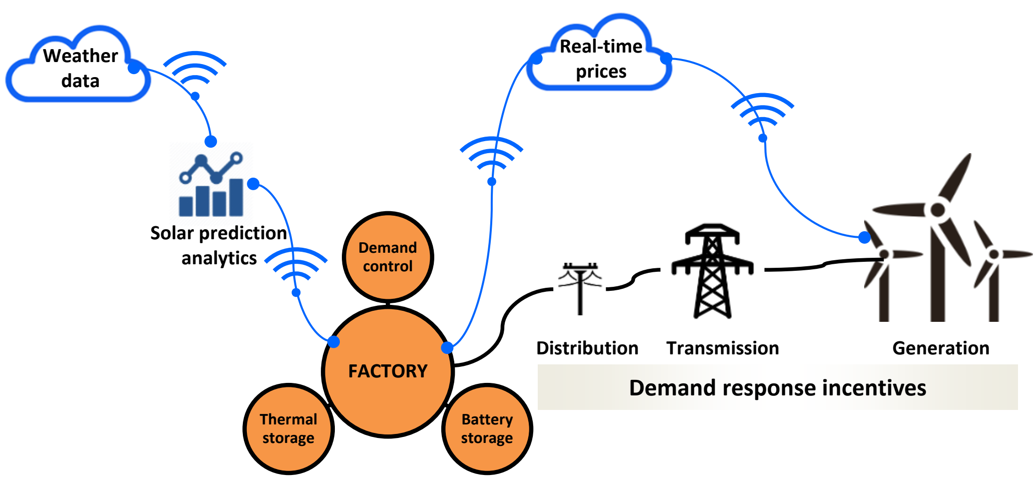
Optimisation of the energy supply chain

The following are opportunities to use Industry 4.0 technologies to reduce your average electricity cost.

- Optimise benefits from your solar PV installation and/or renewable power purchasing agreement (PPA). Industry is installing PV as prices continue to plummet, but often on-site generation of power is not optimised by using demand control to reduce peaks. Companies are also now starting to buy renewable power using corporate PPAs, but again, because this provides cheap supply only when generating, demand control has an important role to maximise the use and value of this resource.
- Demand control: The main action most companies can take now to reduce energy costs is to control peak demand in response to network tariffs, through monitoring your load profile and either shedding discretionary loads or using energy storage to reduce load peaks. (The energy storage used could be batteries, but these are often too expensive to be economic at present, and thermal or material storage could be more attractive.)
- Demand response: There are trials being conducted of demand response incentives that reward sites for reducing their energy usage significantly for relatively short periods when the supply system is short of power to meet demand. This can be an attractive option for sites with controllable loads or energy storage. While most companies believe it is not possible to control site loads in this way, with expert advice it can often be shown to be possible and economically attractive using Industry 4.0 enabled automated control.

In the future it is likely that businesses will be able to optimise their electricity costs by controlling electrical loads and storage automatically in response to price signals from the supply network and availability of on-site power generation using Industry 4.0 technologies.

Optimisation of the energy supply chain – lower costs for the network and consumers



Energy metering – if you can't measure it, you can't manage it: Control of energy use in Industry 4.0

Companies piloting Industry 4.0 in their operations are starting to consider how energy should be integrated into these trials because energy is now so expensive. The first question you should ask yourself when considering this challenge is:

- Do we have adequate energy metering?

  and then,

- Can we relate the consumption of energy (in core processes as well as ancillary energy using plant like air compressors) to the key operating variables which impact throughput and quality?

If the answer to these questions is 'no', then it is important to develop an energy information plan.

Suggested steps to doing this follow:

- Develop a plan to work out where you think out how you might use the additional information, and who will use it, in what format. Engage with users to identify useful information and suitable format, timing, etc.
- Define the key energy uses which have the greatest impact on throughput and quality and meter those.
- Also meter the largest energy consuming equipment if not covered in the previous step – typically 10-20% of energy using equipment will use 80-90% of the energy.

Some challenges you will face are:

- Accessing boards for electricity metering when the plant is running
- Real-time measurement of gas and steam energy use is expensive and requires plant shutdowns to install.

There are developments using Industry 4.0 technologies which show promise for resolving these challenges in future, including the use of artificial intelligence (AI) to recognise digital signatures of particular equipment and using this to provide submetering from measurements at the main board, and using 'digital twin' computer modelling. For example, it is envisaged that the vibrational or acoustic behaviour of moving devices such as fluids, motors etc. can be detected by low cost sensors and correlated to the energy consumption using AI algorithms.

Predictive/modelling tools in Industry 4.0

Conventional enterprises of the Industry 3.0 era have evolved and gradually optimised over years/decades to run efficiently and cost effectively for specific production schedules. In these plants, introducing operation variations for further optimisation or producing new products normally requires lengthy and costly reorganisation, restructuring, and redesigning of the production lines or even the whole enterprise.

Intelligent Industry 4.0 factories are and should be capable of continuously optimising and varying their manufacturing lines. This can't be fully realised unless the factory's responses, including its energy flow, to variations are predictable and measurable. To do so, two important tools are required:

- A digital twin model (DTM) of the manufacturing line that predicts the energy flow and productivity of the processes in different modes of operation, and
- A network of sensors and monitoring devices distributed across the plant to connect the digital model to the live data from the shop level.

A DTM is a virtual representation i.e. computer simulation of the mathematical model of a physical system such as a manufacturing line. A building energy management system is a simple version of such a system. A DTM uses real-time data from sensors and external sources such as suppliers to provide continuous productivity performance statistics. Anyone looking at the DTM data can see how the physical system is functioning in the real world.

The DTM can be extremely helpful to quickly predict the consequences of complex instructions and variations before physically implementing them at the shop floor level. This can include the:

- Energy performance of varying the production schedule
- Economic benefits of adopting new technologies and equipment such as renewables, heat pumps, etc.
- Monitoring and verifying the performance of the existing and newly adopted equipment and technologies, and
- Remotely monitoring and modifying the way the manufacturing line is operating.

Bottom line energy benefits from Industry 4.0

Energy prices have escalated rapidly in Australia in the last decade and most companies have not gained real control of their energy costs, let alone reinvested in plant and systems to make step change improvements in their performance. A focus on energy when implementing an Industry 4.0 program can deliver energy savings of 20%+ and, more importantly, often overall plant productivity can be substantially improved in energy intensive processes and equipment by focusing on energy related solutions. The International Energy Agency (IEA) found that energy projects on average generate 2.5 times the energy savings through other productivity benefits – our experience is that the multiplier is generally much higher.

The following table shows benefits from real projects in the US reported by CESMII[36]. Initial energy reachability equals potential economic/energy productivity increase that is immediately foreseeable. Critically, CESMII's experience shows that these savings are generally increased by learning over time, and then multiplied by replication at other similar facilities.

Initial Energy Improvement Reachability	Operational Focus for Initial Energy Reachability	Real Time (RT) Advanced Sensing Control & Modeling for Initial Energy Reachability
Paper 15-25%	Evaporation; drying; unit & line operation integration	RT process sensing; control; predictive modeling; enterprise optimize
Steel 20 – 25%	Hot rolling; continuous casting; unit & line operation integration	RT property sensing; control; RT analytics; RT high fidelity modeling; enterprise optimize
Metals 20 – 30%	Forging; heat treatment; casting; tooling; unit & line operation integration	RT property measurement, control; machine modeling; high fidelity analytics
Glass 5 – 15%	Melting; heating; precision operations; finishing; supply chain; unit & line operation integration	RT process/property sensing; analytics; model validation; prediction; enterprise optimize
Food 15 – 20%	Heating; drying; demand response; dynamic recipe; unit, line supply chain operation integration; custody chain	RT sensing; prediction and diagnostics; dynamic supply chain enterprise optimize
Micro Electronics 20 – 30%	Precision operations; tooling; line operation integration; tool & machine supply chain	RT multi-tool data aggregation; diagnostics and predictive modeling
Oil & Gas, Chemical 5 – 10%	Heating; compression; cooling; unit constraints; reduce off spec unit & line operation integration	RT sensing; high fidelity modeling; control; diagnostics; predictive modeling
Coatings 20 -25%	Precision operations; material management; unit & line operation integration	Image processing; analytics; high fidelity modeling; control; optimization
Plastics & Composites 20% - 25%	Heating; compression; cooling; tooling; coatings; reduce off spec unit & line operation integration	RT properties; control; diagnostics; predictive modeling; enterprise optimize
Manufacture/ Utility 15-20%	Heating; grid load mgmt.; demand response, renewables; distributed generation	RT energy measurement; ecosystem energy management
Aerospace Parts	3D printing; precision parts; tooling; energy dependent parts; line operations; supply chain;	RT supply chain data; advanced sensing; imaging; chain of custody; tooling
		© SMLC, Inc. All rights reserved

[36] www.cesmii.org

Implementation Planning

This section contains a how-to guide for businesses starting their Industry 4.0 journey and provides an incremental approach for adoption of Industry 4.0 technologies for energy productivity, as a first stage in the transformation from conventional manufacturing to adaptive, intelligent and connected manufacturing.

Starting the journey

This is where a business manager hits lots of jargon, grand visions and promises. The Internet of Things (IoT), the cloud, data analytics, artificial intelligence, Industry 4.0, Smart Manufacturing and energy productivity are just some of them (see the Glossary of Terms at the end of this document).

There is plenty of reason to be confused and sceptical. But this won't protect a business from the wave of disruptive change flowing through our economy. Just as the smart phone and internet have changed our daily lives, modern technologies and services are transforming manufacturing.

Manufacturing activity is spreading beyond its traditional industries, while services are replacing or supplementing physical production. The hot bread shop and micro-brewery are really micro-factories integrated with retail outlets that compete with large scale producers. Downloading music has replaced manufacture of physical media and the equipment needed to play them. A design business may use a 3D printer instead of a low volume component manufacturer.

Step 1: Choose a task or process to start

You are embarking on an exciting and challenging journey. But it will take planning, time, effort and resources. And you will learn from experience, making mistakes and gaining surprising (and often profitable) outcomes.

Every journey starts with a first step and an achievable goal. So, focus on an aspect of your business where you (or your managers or technical staff) see potential for improvement, or where change is necessary. Don't tackle something first that is 'mission-critical' to your business viability.

A process that involves significant energy consumption or costs, where equipment may need to be replaced, upgraded or expanded is a good place to start. For example, as discussed earlier, equipment with high energy losses which may be reduced using digitally controlled technology to provide flexible energy consumption.

Step 2: Ask some questions

Look around to identify:

- Who in this sector or other sectors has already made changes that I can learn from?
- Which suppliers, consultants, researchers, industry associations and/or contractors are familiar with emerging smart solutions – recognising that they will all have their own agendas and preconceptions! But learn what you can from them – or encourage your relevant staff to engage.

Ask your staff questions such as, what information, if provided when you need it, would allow you to:

- operate your equipment better?
- identify emerging problems with equipment sooner?
- when and in what form would you need this information?

Ask yourself what information, with what timing and in what form, could help you to manage and plan better. Where or how could this information be sourced.

Ask what changes to equipment, practices or other factors would be needed. For example, you may need to fit variable speed drives and equipment to monitor key parameters to a machine or equipment, so it can adjust to changes in inputs.

Check for disruptive possibilities. Could something emerge that could change the situation so this change is affected by other factors from other innovative paths?

And explore the kinds of energy productivity benefits your business might gain if the benefits that have been flagged through your explorations can be captured. Make some rough estimates of the value of these benefits to your business. This will help you to decide on the initial scale of resources to allocate.

This process could open your eyes to many possibilities. But you will need to pursue some more thorough processes and allocate resources for them.

Step 3a: Serious analysis – what services are provided?

It is important to understand the fundamental services that are being provided. These include the services to end-use consumers as well as within the process and business. For example, a narrow interpretation, such as ‘This provides steam to drive xx process’ does not explore the fundamentals. What is the outcome of the process the steam supplies, and what temperature and how much heat does it really need?

Within the organisation, steam may be used to provide heat that is not needed if heat is recovered. Or processes that do not even need heat, such as high pressure processing, centrifuging, etc. A process may not require such a high temperature.

Step 3b: Understand the systems

This step is best integrated with assessment of the services being provided. Services are provided by systems, which are often complex.

Analysing energy and material balances often identifies waste of energy, resources, money and time.

It may also reframe opportunities. For example, analysis of a steam system can identify large energy losses and significant unrecognised costs. Incremental improvements can be made to cut these losses. Analysis may also lead to recognition that one process is at the end of a long leg of steam pipe, so savings or changes in the heat source may allow that section of steam pipe to be shut down. Also, once energy waste is reduced, alternative solutions that previously looked impracticable may become attractive. For example, targeted infra-red electric heating may economically replace wasteful use of gas, even though each unit of energy is much more expensive.

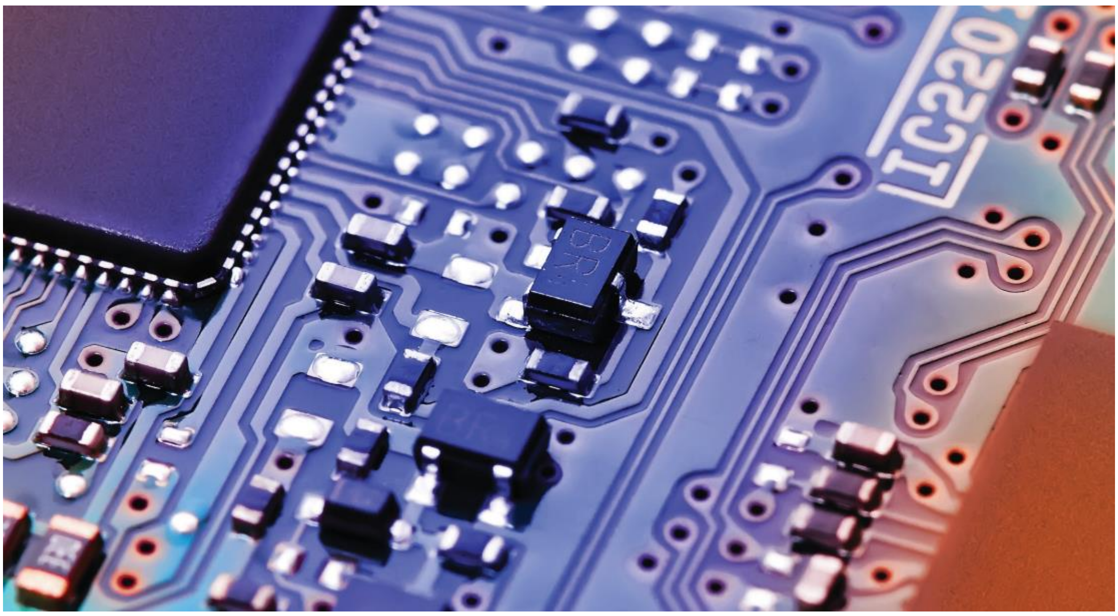
Step 4: implement smart options you are confident will bring benefits while building your experience, networks and capabilities

Transformation is not 'all or nothing'. But you need to start. By now, you should have defined some clear opportunities. These may apply technologies or practices well-proven by others, and that your in-house or contract technical staff can supply, install and maintain. You may add new technology initially as a back-up or supplement, then transition to greater use over time, while keeping the previous equipment as a back-up. Make sure you incorporate adequate monitoring and benchmarking capability so that you can evaluate the benefits and understand the causes of any teething problems or shortfalls in performance below expectations.

Riding the bus to adaptive, intelligent manufacturing

Apply the experience you have gained to other areas in your business. Build relationships with suppliers who can support your transformation. Consider larger, longer term investments and develop strategies and plans as you gain confidence.

At the same time, you will see increasing potential to capture more benefits, such as integrating behind-the-meter renewable energy, energy storage and energy management, and considering energy trading and cost optimisation through peer-to-peer trading, demand response and further energy efficiency improvement.



Glossary of terms

The following is a summary of terms used in this report. Further detail on each of these terms can be found in the Transforming Energy Productivity in Manufacturing report.

Internet of Things (IoT)

The Internet of Things (IoT) refers to a range of networked data collection and communication devices, hardware and software that can be deployed across plants, systems, subsystems, and equipment to monitor certain physical variables. IoT technology includes advanced sensors with a capability to upload digital information onto a database via a data communication network/protocol. Sensors are becoming smaller, cheaper, battery/solar powered and capable of monitoring multiple variables

The connectivity of the sensor can be realised with the help of different technologies. Some of these technologies allow for connecting hundreds of sensors to a single communication gateway.

Cloud computing

The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer

Cloud platforms can enable:

- access to powerful data computation, storage, transfer capability without the need for setting up an independent high-end IT system, and
- create a platform that is accessible by all the stakeholders of a complex supply/manufacturing chain.

Artificial Intelligence (AI)

AI is a computer system able to perform tasks in human interpretable forms that normally require human intelligence, such as visual perception, qualitative analysis, feature interpretation, speech recognition, decision-making, and translation between languages

Machine learning (ML)

ML is a subset of AI. Machine learning can be distinguished from expert systems in that data are used to learn interpretable tasks, behaviours or actions. ML systems learn patterns of behaviours and have the ability to modify themselves when exposed to more data, i.e. when structured appropriately, machine learning can learn and adjust to new behaviours reflected in the data without human intervention. Learning algorithms are optimisation algorithms; they learn from the data they are exposed to by minimising the error between what is learned and what is observed

Data analytics

Data analytics is the process of examining data in order to draw conclusions about the information contained in the data. Technological advancement is allowing faster analysis of larger data sets.

Sensors

Data in smart enterprises originate from sensors. Sensor technology is continuously improving with the costs declining. (See Internet of Things)

Smart Manufacturing

A term used primarily in the US. The goal of Smart Manufacturing is to enable all information about the manufacturing process to be available when and where it is needed across the entire manufacturing supply chain and is broadly consistent with Industry 4.0.

Energy productivity

Energy productivity (EP) refers to the value created from using a unit of energy.

Appendix B: Guide for business: Process heating innovation to boost energy productivity

Why address process heating?

Steam was a valuable medium for heating in the past, providing excellent heat transfer and energy density. But central steam systems are a poor match for the requirements of the Industry 4.0 world – which requires digital control, accurate measurement, and great flexibility.

This guide aims to assist businesses to replace central boilers and steam reticulation systems with distributed (point of end use) alternatives to steam heating, which are more responsive to changes in plant conditions and can be readily digitalised for integration with Industry 4.0.

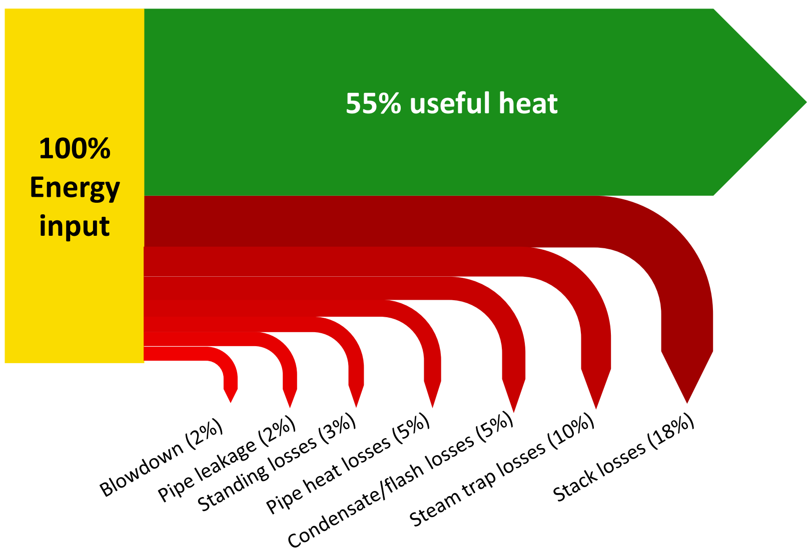
By doing this it is possible to substantially improve energy productivity - not just through energy savings, but also increased value through better reliability/less downtime, improved working conditions, reduced maintenance costs and reduced water use.

Food, beverage, textile and other facilities use steam in a range of processes from boilers fuelled by natural gas (or other fossil fuel), with steam circulation and condensate return.

Often the end process heating requirement is at a much lower temperature than the steam is supplied at. And often the actual process requirement is for heating to a temperature well below 100°C.

Central steam systems are much less efficient than what most operators believe. The large scale of losses is generally hidden by the lack of measurement – steam flows are expensive to measure and often inaccurate. The diagram below shows the sources of losses in a typical system running at full load, **excluding** the large standing losses of a standby boiler. At part-load operating conditions, the efficiency rapidly falls further due to the large fixed losses, resulting in less than 35% of the energy in the gas burned delivering useful heat to the process.

Central steam systems waste a lot of energy even operating at full load



Process heating applications

If we want to consider alternatives to steam systems, we need to understand the purpose of providing heat to each process where it is used. Steam heating is typically used in:

- Food processing for removing water (concentrating, crystallising, drying), preserving, cooking, and cleaning.
- Other industries for forming, melting, or to promote chemical reactions.

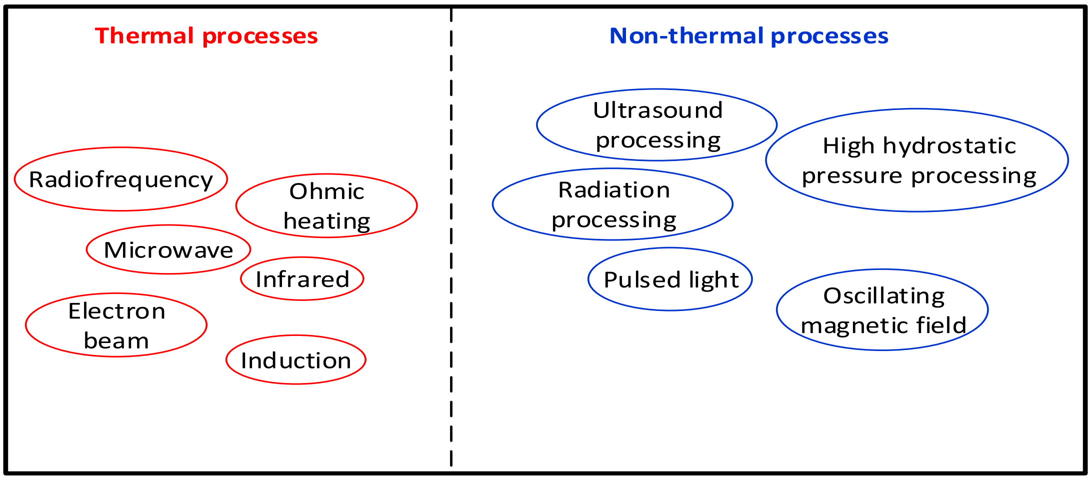
This guide is primarily focused on process heating in food/beverage processing.

[37]The food and beverage sector consumed 14.5% of total energy consumed by manufacturing in 2015-16 and generated 33% of the total value. Note that food and beverage processing activities extend well outside the manufacturing sector as measured by Australian Bureau of Statistics.

Both thermal and non-thermal alternatives to steam heating may be used to achieve the ultimate outcomes that are desired on food processing sites:

1. **Dewatering** - the most energy efficient way to remove water is natural/forced evaporation, followed by mechanical dewatering, and the least efficient is boiling off water.
2. **Preserving** – thermal preservation requires heating to over 70°C and up to 100°C to kill pathogens in food. Preservation can also be achieved by using non-thermal processes to kill bacteria. Non-thermal processes tend to be more energy efficient and may result in a better-quality product because thermal processing may alter the product characteristics.
3. **Cooking** generally needs to raise the food to 100°C+ and often involves some level of dewatering.
4. **Cleaning process plant** – requires heating to over 70°C and up to 90°C to kill pathogens.

Alternatives to boiler systems: Thermal and non-thermal processes



[37]https://www.energy.gov.au/sites/g/files/net3411/f/energy-update-report-2017.pdf

Alternatives to boiler systems

The diagram on the previous page shows there are many electric technologies that can replace fossil fuel-based steam systems. These are point of end use technology applications, which are matched with a specific process need, and thus may only operate when that process is operating. The choice of technologies to best address a process need requires careful examination of each specific process.

In this guide, we are not able to address all electricity technologies and applications, but instead focus on the most generally applicable options:

1. **Mechanical dewatering technologies to reduce the drying task**
2. **Electro-technologies to replace thermal processing for preserving**
3. **High energy productivity electro-technologies for heating/cooking**
4. **Heat pump technology - waste heat recovery and co-producing heat and cold**

Once high productivity electricity technology options for displacing steam heating that are cost effective are applied, if there are still some applications that need steam then consider:

5. **High efficiency localised packaged boilers.**

1. Mechanical dewatering to reduce drying

Evaporating water uses large amounts of energy. Evaporating one litre (1 kg) of water requires about 2.3 MJ (0.64 kWh) of thermal energy. In practice, taking into account dryer efficiency, much more energy may be consumed.

Removing water using free ambient energy or mechanical methods can be far more energy efficient. Options may include ambient forced evaporation using an efficient fan system, microfiltration using membranes to separate water from product, centrifuging (high speed rotation), and crushing. Combinations of technologies can be used in series, and partial dewatering can be done before cooking.

Energy productivity improvements associated with these technologies may include:

- Reduced energy use
- Reduced capital costs of equipment
- Improved quality and consistency of product, e.g., improved extraction of juice from grapes increases wine production, while capturing more flavour
- Reduced quantities of material to be transported and processed, if dewatering can be conducted earlier in the value chain.

Note that a dewatering process could be used in tandem with a heat pump drier to achieve high energy productivity.

Example: Concentrating milk using reverse osmosis

Normally milk is transported with its full water content and dewatered thermally at the processing plant using spray dryers. An alternative, membrane dewatering, is far more energy efficient than thermal drying.

Reverse osmosis technology is suitable for on-farm use where a large farm is a substantial distance from the processing plant (noting care must be taken to maintain low bacterial levels in this additional process step), for inter-factory transfers of milk and milk products, and for sales of bulk milk products interstate and internationally.

It has been demonstrated that milk can be concentrated to 50% of the original volume without adversely affecting the quality of the milk.

This process can be used at the milk processing plant before the driers, but then loses the transport energy saving benefit.

Reverse osmosis at Yanakie Dairy Farm, Vic

Image: https://www.clearwater.asn.au/

2. Electro-technologies for preserving food

Pasteurisation is common in industrial processing to kill bacteria, by heating to a temperature of 65-75°C for a specified period: the higher the temperature, the shorter the period required, but the greater risk of changing flavours or textures.

Alternative options replace heat with other mechanisms to kill pathogens

These technologies reduce or avoid the need for heat. Fuel consumption is thus displaced with electricity, often at much higher energy productivity. The net impact on energy cost and loads on energy infrastructure needs to be considered. Alternative processes may offer value-adding benefits, such as extended shelf life or maintenance of more attractive texture or taste.

Technologies that avoid traditional thermal heating are emerging, though some have been available for many years. They include:

- High pressure processing
- Microwave
- Ultrasonic
- Irradiation (electron beams, X-rays),
- Ultraviolet light (especially suitable for sterilising containers).

In some cases, it is possible to maintain sterile production conditions so that pasteurising is not needed when the product is to be consumed fairly soon, and the cold chain can be well managed, or advanced packaging is used.

Example: High pressure processing (HPP)

HPP uses very high pressures in the range of 300-600 MPa instead of heat processing to kill yeasts, moulds and bacteria. It can be used across a range of product categories such as juices, meat, poultry, seafood, fruit and vegetable products, meal solutions, dips and sauces.

HPP technology has the potential to extend the shelf-life of cooled perishable products, e.g. juices produced using HPP can be stored up to five times longer than other chilled juices. HPP also provides improved safety, taste, texture, quality, fresh-like characteristics and nutritional value, without having to use chemical preservatives.

HPP for pasteurising fruit juice

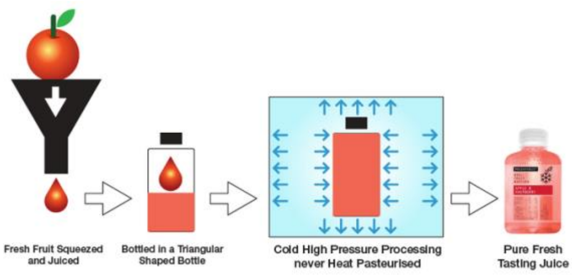


Image: http://www.preshafruit.com.au/process.html

3. Electro-technologies for heating and cooking

Convection-based heating using hot gas or a flame relies on conduction of heat through the bulk of the material. Electro-technology processes, such as microwave and radio frequency, can more accurately target and deliver energy to the point of use volumetrically.

In radio-frequency (RF) heating, material with polar molecules content is conveyed between two electrodes with alternating polarity. The alternating polarity makes the polar molecules, like water, re-orient continuously. The friction caused by this molecular movement rapidly heats up the material throughout.

RF heating can be employed in a large number of thermally driven processes:[38]

- Drying textiles, fabric and garments
- Drying hydrophilic foams
- Post baking drying and moisture control of food products
- Drying water-based coatings, ink, and adhesives
- Heat treating, de-infestation of bagged products
- Pasteurisation of food products.

Ultrasound processing uses interaction between materials and sound waves with high frequency not audible by the human ear. This technology can be used across a range of applications in industry including crystallisation, drying, degassing, extraction, filtration, homogenisation, meat tenderisation, oxidation, and sterilisation[39].

Example: Microwave radio-frequency

Microwave RF generates heat in snack food mainly in areas with more moisture content.

Image: www.radiofrequency.com

Example: Ultrasonic extraction

Ultrasonic extraction from herbs.

Image: www.hielscher.com

[38] http://www.radiofrequency.com

[39] http://www.dolcera.com

4. Heat pumps

Industrial heat pumps use a refrigeration cycle to very efficiently upgrade low temperature heat from the environment to useful, higher temperature levels.

Heat exchangers, which are cheaper than heat pumps, can be used when the waste heat stream is at a high enough temperature to be recovered for use at a lower, but still useful, process temperature. But where the temperature needs to be raised, heat pumps can be used.

The most economically attractive applications occur where heat pumps can be used to upgrade heat from waste streams (e.g. condenser heat from refrigeration systems) and/or capture latent heat (e.g. hot humid air from dryers), and where simultaneous heating and cooling duties can be delivered.

The efficiency of a heat pump is denoted by its 'coefficient of performance' (COP), e.g. a COP of 3 means three times as much heat energy is delivered as the amount of mechanical work input from the compressor. The COP is higher where the size of the temperature 'lift' is lower and when heat exchanger area or heat transfer efficiency is greater.

Example: Hot water for sterilisation and cleaning using heat pump

Lobethal Abattoir in South Australia installed a two-stage ammonia heat pump in 2012 as an alternative to heating water with a gas-fired boiler.

The heat pump utilises waste heat expelled by the condensers of the freezer plant, heating approximately 250,000L of water per day from 11°C to 75°C.

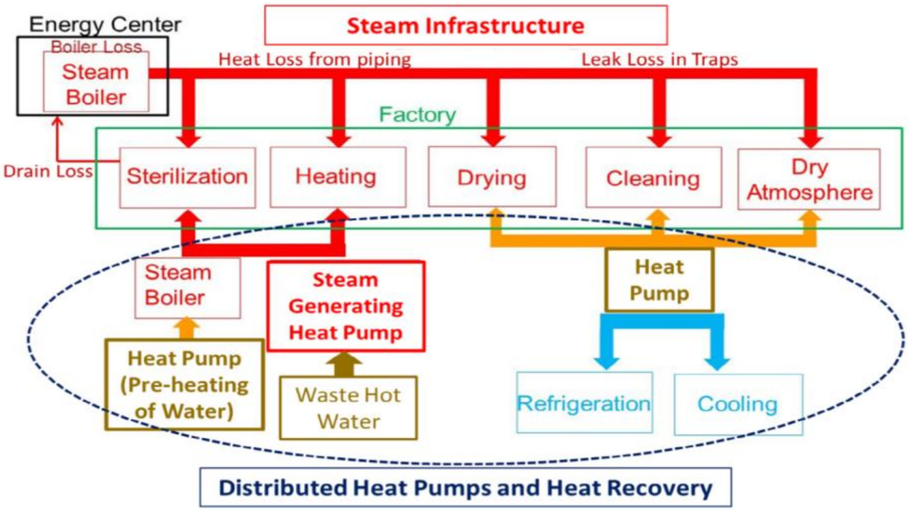
Hot water produced is delivered to a thermal storage tank and is used partly during the night for sterilisation and cleaning purposes and partly during the day for processing e.g. sterilising knives.

Image: www.ampc.com.au

Typical heat pump applications

Application type	Features	Typical Industries
Dryers	Capture sensible and latent heat from exhaust streams	Milk, pasta, noodles
Food washing	Capture sensible and latent heat (water vapour) from exhaust streams	Potatoes, vegetables, fruit
Water heating for process and cleaning	Capture waste heat from process or refrigeration (or air) compressors	All food
Pasteurisation	Can be heating and/or cooling role	Milk, juices
Combined process heating and cooling	Ideal applications use the condenser for heating and evaporator for cooling simultaneously	An example is bread - product cooling and proving

Replacing central steam system with a series of local heat pumps



5. High efficiency localised packaged boilers

Once we have identified ways to replace most of the process heating load with electric technologies, there may be some applications which still require steam, or it is too expensive to convert existing plant.

Small packaged steam/hot water boilers can be installed near the end point of use on the site to cater for these needs.

These boilers can lead to a higher energy productivity because they:

- can be independently shut down when the process is not operating
- have rapid start –up and fast response to transient conditions
- can be individually sized and selected according to a particular end use
- each one can independently operate at a specific temperature/load condition
- allow for higher reliability if packaged boilers are connected.

Note: The recently released report "Gas efficiency: A practical guide for Australian manufacturers" is a useful guide for sites to achieve gas savings by improving the efficiency of existing equipment. In this report we are focused on transformative change rather than incremental change.

Compact electric steam boiler

Image: www.cleaverbrooks.com

Integration of renewable energy to reduce electricity costs and emissions

Deployment of more energy productive, digitally-controlled electricity technologies provides additional opportunity for using renewable energy to reduce carbon emissions.

The renewable energy can be supplied from on-site PV or other options such as biomass, and/or a renewable power purchase agreement from an off-site generation plant.

Either way, by managing the timing of electricity usage, the application of renewables can be optimised to get the best benefit. This is done through making electricity efficiency improvements, focused on loads operating at peak price times, utilising energy storage (thermal storage such as chilled water tanks, material storage or batteries) and use of demand management controls.

Energy storage can be added to heat pumps (hot and chilled water depending on the application) to improve the ability to use the systems preferentially in low energy price periods/avoid peak demand charges.

The control of electricity use to optimise usage patterns based on increasingly cost reflective real-time electricity supply prices is enabled by digitalisation.

Increased use of renewable energy and demand management controls can have additional benefits for manufacturing sites including:

- Improved energy security
- Improved ability to participate in and receive revenue streams for demand response programs
- In some cases, reduce the need for power supply infrastructure upgrades
- Reputational benefits of improved corporate sustainability.

Implementation Planning

This guide suggests steps to replace central steam/hot water systems with energy productive electricity technology.

A. Technical feasibility assessment

1. Is there much to gain from moving to point of end use energy application?

There may be a good case if:

- the existing boiler is close to its end of life.
- hot water, not steam, is the main heating requirement.
- the site is moving to an Industry 4.0 model, where central steam systems will not suit flexible operating requirements.
- the boiler is oversized for duty, hence operating mostly at part load.
- the reticulation system is in need of major maintenance.
- significant waste heat is available, but at a temperature too low for heat exchange for process us (e.g. from refrigeration compressors)
- there are existing large cooling towers
- boiler fuel prices have increased relative to available electricity (including on-site generation or PPA).

If the answer to one or more of these questions is yes, go to step 2.

2. Define the actual requirements of process heating loads

Carry out research to find out the precise customer product specifications that drive the process heating demand.

- What are you specifically trying to achieve with the heating task, and what are all potential options to achieve that objective?
- Is heat definitely required? If so, what is the specific temperature versus time requirement, and the heat transfer characteristics of the product? Note that the temperature of the supply line (e.g. steam pipe) should not be relied on as a guide to process temperature needs.

3. Consider upgrading incrementally

Are there parts of the steam system that are remote from the rest of the reticulation system, or have different operating hours (e.g. operate on a weekend when other plant is off)? In these cases, there may a case to consider closing off one section of the steam system in incremental steps to replace steam. Note that this is generally not the most energy productive option, as the rest of the system losses remain, and it further reduces load on what might already be an underloaded main boiler. However, if it provides significant incremental benefits, it gets the process of boiler replacement started.

4. Technical feasibility analysis of displacing steam

Now, thermal requirements and energy flows across the plant need to be quantified.

4.1. Assess any non-thermal technology replacement options first.

This guide and the accompanying text provide options.

If economical, this will reduce the remaining heating requirement.

4.2. Conduct a plant heat balance.

The heat required by each process heating application needs to be quantified and checked against a balance between heat into and out of the system.

4.3. Are there sources of waste heat?

Identify types of rejected heat sources across the plant.

- At what temperatures and quantities are they available?
- Does the amount of heat vary with throughput, the product, season, etc?
- Does the timing of heat being available coincide with applications that can use it? If not, can it be stored?
- Is it located close to the potential sink?

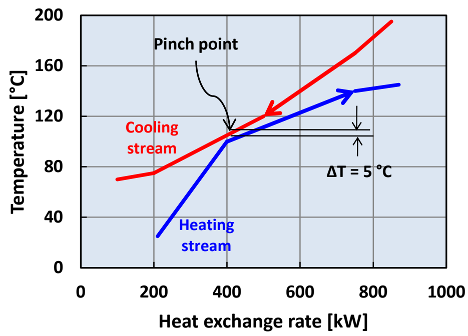
4.4. Can I simply meet key process heat demands with a heat pump or two?

If it is a relatively simple application without multiple heat sources and sinks, a heat pump might be the best option, and in that case, you might proceed straight to a technical and economic feasibility study of that project.

4.5. Do I need to conduct a pinch study?

Pinch analysis is used to systematically identify optimal heat inter-change opportunities within a plant that has many heat sources and sinks at different temperatures.

An exothermic process can transfer its rejected heat to an endothermic one (see the figure below). The point with minimum temperature difference between the two streams is called the pinch point.



Pinch analysis helps to:

- Identify the amount of reusable thermal energy in a complex plant
- Match the available and required thermal energy at exchange points
- Size and locate suitable heat exchangers for heat recovery
- Identify the necessity optimal positioning and size of heat pumps to upgrade low temperature heat sources for use in particular processes.

Pinch analysis is not necessary for plants with simple processes.

Further explanation can be found at http://www.industrialheatpumps.nl/en/applications/pinch_analysis/.

See also ‘Pinch Analysis and Process Integration’ by Ian C Kemp.

B. Economic feasibility analysis

Energy cost of heat pumps vs steam from boiler/steam system

The primary factors influencing the economics of heat pumps to replace boiler systems are:

- The **relative price of electricity and available fuels**
- The relative overall system efficiencies of heat delivery
- The **lift temperature** of the application (between the waste stream temperature and the process).

The relative electricity to gas price ratio has a significant impact on relative heat costs from heat pumps and boilers. This ratio is commonly between 1.5 and 4 around the world.

Typically, the price of electricity and gas in the east coast of Australia in 2017/18 is about 15-17.5 c/kWh ($42-49/GJ) and $10-12 /GJ respectively[40], which means the ratio is about 4. But the large difference between system efficiencies can change this ratio to under 0.7 – that is, the cost of heat supplied by the heat pump can be much cheaper than that of the gas boiler system.

The diagram below provides an indication of the relative cost of a heat pump and gas heating for different lift temperatures.

Example 1: An advanced heat pump can generate 65°C useful heat from 25°C waste heat, with a COP_{Heat} of 4. This means that by consuming 1 kWh of electricity, 4 kWh of heat will be delivered at 65°C. For this case, the cost of heat from the heat pump will be about $10/GJ. A boiler/steam system with 75% efficiency can deliver the same heat at $13-16/GJ. But if that boiler/steam system is only effectively 35% efficient, the delivered heat from the gas systems would be twice as expensive.

Example 2: Heat pumps deliver heat at the condenser side by cooling the evaporator side. This is how they can co-produce cooling and heating which is a significant advantage, particularly for the food industry.

The combined $COP_{Heat+Cool}$ of heat pumps can be much higher than their COP_{Heat} if the cold side (the evaporator) is also utilised.

Heat pump temperature lift vs cost of delivered heat

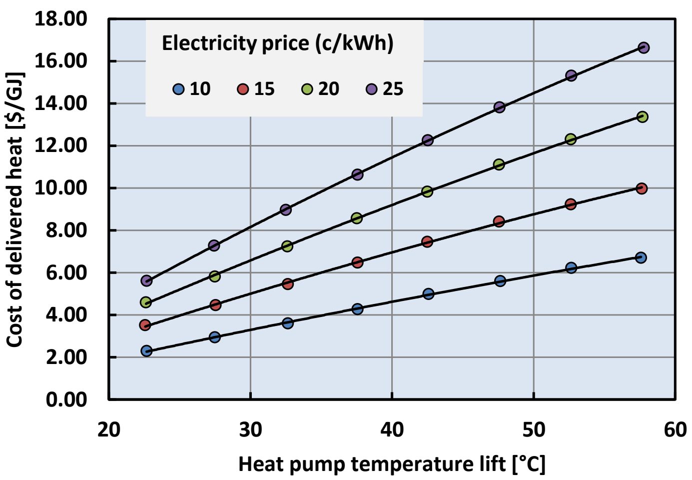


Chart basis:
At pump evaporator temperature = 55°C
Efficiency of heat pump cycle is 65% of thermodynamic maximum
Information intends to present trends and does not apply to all cases.

[40] A2EP, 2017. High temperature heat pumps for the Australian food industry: Opportunities assessment

An advanced CO_2 heat pump can lift a stream temperature from as low as 12°C to 90°C with a COP_{Heat} of 3. This heat pump can also deliver cold water at 7°C at the same time. When you include the production of chilled water the combined $COP_{Heat+Cool}$ = 5.1. This plant can generate 90°C hot water at a cost of about $14 - 16 /GJ which is on parity with heat from a 75% efficient gas fired boiler/steam system. PLUS, for every kW of heating power, 0.7 kW of cooling is also available.

The economic attractiveness of heat pumps is even greater when:

- boiler and steam system efficiency is lower, and this is generally the case.
- renewable PV electricity is available onsite. PV power is often coincident with plant operation hours. Heat pumps can convert PV power into hot and cold thermal energy, which may be stored in hot/cold water tanks to be used when PV is not available.
- the electricity to gas price ratio is lower e.g. when off-peak tariffs are applicable, and/or LPG at >$20/GJ is the only accessible fuel.
- the process has variable load with significant duration of part load operation. Heat pumps are less sensitive to part load conditions than boilers and can maintain ~80% of their peak COP for much of the operating range, whereas the efficiency of boiler systems can drop from 75% to 50% at 50% load. This means that the cost of delivered heat

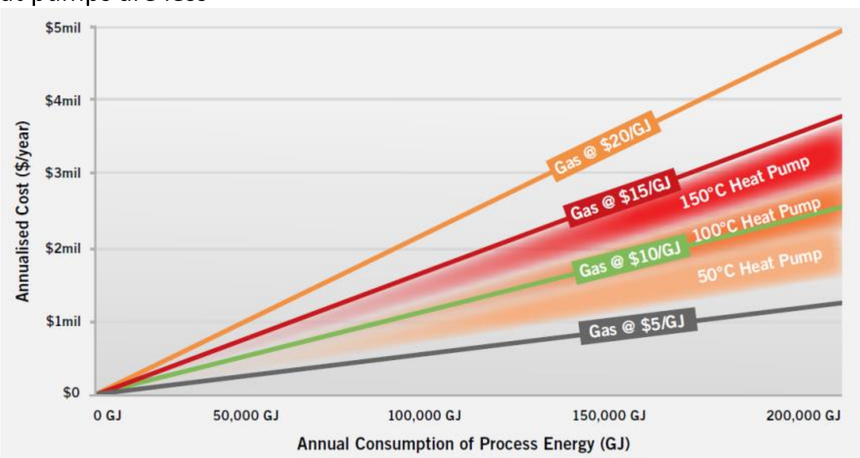
  increases from $16/GJ to $24/GJ whereas heat from a heat pump only increases from $10/GJ to $12/GJ.

A very common scenario: A plant has an average steam/hot water efficiency of 45% for producing cleaning hot water at 65°C. The plant uses LPG at $20 /GJ and has access to electricity at 15 c/kWh.

The cost of heat for this application will be $44/GJ from the boiler. This can be reduced to $10/GJ if a heat pump is adopted.

If this plant uses 5m^3 of cleaning water per day, the cost saving on fuel will be about $8,500 over 300 days of operation.

The capital cost of such industrial high temperature heat pumps is estimated to be about $1000 /kW of heat output installed. However, this can change with varying site and application specifications.



Comparing the annual cost of heat pump system with existing gas boiler *(annual cost includes the running and capital cost of heat pump system)*

Economic issues of boiler replacement with heat pumps and other electricity technologies

An economic assessment for a complete replacement of a boiler and steam system with alternative electricity technologies, requires analysis of all the costs and benefits from this transformative change in energy systems.

Some of the issues that should be considered include:

- The **capital and installation cost of the alternative technology** as a new project or retrofit:
  - (i) Timing of installation to match equipment retirement, plant expansion, development of new plants helps the economics.
  - (ii) The capital cost is impacted by the need for redundancy for plant reliability. One strategy to achieve at least partial redundancy without a cost penalty is to install multiple smaller standard units instead of one large piece of equipment.
  - (iii) The potential cost for upgrading the electricity connection or substation for large consumers may need to be included in the financial estimation to account for increased electric load, although addition of energy storage and/or smart management systems could limit peak demand within limits of existing supply infrastructure.
  - (iv) Alternative technology costs are declining as economies of scale and standardisation are captured, and supply chains mature.
- **System utilisation factor**

  High return on investment for a new capital project is facilitated by high operating hours - ideally 3 shifts/7 days (i.e. 24/7 operation).
- **Importance of fully capturing all indirect energy productivity benefits**
  - Improved plant reliability (partially dependent on redundancy)
  - Reduced system maintenance (particularly where alternative technology displaced all or a significant part of steam reticulation system)
  - Enhanced controllability leading to improved product quality
  - Facilitating increased throughput
  - Reduced water bills, e.g. where a heat pump condenses water that can be utilised on-site
  - Reduced environmental management costs e.g. boiler blowdown and chemicals
  - Space savings compared to a boiler and steam system
  - Improved working conditions – less noise and heat.

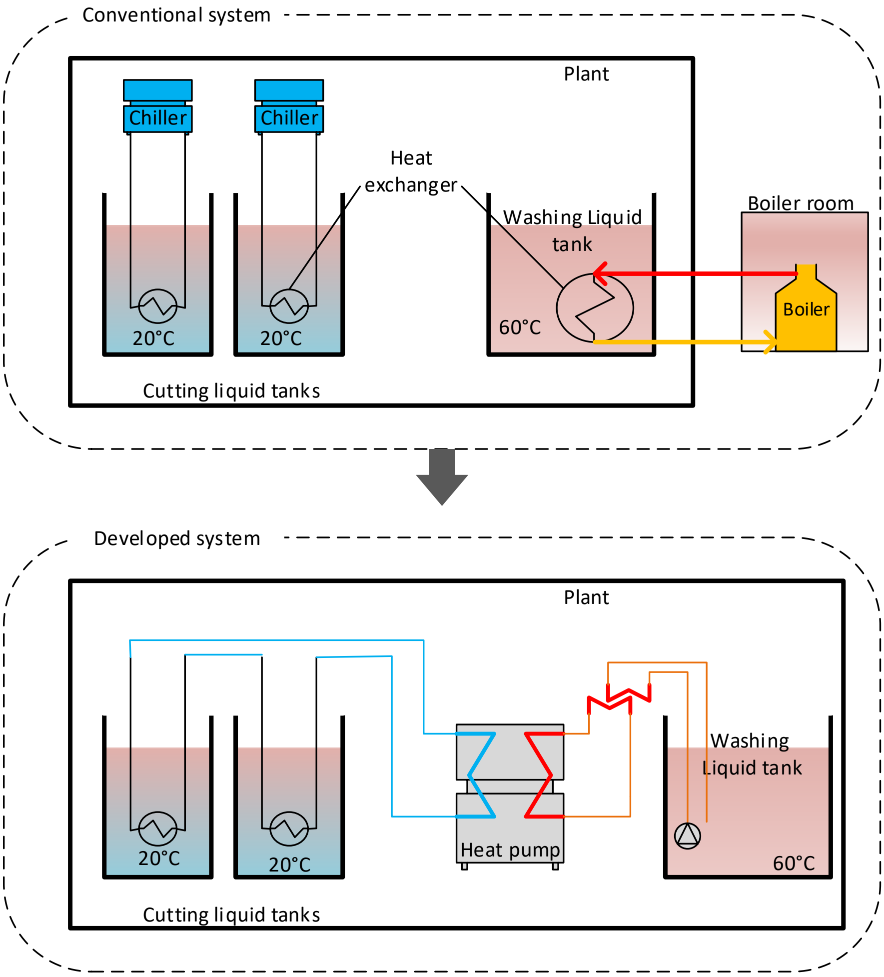
Funding and financing options

Financiers are becoming more interested in financing energy productivity and on-site renewable energy projects as they improve their understanding of them. The Clean Energy Finance Corporation has played a major role in the change, and partners with financiers to offer attractive finance packages.

Example case study: boiler replacement with heat pump

Aisin AW CO. Ltd., is a Japanese Automotive part manufacturer. The company needs to wash parts once they are manufactured.

Replacing central steam system point of use heat pump in a manufacturing plant manufacturing plant



This was conventionally carried out using washing liquid being heated to 60°C by a central steam system. The steam was produced by a boiler running on heavy oil. The boiler was located at considerable distance from the plant leading to poor thermal efficiency of the long steam lines.

Installing a small boiler within the plant was not feasible at the time. The company installed a heat pump within the plant, close to the point of use for heating the washing liquid.

The heat pump was also coupled to the exhaust of the onsite chiller, which is used to cool the cutting tools. The rejected heat from the chiller exhaust used to be lost to the atmosphere as low grade waste heat.

The heat pump delivered the required heat for the washing liquid as well as boosting the chiller performance.

Since 2010 and after the technology had proven its effectiveness, 13 more heat pumps were installed for the same manufacturer.

These 14 heat pumps were comprised of 6 cooling/ heating type heat pumps with a capacity of 22kW, and 8 heating-only type with a capacity 43kW.

With these 14 heat pumps, the plant realised a steam-less thermal system with no need for a central boiler.

After implementing the heat pumps, energy consumption, CO_2 emission, and running cost of the plant reduced by 73%, 76%, and 89% respectively.

Many more examples of offsetting steam consumption with the help of heat pumps have been reported by the International Energy Agency (IEA)[41].

[41] Application of Industrial Heat Pumps Final Report, IEA, 2014

Glossary of terms

The following is a summary of terms used in this report.

Coefficient of Performance (COP)

The efficiency of refrigeration systems and heat pumps is denoted by the coefficient of performance (COP). The COP is the ratio between energy usage of the compressor and the amount of useful cooling at the evaporator (for a refrigeration installation) or useful heat extracted from the condenser (for a heat pump).

Energy productivity

Energy productivity (EP) refers to the value created from using a unit of energy.

Electrification

Eliminating combustion and replacing it using electricity driven processes/systems

Levelised cost of energy

The cost of supplying unit of energy throughout the lifecycle of the equipment/process including its capital and ongoing costs.

High temperature heat pump

Vapour compression heat pumps with heat delivery temperature of over 65°C.

Appendix C: Stakeholders

The list below contains the names of individuals and organisations that were consulted during the course of this report being prepared.

Andrew Bartlett	Bosch
Andy Head	Vodafone
Angus Crossan	Food Innovation Australia Limited (FIAL)
Brad Semmler	Cold Logic
Cameron Stanley	RMIT
Carl Duncan	Teys
Christopher Lee	Climate-KIC
Danielle Kennedy	IoT Alliance of Australia
David Chuter	Innovative Manufacturing CRC Limited
Detlef Zuhlke	SmartfactoryKL e.V.
Englebert Lang	Siemens
Erwin Jansen	Bosch
Gavin Privett	Pyramid Salt
Ian Tuena	CA Group Services
Ivan Fernandez	Frost & Sullivan
Jim Davis	Clean Energy Smart Manufacturing Innovation Institute (CESMII)
Jens Geonnemann	Advanced Manufacturing Growth Centre
Jo Butler	Textor Textiles
Jo Cooper	NSW Office for Environment and Heritage
Kamrul Khan	Mayekawa
Martin Williams	NBN Co
Michael Bellstedt	Minus 40
Michael Blumenstein	Department of Engineering and IT, University of Technology Sydney
Mick Anderson	Goodman Fielder
Mick Humphreys	Apricus Energy
Nathan Epp	Sustainability Victoria
Nico Adams	Swinburne University
Paul Dowling	Clean Energy Finance Corporation (CEFC)
Peter Hook	Bosch
Peter O'Neill	Mayekawa
Phil Wilkinson	AIRAH
Ricardo Hoffman	Johnson Controls
Robert Nicholson	Pitt & Sherry
Robert Thomson	NSW Office for Environment and Heritage
Rod Hendrix	LEAP Australia
Roger Horwood	Energetics
Roger Kluske	Kluske Consulting
Scott Edwards	Coca-Cola Amatil
Shane Timmermans	Mars
Tim Flinn	Emerson
Tim Gibson	Advanced Manufacturing Growth Centre
Trent Miller	Mitsubishi Heavy Industries
Will Mosley	Raygen Resources Pty Ltd

Appendix D: Components of Smart Manufacturing

The components of a Smart Manufacturing system are set out in an ACEEE research paper on the energy saving potential of Smart Manufacturing[42]. The components listed in the paper include:

- ***Smart devices***, which leverage ICT to improve production efficiencies and enable network integration. These are outlined below.
    - ***Sensors*** with connectivity are the first step in collecting and reacting to data in real-time. Smart sensors collect information at the micro-level, as compared to smart meters, which collect information at the subsystem and facility level.
    - ***Input/output devices*** have bidirectional communications capabilities, enabling them to communicate with and respond to the status of other devices within a system, supporting process automation and control.
    - ***Smart parts*** have a unique identifier, such as an RFID tag, that shows what the part is and who it is for. Tagging of individual parts distinguishes the part from other similar parts in the same production line, enabling mass customisation, where products are tailor-made for customers en masse. Mass customisation allows manufacturers to save energy and materials by producing only products customers want and increase revenues by supplying a premium product.
- ***Control systems,*** which involve the establishment of upper and lower set points such that when one of these set points is reached, a new instruction is initiated to optimise productivity and minimise waste. More sophisticated tracking systems will look at rate of change, inputs from multiple sensors and data from external sources to pro-actively adjust to emerging requirements. Control systems are evolving such that they can prevent and predict faults, and maintain control at closer set points or real-time calculated optimal values, realising greater savings in materials, time and energy.
- ***Communication networks***, embedded sensors and transmitters in equipment allows wireless connectivity throughout a plant. To achieve bidirectional data transfer capability, devices must have the ability to accept, store and transmit data at the same time. Bidirectional communication is possible when common software is embedded in a facility's hardware. Devices and systems at a facility may be connected to each other in a local network and that network may be connected to a corporate network residing in the Cloud.
- ***Software,*** embedded in facility devices, which allow these devices to communicate with other devices and participate in a network. It is now possible to store large quantities of data for later use by powerful data analysis. The most sophisticated software systems enable management of facilities and organisations and collaboration between organisations.

[42] https://aceee.org/sites/default/files/publications/researchreports/ie1403.pdf.

- ***Software platforms***, which are necessary for a network to function. Platforms manage the exchange and processing of information and interface with operators. Smart Manufacturing platforms must be able to support multiple data flows. They come with built-in applications, such as data translators and workflow modelling tools. Some platforms can be purchased off the shelf and others are purpose-built.

- ***Systems applications***, software programs or embedded coding that enables some functionality in a device or larger system. Applications are often referred to as either horizontal or vertical. Horizontal applications provide functionality across a system and may be categorised as: status, monitoring and diagnostics; upgrades and configuration management; control and automation; location and tracking; or, data management and analysis. Vertical applications integrate people with business processes and assets and are delivered as managed services. Vertical applications include: asset management and optimisation; supply chain integration and business-process management; customer support; energy management; and security management.

- ***Management systems***, the ultimate goal of Smart Manufacturing is to handle information only once, enabling the optimisation of assets, synchronisation of enterprise assets with supply-chain resources, and automation of business process in response to customer demands. Companies with advanced data analytics capabilities are able to store data remotely for benchmarking of performance over time and under varying conditions and have user interfaces that convert data into actionable information that enables real-time problem solving by humans. In response to the need for the machine-human interactions information is often presented on dashboards using, for example, comparative charts and graphs, to communicate system performance.

- ***Intelligent maintenance***, predictive maintenance of production equipment can significantly reduce variable and non-variable costs of production. Condition-based monitoring and data analytics reduce downtime. A networked monitoring system compares a device's performance against historical data of that device and other like devices within the company and/or sold by the vendor. The system identifies degradation and prognosticates the need for maintenance instead of waiting for fault detection. This has major business implications, as it can reduce or avoid loss of production through process equipment failure.

- ***Smart design***, products designed digitally through computer-aided design need not be physically modelled through expensive and energy-intensive custom manufacturing. Instead they can be virtually rendered, tested and used. This accelerates time to market and reduces the likelihood of making a product that will not perform well. Smart design also includes developing the process by which the product will be manufactured and may also take into account the waste that customers will generate using the product and the ability to recycle the product at its end of life. Design processes can integrate feedback from actual production operations so material flows can be optimised during ramp up of production.

In addition to the components of Smart Manufacturing listed in the ACEEE research paper, as detailed above, responsive process equipment, such as motors with variable speed drives, fans with variable pitch blades or dimmable lighting, that can respond to signals from sensors or smart control systems linked to communication networks are also an important feature of Smart Manufacturing systems.

Appendix E: Organisations promoting the transition to Industry 4.0

Organisations key to the promotion of Industry 4.0 in Australian manufacturing activity are set out in the table below.

Prime Minister's Industry 4.0 Taskforce

The Prime Minister's Industry 4.0 Taskforce[43] was formed in 2015 with the purpose of co-operation and information sharing with the German Plattform Industrie 4.0 group in relation to digital transformation and the linking of manufacturing processes along the global value chain via the internet. Government, industry, and standards and research organisations within both countries will support this cooperative work.

Plattform Industrie 4.0 and the Taskforce have agreed to cooperate in the areas listed below[44].

- ***Reference architectures, standards and norms*** – interoperability and global standardisation are crucial in the adoption of Industry 4.0.
- ***Support for small and medium sized enterprises*** (SMEs) to rethink processes, products, and possibly business models, to prepare for the digital economy.
- ***Industry 4.0 Testlabs*** - a network of Industry 4.0 'Test Laboratories' will be set up in Australia and be accessible by Australian companies to test Industry 4.0 technologies, applications and standards. Many testlabs already exist in Germany. (See also "Industry 4.0 Testlabs in Australia"[45] report.)
- ***Security of networked systems*** is vital in ensuring increased adoption of Industry 4.0 and systems are safe from vulnerabilities. Methodologies and best practices on security of networked systems will be shared.
- ***Work, education and training*** – promotion of digital skills in vocational training, education and on-the-job training.

Advanced Manufacturing Growth Centre

The Advanced Manufacturing Growth Centre (AMGC) is coordinating the work of the Prime Minister's Industry 4.0 Taskforce. Dr Jens Goennemann, CEO of AMGC Ltd, is a member of the Prime Minister's Industry 4.0 Taskforce.

The AMGC[46] is an industry-led, not-for-profit organisation that supports the development of an internationally competitive advanced manufacturing sector in Australia.

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43 https://industry.gov.au/industry/Industry-4-0/Pages/PMs-Industry-4-0-Taskforce.aspx
44 https://industry.gov.au/industry/Industry-4-0/Documents/Australia%20Industry%204.0%20cooperation%20agreement.pdf
45 https://industry.gov.au/industry/Industry-4-0/Documents/Industry-4.0-Testlabs-Report.pdf
46 https://www.amgc.org.au

Siemens   Siemens is leading the Prime Minister's Industry 4.0 Taskforce, with Mr Jeff Connolly, Chair and CEO of Siemens Australia and New Zealand, chairing the Taskforce.   Siemens[47] is a global technology company headquartered in Germany. Siemens' focus areas are electrification, automation and digitalisation and is one of the world's largest producers of energy-efficient, resource saving technologies.
SAP   Mr Bruce McKinnon, Vice President and Head of Service and Support of SAP Australia and New Zealand, is a member of the Prime Minister's Industry 4.0 Taskforce. Mr McKinnon is leading the Work, Education and Training working group of the Taskforce.   SAP[48] is the world's third largest independent software manufacturer. SAP is aggregating new technologies such as machine learning, the Internet of everything, blockchain and the Cloud and combining them in SAP products.
Bosch   Mr Gavin Smith, President of Bosch Australia, is a member of the Prime Minister's Industry 4.0 Taskforce. Mr Smith is leading the Security of Networked Systems working group of the Taskforce.   Bosch[49] is a global supplier of technology and services with four operational divisions: Mobility Solutions, Industrial Technology, Consumer Goods and Energy and Building Technology. It has expertise in sensor technology, software, and services and has its own IoT cloud.
CSIRO   Dr Keith McLean, Manufacturing Director at CSIRO, is a member of the Prime Minister's Industry 4.0 Taskforce. Dr McLean is leading the Research and Innovation working group of the Taskforce.   In 2016 the CSIRO released a roadmap for unlocking advanced manufacturing opportunities in Australia[50]. The report asserts Australia's manufacturing industry will transform over the next 20 years into a highly integrated, collaborative and export-focussed system that provides high-value customised solutions. The sector will focus on pre-production (design, R&D) and post-production (after-sales services) value adding, sustainable manufacturing and low volume, high margin customised manufacturing.   The report also contends development and adoption of digitally connected technologies is important for all growth opportunities, as is a shift towards a more collaborative mentality. Globalisation, digitalisation and increased demand for more bespoke and complex solutions are

[47] https://www.siemens.com/global/en/home/company/about.html#Siemensworldwide
[48] https://www.sap.com/corporate/en/company.fast-facts.html#fast-facts
[49] http://www.bosch.com.au/en/au/our_company_2/our-company-lp.html
[50] https://www.csiro.au/en/Do-business/Futures/Reports/Advanced-manufacturing-roadmap

causing Australia's long-standing disadvantages such as high labour costs, geographical remoteness and small domestic market to be less important.

Standards Australia

Dr Bronwyn Evans, CEO of Standards Australia and Chair of the Medical Technologies and Pharmaceuticals Growth Centre, is a member of the Prime Minister's Industry 4.0 Taskforce. Dr Evans is leading the Reference Architectures, Standards and Norms working group of the Taskforce.

Standards Australia[51] is the country's leading independent, non-governmental, not-for-profit standards organisation. Standards Australia is a specialist in the development and adoption of internationally aligned standards in Australia.

Swinburne University of Technology

Professor Aleksandar Subic, Deputy Vice-Chancellor (R&D) of Swinburne University, is a member of the Prime Minister's Industry 4.0 Taskforce. Professor Subic is leading the Test Laboratories work stream of the Taskforce.

The Manufacturing Futures Research Institute is located at Swinburne University. The focus of the Institute[52] is addressing questions such as:

1. How can Australia develop bespoke manufactured goods of high value?
2. What new materials can be developed into high-value products?
3. How can Australia's manufacturing base become more agile and productive?
4. How can Australian industry implement Industry 4.0 strategies?

The Factory of the Future[53], located in Swinburne's Advanced Manufacturing and Design Centre, provides industry and organisations with state-of-the-art facilities to explore conceptual ideas for manufacturing next generation products. Equipped with advanced visualisation and design tools, designers will have the resources to develop prototypes rapidly, create innovative products and research potential manufacturing methods.

Engineering firm Siemens has granted the Factory of the Future $135 million of industrial software[54]. The grant provides a suite of advanced product lifecycle management software designed to integrate data, processes, business systems and people in an extended enterprise. A new generation cloud-based Internet of Things platform, MindSphere, is also part of the suite.

[51] https://www.standards.org.au/about/what-we-do
[52] http://www.swinburne.edu.au/research/our-research/institutes/manufacturing-futures/
[53] http://www.swinburne.edu.au/research/strengths-achievements/strategic-initiatives/factory-of-the-future/
[54] http://www.swinburne.edu.au/news/latest-news/2017/08/135-million-grant-to-digitalise-swinburnes-factory-of-the-future.php

Australian Advanced Manufacturing Council   Mr John Pollaers, Chairman of the Australian Advanced Manufacturing Council (AAMC), is a member of the Prime Minister's Industry 4.0 Taskforce.   The AAMC[55] is a CEO-led private sector initiative pursuing Australian success in advanced manufacturing. The AAMC brings together industry leadership to drive innovation success and resilience in the Australian economy.
Business Council of Australia   Ms Jennifer Westacott, CEO of the Business Council of Australia, is a member of the Prime Minister's Industry 4.0 Taskforce. The Business Council of Australia[56] provides a forum for Australian business leaders to contribute to public policy debates, particularly in relation to economic and business reforms.
Engineers Australia   Mr Ron Watts, COO of Engineers Australia, is a member of the Prime Minister's Industry 4.0 Taskforce. Engineers Australia[57] is Australia's largest engineering professionals association.
Innovative Manufacturing Cooperative Research Centre   The Innovative Manufacturing Cooperative Research Centre[58] (IMCRC) is a not-for-profit, independent cooperative research centre to help Australian companies increase their global relevance through collaborative, market-driven research in manufacturing business models, products, processes and services. The IMCRC encourages and helps manufacturers invest in collaborative research and embrace digital technologies to deliver intellectual property, value adding, customisation and business models to sell new products and services to a global market.   The IMCRC's Industrial Transformation Program[59] focuses on digital and data driven manufacturing innovation, leadership development and accelerating the uptake of Industry 4.0 tools and disciplines. In collaboration industry groups and technical research organisations, the IMCRC is developing a set of diagnostic, education and training tools and materials that SMEs can access to review and address their technology and knowledge gaps. The program is setting up a national network of demonstrators and industry exemplars through which SMEs can experience the practical and tangible benefits of advanced manufacturing technologies, materials and information systems.
Australian Industry Group   Ai Group[60]is a peak employer organisation representing traditional, innovative and emerging industry sectors. It provides its membership with information on Industry 4.0 and has embarked

[55]http://aamc.org.au
[56]http://www.bca.com.au/about-us
[57]www.engineersaustralia.org.au/About-Us
[58]http://imcrc.org/about/
[59]http://imcrc.org/industrial-transformation/
[60]https://www.aigroup.com.au/policy-and-research/mediacentre/releases/apprenticeships-training-Sep5/

on a major project with Siemens Ltd and Swinburne University of Technology to create an apprenticeship model that will support the higher skills needed for Industry 4.0. The new Diploma and Associate Degree in Applied Technologies qualification will meet the needs of industry by focusing on the adoption of high-level technology skills and the tools required for the future workforce. It will combine university and vocational learning to improve the STEM skills of technically minded participants and will provide a pathway to a relevant Bachelor Degree by 2020.

Cisco

Cisco is a global technology conglomerate headquartered in the US that develops, manufactures and sells networking hardware, telecommunications equipment and other high-technology services and products. Cisco is currently conducting a pilot project using sensors to monitor traffic patterns in Adelaide[61]. Adelaide is one of Cisco's "Lighthouse" cities for showcasing its IoT technology.

IoT Alliance Australia

IOTAA[62] is the peak body representing IoT in Australia with a vision to empower industry to grow Australia's competitive advantage through IoT. The purpose of the organisation is to accelerate IoT innovation and adoption by: activating and supporting collaboration across industry, government, research and communities; promoting enabling, evidence-based policy and regulation; and, identifying strategic opportunities for economic growth and social benefit.

Internationally, there are several organisations very active in the promotion of Industry 4.0 technologies in manufacturing. Of particular note are the US based Clean Energy Smart Manufacturing Institute (CESMII), the Smart Manufacturing Leadership Coalition (SMLC) and the American Council for an Energy Efficient Economy (ACEEE).

[61]https://www.computerworld.com.au/article/632883/adelaide-trials-smart-city-technology/
[62]http://www.iot.org.au/about/

Appendix F: Industry 4.0 technologies – supplementary information

Selection of IoT sensors

Although, a large number of commercially viable sensors with IoT connectivity are available, selecting the right sensor for a specific application is not always trivial. In order to choose a suitable sensor, one should take into account several aspects such as the:

- required accuracy - does the sensor read data with enough accuracy and rate?
- chemical and physical compatibility - does the sensor break down when exposed to e.g. chemicals or high temperatures present at the spot of measurement?
- installation procedure - is the sensor intrusive; can it be installed at the right location without affecting the processes or requiring costly procedures?

Table 1 - Some IoT enabled sensor manufacturers for industrial applications

Manufacturer	Website
MEMSIC	http://www.memsic.com/
MONNIT	https://www.monnit.com/
TE Connectivity	http://www.te.com
STMicroelectronics	http://www.st.com
SICK	https://www.sick.com/
NXP Semiconductors	https://www.nxp.com/
TEXAS Instruments	http://www.ti.com/
Dialogue Semiconductor	https://www.dialog-semiconductor.com/
Emerson	http://www.emerson.com
Veris	https://www.veris.com
Kistler	https://www.kistler.com
Pepperl+Funchs	https://www.pepperl-fuchs.com
Bosch	https://www.bosch-connectivity.com/

Cloud computing

IoT devices are capable of generating a large amount of data. Particularly, if

(i) they are equipped with a large number of sensors that are continuously generating and reporting data, and/or

(ii) they have been set to monitor equipment, subsystems, and systems at a high frequency mode.

Such high frequency mode can add an extra dimension to the collected data enabling e.g. accurate condition monitoring.

The available cloud platforms enable enterprises to:

- access powerful data computation, storage, transfer capability without the need for setting up an independent expensive high-end IT system, and
- create a platform that is accessible by all the stakeholders of a complex supply/manufacturing chain.

Such a platform is a shared information/communication/decision-making hub for all the subsystems involved in the business to coordinate and expedite processes and be aware of any bottlenecks, faults, and delays.

Artificial Intelligence (AI)/learning algorithms

The computational power provided by cloud computing allows for harvesting the next level of benefits in Smart Manufacturing. The large amount of collected data can be used in machine learning platforms that transform the raw data into actionable information to

- manage and control a complex set of processes in a very optimal and autonomous way,
- conduct condition monitoring and prevent failures in the system
- translate human requests into machine-based systems' language (action codes).

Robotics and their impact on energy use

Smart Manufacturing involves the heavy use of automation and data exchange in the manufacturing environment and the associated supply chain. Robots play a vital role since they can

(i) collect useful data while in operation

(ii) also accurately follow the instructions defined by optimisation algorithms.

This allows the operators of the plant to see through the processes and observe the consequences of the changes that they implement. This leads to a manufacturing plant that responds to instructions consistently. Using robots can lead to higher energy productivity for the following reasons:

- Robots minimise overhead energy consumption. With no requirement for minimum lighting or heating/cooling levels, robots can offer great energy saving opportunities. It is estimated that for 1°C reduction in heating level, 8% energy saving in air-conditioning can be achieved.
- Robots have superior repeatability leading to minimised defective products. Defective products in the production lines have an adverse effect on the energy productivity of the plant. Note that robots are not well suited to variability i.e. robots are better suited to uniform upstream processes.
- Robots increase the production output rate. Since a portion of the energy demand of any plant is fixed, this can increase the energy productivity of the plant.
- Robots can be mounted in multilevel configuration reducing the required space. This can lead to saving the energy required to operate the space.

Energy storage

Energy management and sourcing low cost energy is a key element of Industry 4.0 and energy productivity. Storing energy can play a critical role in managing energy on the consumption side. Under suitable conditions, energy can be stored cost effectively in the form of electricity in batteries, thermal energy in heat/cold storage units, potential energy in pumped storage, or even in partly processed product. These storage systems can:

- entirely shift the consumption from high demand to low demand periods and reduce the cost of energy,
- act as a buffer and reduce the peak demand and lower the demand cost of the plant as well as preventing oversizing the equipment such as the heating/cooling units, and
- increase the self-consumption of on-site generated renewable energy.

Appendix G: Literature on Industry 4.0 and energy

The following references include discussion of the impacts of Industry 4.0 technologies on energy use.

Finn, P. & Fitzpatrick, C. Demand side management of industrial electricity consumption: promoting the use of renewable energy through real-time pricing. Applied Energy 113 (2014): 11-21. Finn and Fitzpatrick conducted a study on the financial benefits of load shifting in industrial plants. They compared two energy consumers: (i) a modern cold storage with flexible load profile shape and (ii) a manufacturing plant with less load profile flexibility due to process constraints. The study showed that price incentivised demand response is directly proportional to the renewable energy consumption performance for both plants in different degrees. This is beneficial for the consumers and the supplier (in Ireland).
Davis, J., 2017. Smart Manufacturing. In: Abraham M.A. (Ed.), Encyclopedia of Sustainable Technologies. Elsevier, pp. 417-427. This paper sets out in detail the objectives and characteristics of a Smart Manufacturing system and including discussion of the opportunities Smart Manufacturing provides to improve energy productivity outcomes.
Rogers, E.A., 2014. The energy savings potential of Smart Manufacturing. American Council for an Energy-Efficient Economy. Washington, DC. In the US, the ACEEE found implementing Smart Manufacturing can reduce the electricity consumption by 20%. This paper states the investment required to achieve such energy savings is expected to have a payback period of less than 2 years. A2EP notes this report focuses on incremental rather than transformative change and excludes the benefits of deploying new process technologies (replacing boilers with heat pumps, for example). Therefore, may understate the potential energy savings achievable with Industry 4.0 technologies.
International Energy Agency. 2017. Digitalization and Energy IEA report discussing the impact on energy systems of current and future rapid changes and improvements in digital technologies– examining both the enormous potential and challenges these changes pose as they flow throughout all sectors of the economy. http://www.iea.org/digital/
DOE Project Report. 2016. Industrial scale demonstration of smart manufacturing (SM): Achieving transformational productivity energy gains. Award no. UTA13-001076. University of Texas Austin. Project report on US Department of Energy project to develop a prototype open architecture Smart Manufacturing platform to facilitate extensive application of real-time sensor-driven data analytics, modelling and performance metrics. Project involved two test beds: 1. image based temperature measurements were installed on a Steam-methane reforming unit so real-time model-based decisions can be made to reduce energy use and increase productivity 2.

Measurement and software installed to reduce energy use and increase productivity in heat treatment and machining of artillery shell casings and commercial metal parts. www.energy.gov/sites/prod/files/2015/06/f22/R26-AMO%20RD%20SM%20Project%20Edgar-2015_6.0.pdf

AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY