Options to Reduce New Zealand's Process Heat Emissions

March 2019

Report Prepared by Dr Martin Atkins

Energy Research Centre

University of Waikato

Contents

Introduction

The New Zealand Energy Efficiency and Conservation Strategy (NZEECS) 2017-2022 committed MBIE and EECA to prepare an action plan for mitigating the greenhouse gas emissions impact of process heat in New Zealand. To meet this commitment the Process Heat in New Zealand (PHiNZ) project was initiated and this work will contribute to PHiNZ. The purpose of this work was to identify, quantify and cost mitigation options to reduce the GHG emissions associated with the use of process heat in New Zealand. The information supplied by the work will inform:

- analysis and policy development, both by MBIE and EECA as part of PHiNZ but also by the Ministry for the Environment (MfE) as part of its wider climate change work;
- priority areas for action by government;
- process heat users about their emissions profile;
- process heat users of possible options to mitigate their emissions.

Scope

The work was intended to cover at least 90% of the current emissions associated with supplying and using process heat in New Zealand. The work was carried out on a process or sector level basis. This is because the possible mitigation options depend on a process' specific underlying technical characteristics and requirements.

For each mitigation option identified:

- the option is described;
- the potential amount of emission mitigation is quantified;
- capital and operating cost of the option is quantified.

These outputs will allow the marginal abatement cost (MAC) of each option to be calculated, and aggregating this information will allow a MAC curve to be produced for the process.

Methodology/Approach

Top-down analysis methods for industrial process heat emissions reduction have some major limitations. Emissions reduction measures specific to that process or sector may not be included or accurately represented. Specific technical issues may also not be captured sufficiently by top-down approaches. The way measures are integrated into the industrial system is also important to consider and as a result of the top-down approach, important technical aspects of GHG reduction measures and their integration, are usually overlooked or trivialised. Therefore two bottom-up analysis methods were used to capture the specific reduction measures and to take into consideration the integration implications. These two approaches are an engineering approach and a benchmarking approach.

Engineering Approach

The engineering approach is a bottom-up approach that utilises engineering knowledge of the process to identify the specific mitigation options. It may also include preparing engineering models of a representative process so that techniques such as pinch analysis can be used to quantify the opportunity. The capital and operating cost estimates for each option are included. Any assumptions and their basis are stated and referenced.

In the case of Milk Powder Production two detailed process models (i.e. mass and heat balance) have been developed because of the large total amount of emissions from this activity, numerous sites, and several emissions reduction options that involve complex process integration to maximise the benefit. Process models have not been created for the other processes although an engineering approach has been taken and emissions reduction measures have been estimated using engineering calculations and estimation.

Benchmarking Approach

A benchmarking approach is employed for the most emissions intensive processes which are only found on a single or limited numbers of sites in New Zealand.

The benchmarking approach:

1. Described the process and its characteristics.
2. Assessed the process's current fossil fuel use, absolute emissions and emissions intensity (per unit of production).
3. Identified and applied relevant benchmarks for comparison, including:
    a. Average emissions intensity for the process (internationally);
    b. Best available technology emissions intensity.
4. Identified mitigation options from literature and using a sensible methodology applied this information to the New Zealand context. For example, translating a plant upgrade into New Zealand dollars and adjusting for the relative cost of implementing projects in New Zealand (if these tend to be higher or lower than the example location).
5. Described the identified options, calculate the mitigation potential and marginal abatement cost.

The benchmark approach still applies engineering knowledge and knowledge of the underlying process when adapting estimates of emission reduction opportunities to New Zealand.

Sectors

The sectors and processes that were examined and information regarding the number of plants and estimated emissions for each sector are summarised in Table 1. The source and basis for energy and emissions data along with the type of assessment approach used for each sector and process are summarised in Table 2.

Table 1. Summary of sectors and processes examined and estimated emissions.

Sector/Process	Number of Plants in New Zealand	Estimated Emissions [t_{CO_2}/y]	Emissions [% of total NZ]
Dairy	**≈80**	**2,165,230**	**23.4%**
Milk Powder	≈50	1,581,430	17.1%
Other	≈30	583,800	6.3%
Methanol	**2**	**1,884,960**	**20.3%**
Refining	**1**	**1,170,558**	**12.6%**
Steel	**1**	**692,452** **1,778,400**[a]	**7.5%**
Aluminium	**1**	**667,402**	**7.2%**
Meat	**86**	**361,000**	**3.9%**
Rendering		301,435	3.3%
Slaughterhouse		59,565	0.6%
Food	**44**	**359,228**	**3.9%**
Other	**5**	**302,036**	**3.3%**
Urea	1	302,036	3.3%
Cement	**1**	**237,271** **790,904**[a]	**2.6%**
Wood Processing	**75**	**184,260**	**2.0%**
Kraft Pulp	**2**	**138,320**	**1.5%**
Total		8,172,717 9,268,000[b]	88.1%

[a] Total sector emissions including process emissions

[b] Total estimated process heat emissions in New Zealand

Table 2. Summary of basis for production, energy use, emissions and modelling approach for each sector and processes.

Sector/Process	Production Information	Energy Use	Emissions	Modelling Approach / Estimate Level
Aluminium	2017 Production Data	SEC - Heavy Industry Report (2009)/estimate	Estimated Average based on previous years	Benchmark Plant Level Estimate
Cement	Nominal Plant Capacity	Fuel mix ratio - back calculation based on emissions	Fuel emissions = 30% of total plant emissions. Plant emissions based on ETS Allocation Factor	Benchmark Plant Level Estimate
Kraft Pulp	Nominal Plant Capacity - APPITA Figures	Gas use based on expert estimate	Based on gas usage	Engineering Plant Level Estimate (2 Plants treated as 1)
Methanol	Methanex Annual Report. Nominal Plant Capacity	SEC estimate + back calculation based on ETS allocation	Plant emissions based on ETS Allocation Factor	Benchmark Plant Level Estimate (2 Plants treated as 1)
Refinery	Nominal Plant Capacity	SEC estimate from figures taken from annual report	Based on Specific Emissions Factors taken from annual report	Benchmark Plant Level Estimate
Steel	95 % Nominal Plant Capacity	SEC estimate + info from Heavy Industry Report (2009)	Specific Emissions Factors estimate - Heavy Industry Report (2009)	Benchmark Plant Level Estimate
Urea	Nominal Plant Capacity	SEC estimate + info from Heavy Industry Report (2009)	Based on fuel gas usage	Benchmark Plant Level Estimate
Dairy - Milk Powder MVR	Plant Model - Nominal Plant (can be changed); National level based on estimate of energy use for milk powder	Process Model and Sector Level Estimate	Industry weighted emissions factor and process model energy use	Engineering Detailed Process Model of Typical Plant
Dairy - Milk Powder DSE TVR	Plant Model - Nominal Plant (can be changed); National level based on estimate of energy use for milk powder	Process Model and Sector Level Estimate	Industry weighted emissions factor and process model energy use	Engineering Detailed Process Model of Typical Plant
Dairy - Other	Sector Level	Sector Level Estimate	Industry weighted emissions factor and sector energy use	Engineering Sector Level Estimate
Food - Other	Sector Level	Back calculation from emissions and fuel split (EECA End Use Database 2016)	EECA End Use Database (2016)	Engineering Sector Level Estimate
Meat - Rendering	Sector Level - MBIE Investors Guide to NZ Meat Industry 2017	Sector Energy Use Survey (Kemp 2011) + Specific Energy Consumption + Back calculation from emissions and fuel split (EECA End Use Database 2016)	EECA End Use Database (2016)	Engineering Sector Level Estimate
Meat - Slaughterhouse	Sector Level - MBIE Investors Guide to NZ Meat Industry 2017	Sector Energy Use Survey (Kemp 2011) + Specific Energy Consumption + Back calculation from emissions and fuel split (EECA End Use Database 2016)	EECA End Use Database (2016)	Engineering Sector Level Estimate
Wood Processing	Sector Level	EECA End Use Database (2016)	Based on energy use and fuel emissions factors	Engineering Sector Level Estimate

Mitigation Option Descriptions

This section outlines general options that have broad applicability across multiple sectors. Individual sectors are then covered with specific options covered.

General Options

Emissions reduction measures, or mitigation options, can be divided into two broad categories, demand side reductions and supply side reductions.

Demand side reduction measures are methods to reduce the amount of heat required to manufacture the final products. Examples include, energy efficiency improvements or installing new processing technology that require less energy.

Supply side reduction measures supply the same amount of heat to the process but do this with lower emissions. Improving the efficiency of the utility system (i.e. burning less fuel to supply the same amount of energy) or switching to a lower carbon fuel are both examples of supply side emissions reduction.

This section examines the two categories, outlining specific opportunities and barriers for each broad measure. These measures are summarised in Figure 1.

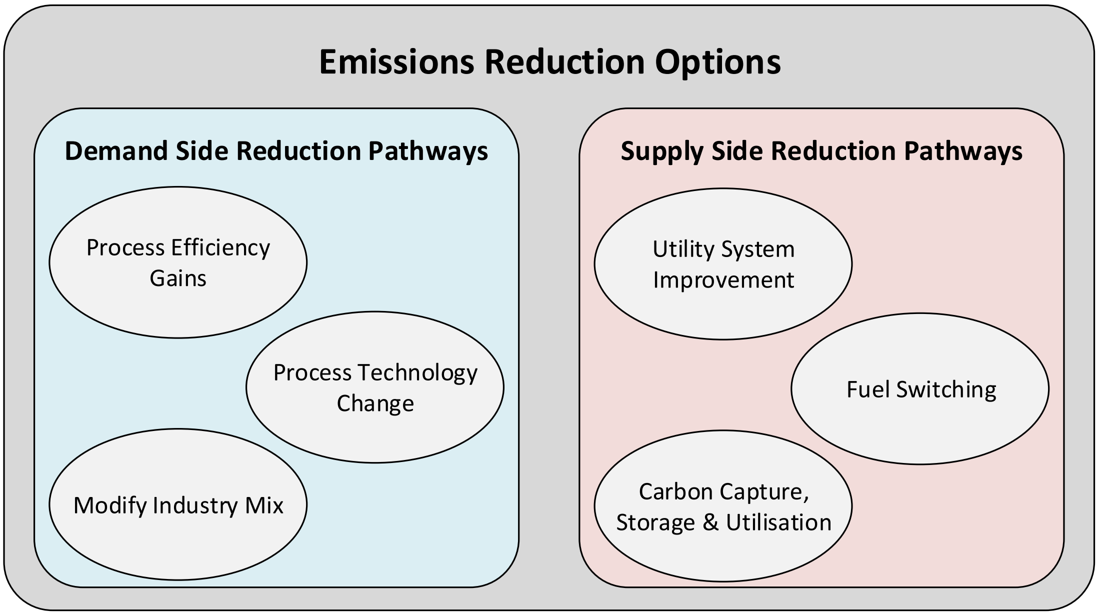

Figure 1. Emissions reduction categorised by Demand and Supply Side reduction measures.

Demand Side Reduction

Demand side reduction measures are simply methods that reduce the amount of heat/energy required to manufacture products and therefore less fuel is used to supply that energy. Ideally, for long-term large-scale reductions in emissions, demand-side reduction should be conducted first before the supply-side is addressed. This will ensure that the transition to low-carbon manufacturing follows a roadmap/framework rather than a series of ad-hoc reduction projects that might limit large-scale reductions in the future. A systems integration approach that considers the demand (process) and supply (utility) system holistically is required to achieve the level of emissions reduction needed.

Energy Efficiency & Heat Recovery

Stage of Availability: Commercial

Energy Efficiency typically means producing the same products but at a lower specific energy consumption (i.e. energy consumed per unit of production). This can be improved in several ways including good housekeeping, heat recovery, operating at design or optimal production rates, and producing a product that is within specification. Using Best Available Technology (BAT) is also an important factor for improving efficiency however the opportunities for implementing BAT are generally limited to initial plant construction, production upgrades, or assets replacement. Energy efficiency is widely considered the major option for GHG emissions reduction for the industrial sector[1]. It is also often the most cost effective method for reduction and there typically exists a large number of cost effective measures that are not fully taken advantage of. Figure 2 illustrates conceptually that increased energy reduction requires larger commitment of resources (e.g. capital, time). Only limited reductions will be achieved if only the "low-hanging fruit" is targeted. Many of these opportunities are considered housekeeping and savings can quickly deteriorate due to neglect of up-keep of systems.

Good house-keeping include adequate maintenance practices, staff following standard operating procedures, regular boiler tuning and steam trap management, etc. These measures do not lock in efficiency gains and must constantly be reassessed as to their effectiveness. The efficiency gains can be lost due to apathy, change in staff or procedure, changes in production or production pressures, or loss of emphasis or prioritising of other production measures (e.g. production rate or quality). They generally require no or minimal amounts of capital to implement. The improvements tend to be modest but cost effective.

Increased heat recovery is a major potential for emissions reduction, which is achieved by reducing the required amount of external heating (hot utility) that has to be supplied. The amount of heat recovery from heat sources (hot streams) to heat sinks (cold streams) is an important measure of the overall efficiency of a process. There are strict thermodynamic limits to the amount of heat recovery that can be achieved and well established systematic methods exist to clearly determine the thermodynamic and economic amounts of heat recovery that can be achieved. Furthermore these methods can rigorously design heat exchanger networks that can implement the heat recovery on site. These methods include Pinch Analysis and Process Integration. In many industries these methods are poorly understood and seldom utilised for a variety of reasons including lack of awareness, lack of expertise, cost of analysis, and perceived lack of applicability to the plant. It has been well established for several decades over numerous sectors that large improvements in heat recovery and efficiency

---

[1] Fischedick M., et al., 2014, Industry. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

can be gained through the use of these methods. Furthermore they include important guidelines and principles for the integration of utility systems and heat pump technology[2].

For several decades Pinch Analysis has been extensively used throughout the refining and petrochemical industries to substantially reduce energy use. Other industries such as chemical, pulp and paper, and the food and beverage industries have also benefited from Pinch Analysis although these sectors have not applied these methods as widely. Energy reduction through increased heat integration/recovery range from around 10 to 40%, with much of the identified savings being economic to implement.

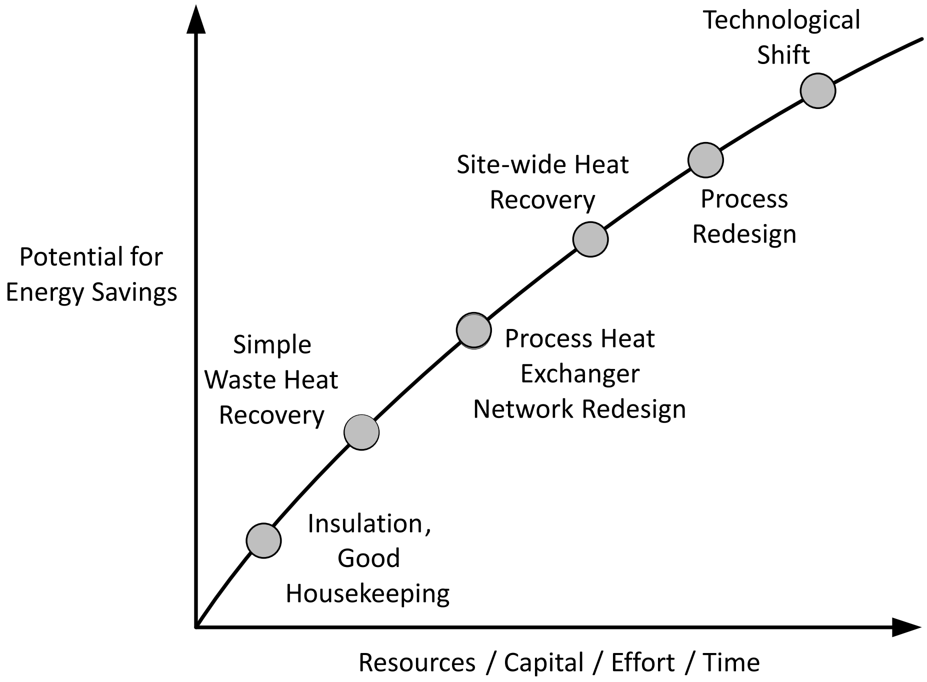

Figure 2. Different demand side reduction measures potential for savings versus resources to achieve the savings.

Heat Pumps

Stage of Availability: Commercial

An electric heat pump is used to upgrade heat from process cooling or ambient conditions to produce hot air, hot water or steam. Heat pumps are very efficient and provide both process heating and process or utility cooling are used in many industrial processes. High temperature heat pumps can be used to upgrade (i.e. increase the temperature) waste heat to a temperature that can be used in the process. It is important to state that the high temperature range is around 100 – 120°C. Unlike a domestic system, industrial heat pumps use rejected heat (i.e. from the cooling system/process), and not heat from the surroundings. Although ambient heat from the surroundings could be used, it is highly unlikely this would be economic for industrial processes. Heat pumps therefore provide both process heating and process cooling in an industrial setting.

The Coefficient of Performance (COP) is a measure of the efficiency of the heat pump and is simply the ratio of useful heat provided to the amount of electricity used to upgrade the heat. Typical COP will range from 2 to 6

---

[2] Smith, R., 2005, *Chemical Process – Design and Integration.* John Wiley & Sons, Ltd.

for vapour compression cycles but can be as high as 50 depending on the situation. COP is a function of temperature lift (i.e. how much the temperature is upgraded) and decreases as the temperature lift increases.

Most commercially available heat pumps supply temperature below 100 °C, however the upper limit is increasing with heat pumps manufacturers claiming supply temperatures of up to around 165 °C.

The integration of heat pumps into an industrial process system is also non-trivial and highly dependent on energy and temperature demand of the process (both heating and cooling demands). Pinch analysis illustrates that heat pumps must be correctly integrated into the process otherwise usable heat is supplied with an effective COP of one (i.e. expensive heat) or excess waste heat equal to the amount of work supplied to the heat pump (W) is produced – increasing the site cooling demand. Integration is highly site specific and the analysis, selection of heat pump technology and operational conditions must be conducted by an experienced engineer.

Mechanical vapour recompression (MVR) is a special type of heat pump (open cycle) that compresses vapour from of the fluid being processed (usually water), rather than a refrigerant. MVR systems are used extensively in milk powder production and compress water vapour at between 50 – 70°C and increase the steam temperature by 10 – 15°C, with a COP in the range of 30 – 50. Common MVR applications are removing water or vapour in drying (de-watering of landfill leachate, oil emulsions and saline, acid solutions), dehumidification, distillation (alcohol and organics), concentration of liquids (such as milk, black liquor, fruit juices), and heat recovery of low-grade heat (low pressure steam to high pressure steam).

Process Technology Change

New and developing technology is often presented as a major source of emissions reduction, however the role of new technology in emissions reduction remains uncertain. For example, new technology might be in the form of a new way to make an existing product, or produce a substitute product using lower material and/or energy inputs. New production technologies are sector and product specific. Best available technologies are often extremely efficient and many approach efficiency limitations bound by the laws of thermodynamics[3]. However these technologies are often overlooked or not implemented. The barriers to further uptake of best available technologies are not well understood and further research is needed to identify them.

For most industrial products alternate methods for production already exist but fail to be widely adopted due to a range of factors such as scale, capital cost, unresolved technical challenges, scale-up, and simple economics. Furthermore, many new technologies simply do not live up to the hype of the development and commercialisation process (Figure 3). Emerging technologies tend to go through a hype-cycle and many do not reach commercialisation, live up to expectations, or deliver on the benefits promised. In the industrial sector capital turn-over is in the order of decades and most sectors are risk adverse and as a result adoption and implementation of new proven technology is difficult to predict.

---

[3] Brown, T., Gambhir, A., Florin, N., and Fennell, P., 2012, Reducing CO_2 emissions from heavy industry: a review of technologies and considerations for policy makers, Imperial College London, Grantham Institute for Climate Change. https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Reducing-CO2-emissions-from-heavy-industry---Grantham-BP-7.pdf

Disruptive technologies are by nature difficult to anticipate and account for in forecasting. In summary, technological change will affect to some extent the processing industries, however the rate of uptake, overall benefits and emissions impact are highly uncertain. In the short to medium term, encouraging industry to use best available technology is the best option for large scale emissions reduction.

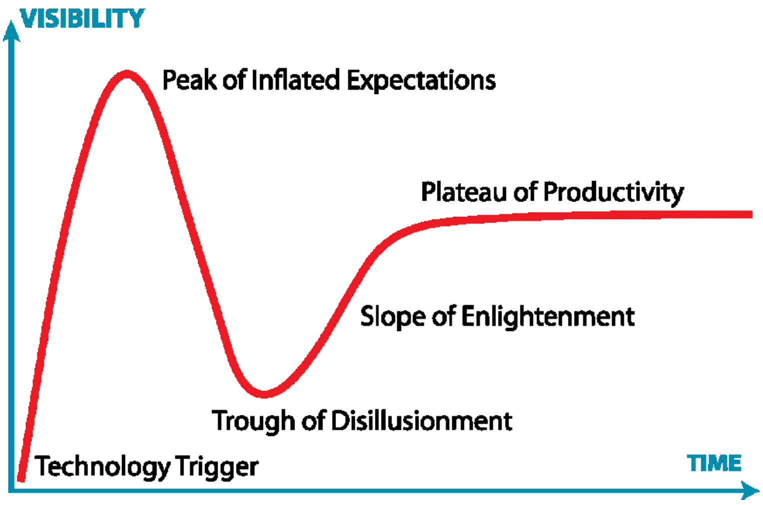

Figure 3. Gartner Hype Cycle for emerging technologies[4].

Supply Side Reduction

Several supply side emissions reduction categories exist. These are all methods where heat is supplied to the process via a more efficient system or lower carbon alternative.

Utility System Efficiency Improvement

Stage of Availability: Commercial

The utility system of a plant is the system that supplies heat to the process and typically consists of a boiler, steam headers at different pressures, steam distribution, and condensate return systems. A number of zero/low cost efficiency improvements can be realised providing low to modest emissions reduction. These are mostly housekeeping/maintenance measures but need to be performed on a regular basis to maintain high levels of efficiency. These measures include:

- Boiler/burner tuning;
- Steam trap and condensate management programmes;
- Pipe and process vessel insulation;
- Heat exchange cleaning and maintenance.

Although these measures improve the overall efficiency of delivering/supplying heat to the process they are often conducted on a semi-regular or ad-hoc basis rather than as a regular standard operating procedure and scheduled as part of regular maintenance operations. EECA has conducted programmes that have encouraged regular boiler tuning with moderate success. Regular boiler tuning maximises efficiency and can have a modest

---

[4] http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp#

improvement in fuel reduction. These measures are important but will have limited impact and not deliver large-scale emissions reductions.

Fuel Switching

Stage of Availability: Commercial

Emissions reduction through fuel switching involves replacing a currently used fuel with a lower emissions alternative. After demand reduction measures have been applied the next major emissions reduction measure is fuel switching or substitution. Substitution may involve a fairly straight forward substitution in existing boilers or may require completely new heat plant. Replacement of fuel with electricity is also considered here as a fuel switching measure and electrode boilers to produce steam are current commercially proven and available technology. There is also potential for heat to be supplied directly with electric heating elements or indirectly through heat pump technology. Note heat pumps can be considered as both a demand reduction and fuel switching measure.

An important factor in the economics of fuel switching is the difference in fuel price, as this typically makes up around 60 – 80% of the total life-cycle cost for heat plant. Where fuel switching involves additional/new heat plant, capital cost can play a major role in the economic viability of switching. There is a large variance between capital cost of boilers and fuel handling/storage requirements for different fuels.

There are two main fuel switching options that are of particular interest for New Zealand industry, wood based biomass and grid sourced renewable electricity.

Wood Energy

Woody biomass is an important national fuel source for moving to a low carbon economy. There are generally three main potential sources of biomass for use as boiler fuel: forest based residues, wood chip and processed wood pellets. Estimated wood residue volumes by region are shown in Figure 4. The amount of wood available for energy is very location and time dependant as supply can vary due to planting and harvest rates. A major component in the fuel price for biomass is the cost of transportation and the rule of thumb is that distances greater than 100 km will be uneconomic.

Forest Residues

Forest residues are under-utilised as a fuel source, but are costly to gather and transport. The potential annual supply is also variable depending on the harvesting activity and existing forest plantations. In many regions supply potential peaks around 2025 then drops considerably out to 2035. The estimated costs for forest residues are in the order of $7 – 15/GJ but vary depending on the fuel grade, volume required and transportation distance.

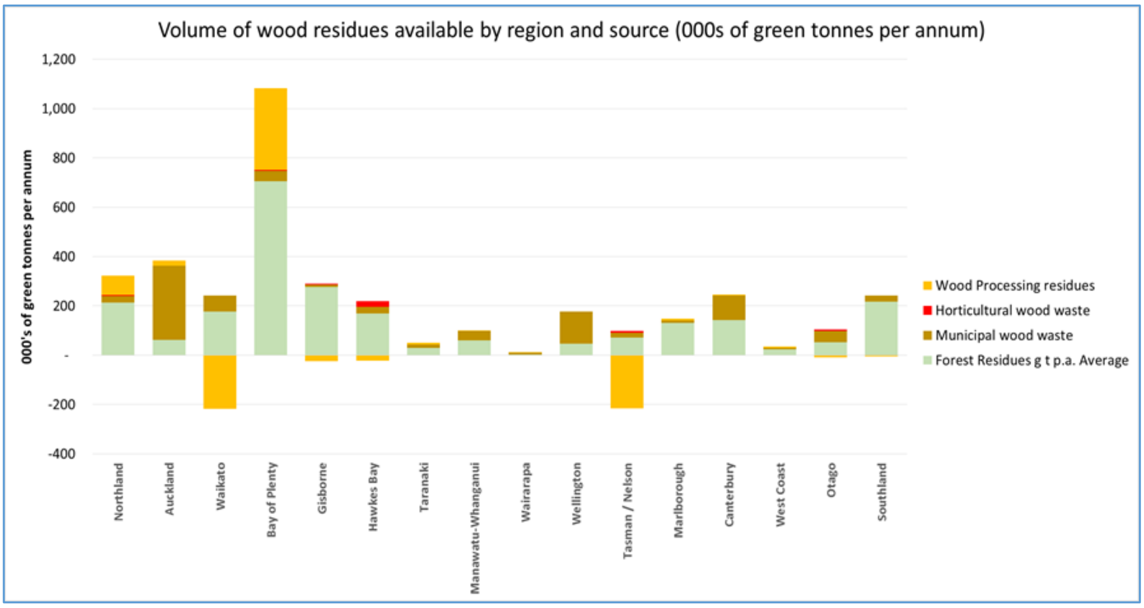

Figure 4. Estimated wood residue volume by region.[5]*Note negative availability indicates a net deficit for that region due to demand for residues such as wood chip for pulp and paper or board manufacture.*

There are several other important factors that need to be recognised when biomass is used, especially at an industrial scale within urban areas. Air quality issues, including particulate emissions, are much higher than for natural gas combustion. Due to the much lower energy density of the fuel, increased transportation is involved and additional heavy truck movements are required to deliver fuel to site. Fuel handling and fuel storage can also be an issue with dust and noise being the major concern, especially in urban areas.

Wood Pellets

Wood pellets are a processed fuel and are made from waste sawdust, wood shavings, and off-cuts. They have a higher energy density than forest residues, have higher uniformity, are easier to handle, and tend to be cleaner burning. To date there has been limited uptake of wood pellets as an industrial fuel, although they are used for some commercial applications. Indicative industrial costs are in the order of $12 - $20/GJ.

Electrification

New Zealand has a high proportion of renewable electricity generation, underpinned largely from hydro generation. The Grid Emissions Factor (GEF) is the average emissions per unit of electricity generated for the entire NZ electricity system and has typical units of $t_{CO2\text{-}eq}/MWh_{el}$. The GEF is highly dependent on the mix of generation sources and can increase dramatically when there is a dry year. Emissions savings through increased use of electricity is due to the low GEF for New Zealand electricity.

---

[5] Hall P. (2017). Residual biomass fuel projections for New Zealand – indicative availability by region and source. Scion contract report for Bioenergy Association of New Zealand and the Energy Efficiency and Conservation authority. Scion SIDNEY No. 59041. https://www.bioenergy.org.nz/documents/resource/Reports/Wood-residue-resources-report-2017_170824.pdf.

There are several ways low carbon/renewable electricity can be utilised for process heat emissions reduction, including direct heating, indirect heating and heat pumping. Electricity is highly flexible and is considered an extremely high quality of energy and this is reflected in the cost.

High temperature process heat (>400°C) can be supplied using electric heating elements or via the combustion of hydrogen gas, produced using electrolysis. Electrolysis using alkaline electrolysers are around 50 – 65% efficient, while Polymer Electrolyte Membrane electrolysis is around 75% efficient. Assuming a scenario of increased renewable electricity generation and GEF of 0.05 t_{CO2}/MWh_{el} (0.0278 t_{CO2}/GJ_{el}) hydrogen gas as a fuel would have an emissions factor of 0.028 - 0.019 t_{CO2}/GJ_{fuel}.

Electricity can also be used to produce high pressure steam (≈40 bar) that can be directly used in existing steam distribution networks. These electrode boilers are relatively simple, low capital cost, easily controlled with high turn-down, and high efficiency (≈99%). The real drawback is that steam is produced with a Coefficient of Performance (COP) of one and therefore the equivalent fuel price is very high. Based on current electricity prices, process heat would be in the order of $20 - $38/GJ. Even if a levelised cost (i.e. total life-cycle cost) is considered, heat delivered in this way is expensive relative to other available options. Thus the major barrier to increased use of renewable electricity is the cost of electricity. The average industrial price is between $25 - $38/$GJ_{el}$ for the industrial sector (Figure 5). Higher peak pricing can also be a major risk during production periods. Distribution and network charges are also significant. However, there may be specific situations where using electricity directly could still be attractive such as for sites that already use high-cost fuels, such as LPG and diesel, and which tend to do so because natural gas is unavailable and the operating characteristics of coal and wood boilers are not well matched with the site's requirements. For major users additional/upgraded transmission infrastructure would also be required, which involves large amounts of capital. How renewable electricity is integrated into industrial heat demand economically is a major area of future research. The current consensus is that we have enough renewable generation resources to provide for demand increased from significant process heat demand.

Electro-technologies used for heating and drying include micro-waves, infrared, induction, radio-frequency heating, and resistance heating. Efficiency is increased over conventional methods. The suitability and economics of each technology is dependent on the specific application and factors such as heating demand. See "Zero Carbon Industry Plan: Electrifying Industry"[6] for a good summary of electro-technologies and their applications.

---

[6] Zero Carbon Industry Plan: Electrifying Industry, Beyond Zero Emissions. September 2018.

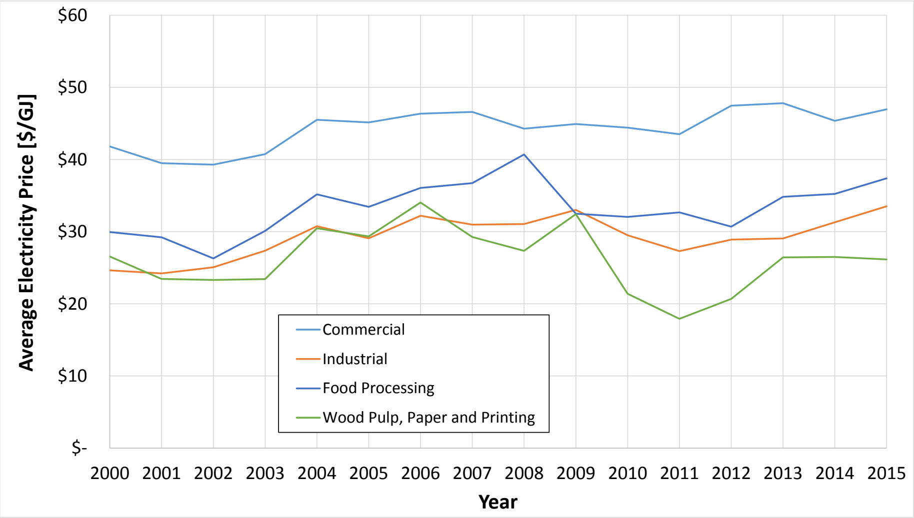

Figure 5. Average electricity price by selected sectors, 2000 – 2015[7].

Aluminium

A simplified process flow diagram of the Aluminium process is shown in Figure 6. Bauxite is mined in north Queensland, refined in central Queensland to Alumina, and then this Alumina is shipped to NZAS for smelting into Aluminium. The emissions involved in refining Bauxite into Alumina is not included in NZAS emissions. Alumina refining emissions in 2014 for the two mills in Queensland that supply NZAS were 0.66 and 1.03 $t_{CO2-e}/t_{Alumina}$. Approximately two tonnes of Alumina is used to produce one tonne of Aluminium.

$3Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$

The current world average is around 11.5 t_{CO2-e}/t_{Al}, with plants that use electricity from coal being around 18 t_{CO2-e}/t_{Al}. Several companies market low carbon products that have a footprint less than 4 t_{CO2-e}/t_{Al}. Available data for Tiwai Point indicates emissions are between 1.87 and 2.11 t_{CO2-e}/t_{Al}.

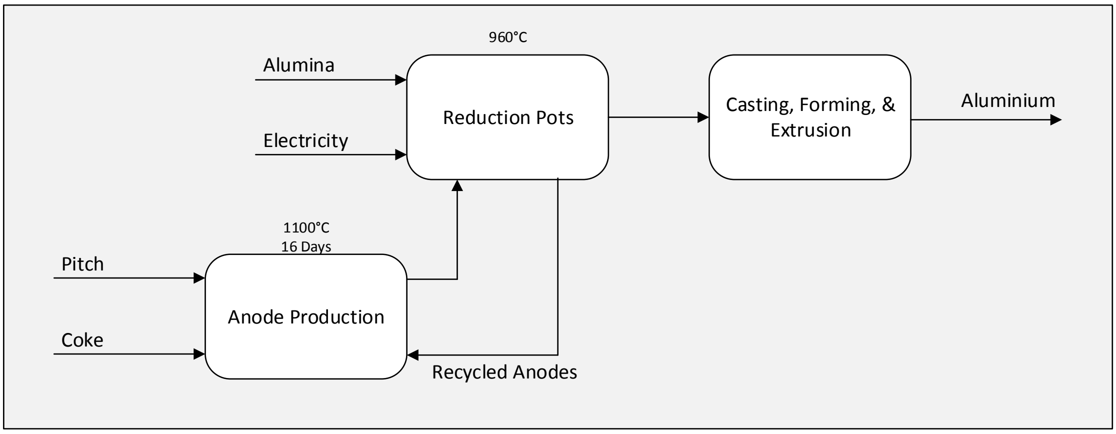

Figure 6. Simplified process flow diagram of the Aluminium process.

---

[7] Data based on statistics from the Ministry of Business, Innovation and Employment (http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/prices).

New Anode Technology

Stage of Availability: Demonstration

In May 2018, Elysis[8], a joint venture including Rio Tinto, Alcoa, the government of Canada, and Apple were building a demonstration plant in Quebec to trial a zero-carbon anode technology that produces oxygen instead of carbon dioxide. The new anode technology is claimed to last up to 30 times longer than current carbon anodes and can be retrofitted into existing smelters. As yet there is no information of capex and opex costs available. A 2024 timeframe for commercial availability has been indicated.

New aluminium smelters cost between €4,000 and €5,000 per tonne of production capacity per year. It is estimated that anode production is 1/3 of the capital cost. Capital costs for Elysis technology (retrofit) is estimated to be 1/3 cost of new plant ($2,000 - $2,500 per tonne of production capacity per year) with no change to opex costs.

Carbon Capture (excluding storage)

Stage of Availability: Pre-commercial

The other potential option is carbon capture using MEA (monoethanolamine) based capture system. The process air CO_2 concentration would need to be 4 vol% to assist the economics. The energy requirement for 85% removal is 3.5 GJ/t_{CO2}[9].

Cement

Emissions from cement manufacturing comprises around 8% of global emissions[10]. Around 70% of the emissions are process related emissions with a significant proportion of these occurring during the calcination reaction of limestone ($CaCO_3$) into lime (CaO). The remaining emissions are associated with the fuel required to provide the high temperature (1450 – 1500°C) required for the process. Typical fuels include coal and natural gas although biomass can also be used to a certain amount.

Currently there is only one cement manufacturing operation in New Zealand operated by Golden Bay Cement. The options listed here are relevant to the local industry and other options discussed for other countries have less applicability in New Zealand.

---

[8] https://www.elysistechnologies.com/en

[9] Mathisen et al., Integration of post-combustion CO_2 capture with aluminium production. Energy Procedia, 63(2014) 660-6610.

[10] Beyond Zero Emissions. Zero Carbon Industry Plan: Rethinking Cement. Aug 2017. www.bze.org.au

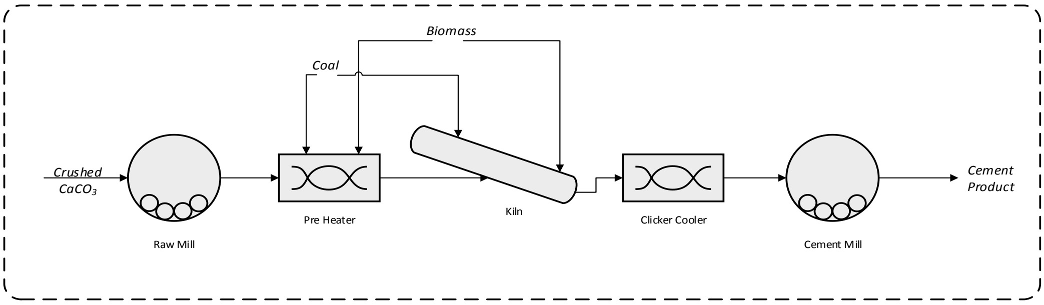

Figure 7. Simplified process flow diagram for cement manufacturing.

Fuel Switching – Tyre Derived Fuel (TDF)

Stage of Availability: Commercial

Cement manufacturing companies use Tyre Derived Fuel (TDF) to supplement their primary fuel for firing cement kilns. Several characteristics make scrap tires an excellent fuel for the cement kiln. The very high temperatures and long fuel residence time in the kiln allow complete combustion of the tires. There is no smoke, odor or visible emissions from the tires. Because the ash is incorporated into the final product, there is no waste.

The US Department of Energy estimated that the combustion of TDF produces less carbon dioxide (CO_2) per unit of energy than coal. This means that when TDF replaces coal in a Portland cement kiln, less CO_2 will be produced. Higher production rates, lower fuel costs and improved environmental quality achieved when tire fuels are combusted in cement kilns continue to define scrap tires as a viable fuel choice for cement kilns.

Energy Efficiency Improvement

Stage of Availability: Commercial, Developing, Pre-commercial

Through energy efficiency and heat recovery improvement the carbon dioxide emissions from fuels and cement production costs can be reduced. Optimisation of the kiln, optimisation of the clinker cooler, pre-heating/pre-calcination efficiency improvement, improvement of the burners, and process control are possible energy efficiency examples.

Calcination Chemistry Improvement

Stage of Availability: Developing, Pre-commercial

Short Description: Another option to reduce CO_2 emissions in the calcination kiln is change in chemistry. In the conventional chemistry calcium carbonate ($CaCO_3$) converts to CaO and CO_2 in about 1450 °C. Minerals such as C2S, C3P, and C3A may be added to the calcium carbonate. The influence of minerals might have an influence on the clinker properties and can have effects on the performance of cements produced with the clinker, e.g. lower early strength or longer setting times which requires closer studies.

Kraft Pulping

A simplified process flow diagram of the Kraft pulping process is shown in Figure 8. Kraft pulping is a highly energy intensive process however is low or zero emission due to the use of biomass/wood as an energy source.

The only emissions come from fossil fuel used to provide supplementary energy to the mill. In NZ there are two kraft pulp mills (Kinleith and Tasman) owned and operated by Oji Fibre Solutions. Both use natural gas as a supplementary fuel source. Kinleith uses waste biomass and Tasman uses waste biomass and geothermal as additional supplementary fuels. Both have complex utility systems that include co-generating electricity.

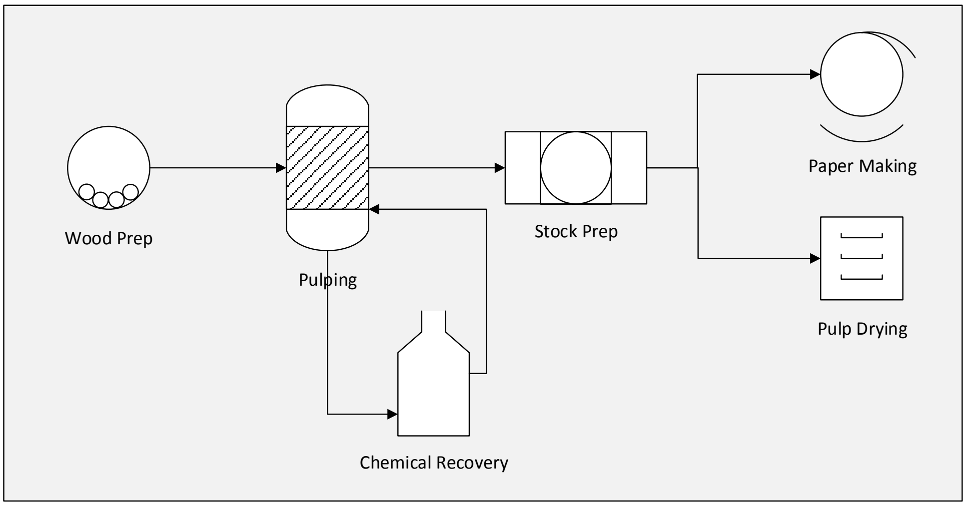

Figure 8. Simplified process flow diagram for Kraft pulping.

Energy Efficiency Improvements

Stage of Availability: Commercial

Both mills have been operating for many decades and there are general efficiency improvements available at each mill. These have been estimated based on past experience in the sector and at these mills. A challenge is with energy efficiency improvements is that the marginal fuel use (e.g. natural gas) may not be affected greatly depending on the project and the steam system.

High Efficiency Recovery Boiler

Stage of Availability: Commercial

Recovery boilers at Kraft pulp mills are essential parts of the process allowing chemicals used in the pulping process to be recovered and reused. Black liquor (a mixture of the pulping chemicals and organic material extracted during pulping) is combusted and the pulping chemicals collected and passed on to the chemical recovery process. The heat generated through combustion in the recovery boiler is used to produce steam to supply heat and power to the mill. Older recovery boilers (such as those in NZ) have a black liquor feed concentration of around 70% solids. Due to the efficiency of the boiler only a portion of the mill's heat demand could be supplied by the recovery boiler. Modern recovery boilers operate at higher feed solids (around 85%) and have higher efficiencies and as a result can produce enough energy to supply a mill's heat and power demand and export energy (typically electricity). Recovery boilers operate at high temperatures (≈600°C) and pressures (>100 bar) and are expensive comprising around 20% of the capex for a new mill.

The potential emissions reduction opportunity with using a High Efficiency Recovery Boiler is that any fossil fuel used to provide supplementary heat to the mill can be reduced or eliminated.

Methanol

Methanol is produced via steam reforming of natural gas to produce synthesis gas (a mixture of H_2, CO and CO_2) before being fed to the reactor that produces a methanol/water mixture. Concentrated methanol is then distilled. A simplified process flow diagram is given in Figure 9. The emissions factor for Methanex NZ is 0.7854 t_{CO2}/t_{CH3OH} (based on EPA Industrial Allocation of NZUs[11]). BAT using natural gas is between 0.54 and 0.67 t_{CO2}/t_{CH3OH}. Methanex reports an overall company weighted emissions factor between 0.653 t_{CO2}/t_{CH3OH} and 0.587 t_{CO2}/t_{CH3OH}. By contrast methanol from coal has an emissions factor of 2.4 to 3.5 t_{CO2}/t_{CH3OH}.

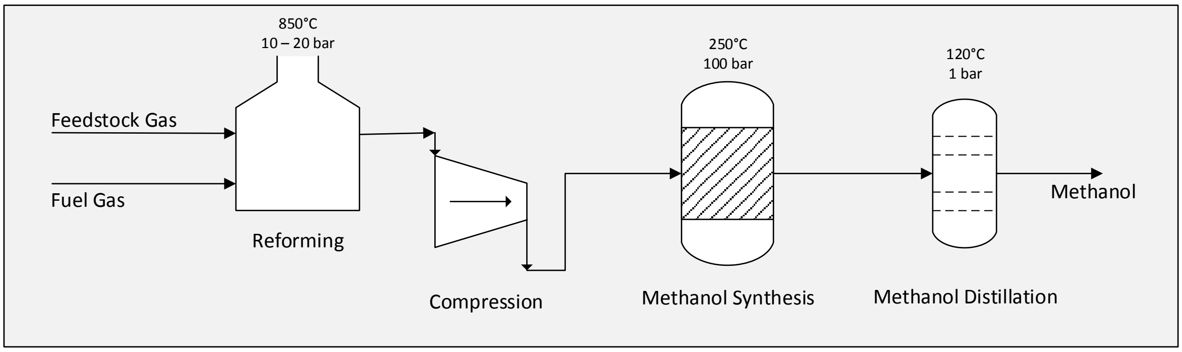

Figure 9. Simplified process flow diagram for methanol production.

Carbon Capture, Storage and Utilisation

Stage of Availability: Commercial

CO_2 from the fuel gas and combustion of fuel gas can be captured and injected into the syngas stream to alter the ratio of CO and CO_2 to H_2 to improve methanol synthesis rates. The optimal ratio[12] is:

$2CO + 3CO_2 \leq H_2$

Conventional Amine based capture technologies for Steam Methane Reforming (SMR) have been considered and extensively modelled[13]. Methanex's Medicine Hat plant in the USA captures CO_2 (from an adjacent facility) and injects to the methanol synthesis process. Methanex has also stated they have considered using of carbon capture and utilisation for their Taranaki operations although extensive capital investment would be required[14].

A capture rate of 90% is assumed. Achieving a 100% capture rate is technically difficult and expensive. A 90% capture rate is an optimal rate for Amine based methods[15].

New Plant Efficiency Improvement

Stage of Availability: Commercial

---

[11] https://www.epa.govt.nz/industry-areas/emissions-trading-scheme/industrial-allocations/eligibility/
[12] Udugama, I.A., 2016, Improving Operations of Methanol Refining. PhD Thesis, Auckland University.
[13] IEA, 2017, Techno-economic evaluation of SMR based standalone (merchant) hydrogen plant with CCS. and Collodi et al., 2017, Demonstrating large scale industrial CCS through CCU – a case study for methanol production. Energy Procedia, 114, 122-138.
[14] Methanex, 2017, Submission on the Productivity Commission Low Emissions Economy Enquiry.
[15] IEA, 2017, Techno-economic evaluation of SMR based standalone (merchant) hydrogen plant with CCS.

The specific energy use for the two NZ sites is around 36 GJ/t_{CH3OH}. The BAT benchmark is 32 GJ/t_{CH3OH}. Assuming a new plant would be required to achieve this, the capital cost of a new methanol plant is between $500 and $700 USD per tonne of production capacity per year. Achieving the BAT benchmark would only reduce emissions by about one third.

Oil Refining

Oil refining is an energy intensive process and a simplified process flow diagram is shown in Figure 10. The Marsden Point Refinery has been operating since the mid-1960s with a major expansion in the mid-1980s. Marsden Point is owned and operated by the New Zealand Refining Company. In 2003 they entered a Negotiated Greenhouse Agreement with the Government. Under this type of agreement they do not participate in the Emissions Trading Scheme but have other conditions and commitments. These are confidential and are not in the public domain. The agreement terminates at the end of 2022. Based on the energy consumption data there have been a slight improvement in specific energy consumption over the past 5 years.

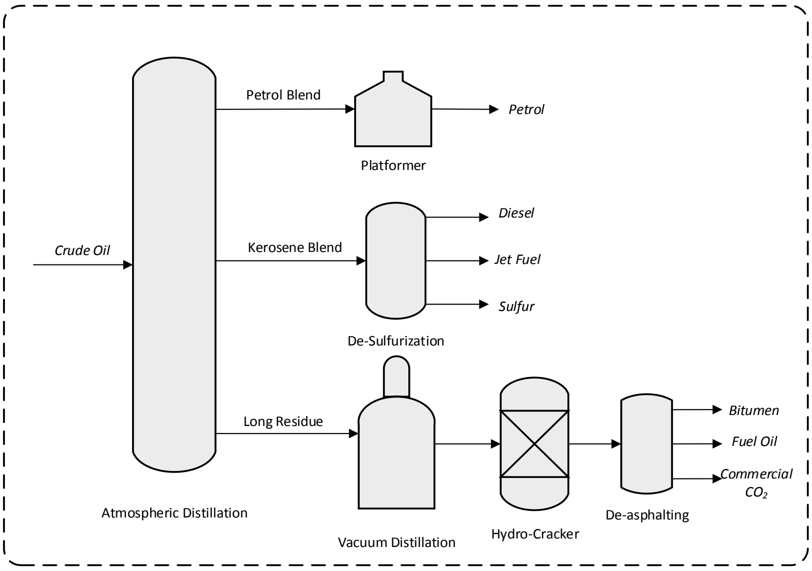

Figure 10. Simplified process flow diagram for refining.

Heat Integration and Waste Heat Recovery

Stage of Availability: Commercial, Developing, Pre-commercial

Industrial energy efficiency can be vastly improved (30-50%) by applying the engineering concepts of Process Integration and Heat recovery for green-field and retrofit design. Heat Integration methods, which include Pinch Analysis preliminary aim to reduce energy, in term of waste heat, and resource emissions in industrial production plants and has been successfully applied across many industries. Pinch analysis has been used regularly and extensively in the refining sector for many decades. Options such as heat transfer enhancement can be also considered to improve heat recovery.

Fouling Mitigation

Stage of Availability: Commercial, Developing, Pre-commercial

Heat Exchanger fouling is a widespread economic problem, accounting for 0.25% of gross national product in the industrialised developed countries; 10 % of energy losses in a crude oil processing is due to fouling, besides fouling generates 10 % of CO_2 emissions in the crude oil refinery. Two main factors are connected with fouling that influence operating performance of heat exchanger network. First, the thermal efficiency increases the thermal resistance, decreases the heat transfer coefficient and enlarges the utility consumption. Second is a hydraulic effect that increases pressure drop, reduce the cross-sectional area of heat exchangers and blocks tubes with flow redistribution. Several solutions for mitigating the fouling in refineries have been studied such as using tube inserts in the tube side or helical baffles in the shell side of shell and tube heat exchangers.

Advanced Process Control

Stage of Availability: Commercial, Developing, Pre-commercial

Advanced process control techniques not only increases process safety features but also can help energy efficiency in a process plant. By implementing new process control techniques hear recovery and utility consumption will be improved, therefore, up to 10 % of emissions can be reduced.

Motors, Pumps, Compressors, and Fans Optimisation

Stage of Availability: Commercial, Developing,

The energy requirement of Pumps, motors, compressors and fans are known as hidden costs in process plants. Fossil fuel-based electricity is as is a source of CO_2 emissions in either direct generation or co-generation within a refinery. To minimise energy loss and emissions operational improvements such as using variable speed drivers for pumps, compressors, and electrical motors in fans and air coolers are suggested to achieve good engineering practices. This can cause about 7 % of CO_2 emission reduction in an oil refinery. Note that in oil refineries steam turbines are used extensively as prime movers for pumps, compressors etc.

Utility System Optimisation

Stage of Availability: Commercial, Developing

At large sites heat can be recovered from process streams and transferred indirectly via the utility system. An example would be using a high temperature stream to generate steam that is then fed into the steam system and used to provide process heating elsewhere on site. This can allow inter-process heat recovery on site and increase overall heat recovery. The selection and optimisation of the utilities involved and used is important for the technical feasibility and economics. Advanced methods within Pinch Analysis known as Total Site Analysis exist to design and optimise this type of heat recovery system.

Renewable Hydrogen Production

Stage of Availability: Commercial, Developing, Pre-commercial

Renewable electricity can be converted into hydrogen through the electrolysis of water, passing an electric current through water, to split into oxygen and hydrogen. Renewable hydrogen can also be combined with carbon to synthesise a range of hydrocarbons, including substitute natural gas. Hydrogen can be burned to fuel industrial heating processes in a similar way to natural gas. It burns at a higher temperature than natural gas and generates 2.5 times more thermal energy per kilogram. The only by-product of burning hydrogen is water. It is possible to modify existing gas heating systems to allow them to burn pure hydrogen.

Distillation Column Substitution

Stage of Availability: Commercial, Developing, Pre-commercial

The divided wall column (DWC) to distillate crude oil is receiving increasing interest in industrial applications due to the potentiality in energy savings. The dividing wall distillation column which is a fully thermal integrated system also brings significant capital cost reduction. In the DWCs, avoiding the mixing of feed and intermediate product at the feed tray results in higher thermodynamic efficiency of distillation since the feed mixing is a key role in the thermodynamic efficiency of the column. Compared to the conventional columns DWCs offer 25 % capital cost reduction and up to 40 % energy reduction which causes emissions reductions.

Steel

A simplified process flow diagram for steel making is shown in Figure 11. There are significant challenges to emissions reduction in the steel making process and it is doubtful that potential measures will be cost effective in the short to medium term. Furthermore any sizable reductions would require significant capital expenditure and be coupled with a high degree of technical risk. One of the main potential reduction measures is the substitution of coal with bio-based coal/coke in the iron ore sintering process, which has not yet been achieved commercially. There are substantial technical problems that still need to be solved before this would be commercially feasible and would also require major redesign of the equipment at considerable capital cost[16,17].

There is currently a NZ based company, Carbonscape, in the process of commercialising a bio-based alternative that it is claimed can be a direct substitute for coal and coke used in the steel making process[18]. The economics, potential scale of substitution, and subsequent technical risk and changes are not able to be evaluated although it is likely that in the short to medium term this will be an economic or technically viable option for large scale emissions reduction at Glenbrook. It should be noted that a large amount of research, especially in China, has been conducted into substitution of bio-based coal/coke alternatives and significant technical and economic challenges remain before this will be a commercially viable option. Furthermore, if this does become a commercially viable option large capital expenditure will be required to facilitate its use.

---

[16] Cheng, Z.-L., Yang, J., Zhou, L., Liu, Y., Wang, Q.-W., 2017, Study on replacement of coke with charcoal and methane in iron ore sintering, Kung Chen Je Wu Li Hsueh Pao/Journal of Engineering Thermophysics, 38, 188-192.

[17] Kuramochi, T., 2016, Assessment of midterm CO2 emissions reduction potential in the iron and steel industry: a case of Japan. Journal of Cleaner Production, 132, 81-97.

[18] Carbonscape, 2016, www.carbonscape.com

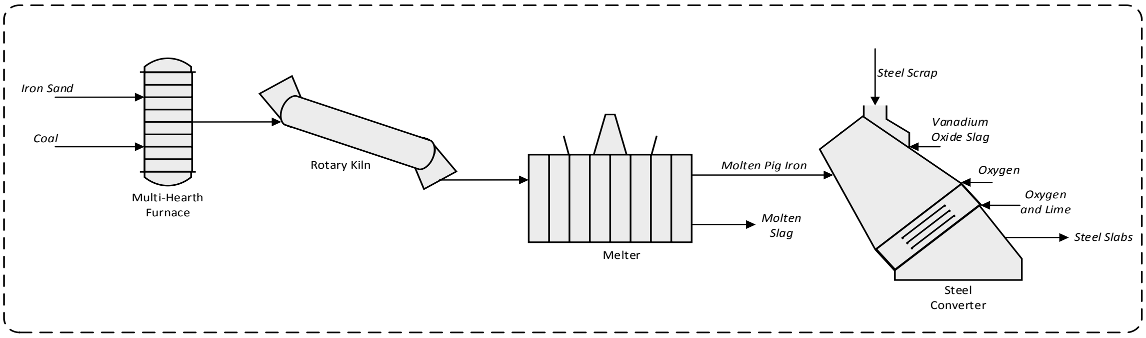

Figure 11. Simplified process flow diagram for steel making.

Carbon Capture, Storage and Utilisation

Stage of Availability: Pre-commercial

CO_2 from the fuel gas and combustion of fuel gas can be captured for sequestration. Conventional Amine based capture technologies have been considered and extensively modelled. A capture rate of 90% is assumed. Achieving a 100% capture rate is technically difficult and expensive. A 90% capture rate is an optimal rate for Amine based method.

Urea

Urea is manufactured using ammonia produced via steam reforming of natural gas as shown in Figure 12. Based on available energy and production data the specific emissions factor for Urea produced in NZ is 1.140 t_{CO2}/t_{urea}[19]. The EPA Industrial Allocation of NZUs is 1.6245 t_{CO2}/t_{urea}. BAT for production of urea using NZ natural gas is 0.865 t_{CO2}/t_{CH3OH} but this can vary significantly depending on the gas supply[20]. The age of the plant is the main factor in the high specific emissions factor. Reducing emissions from urea production has is somewhat similar to methanol production as they both involve steam reforming of natural gas to produce syngas.

Urea can be produced via gasification of biomass or using renewable hydrogen but these have different feedstocks and represent a significant shift in the process.

---

[19] This figure is in line with that calculated by the Parliamentary Commissioner for the Environment. https://www.pce.parliament.nz/media/1291/lignite-appendix.pdf

[20] Worrell et al., 2008, World Best Practice Energy Intensity Values for the Selected Industrial Sectors. https://eaei.lbl.gov/sites/all/files/industrial_best_practice_en.pdf

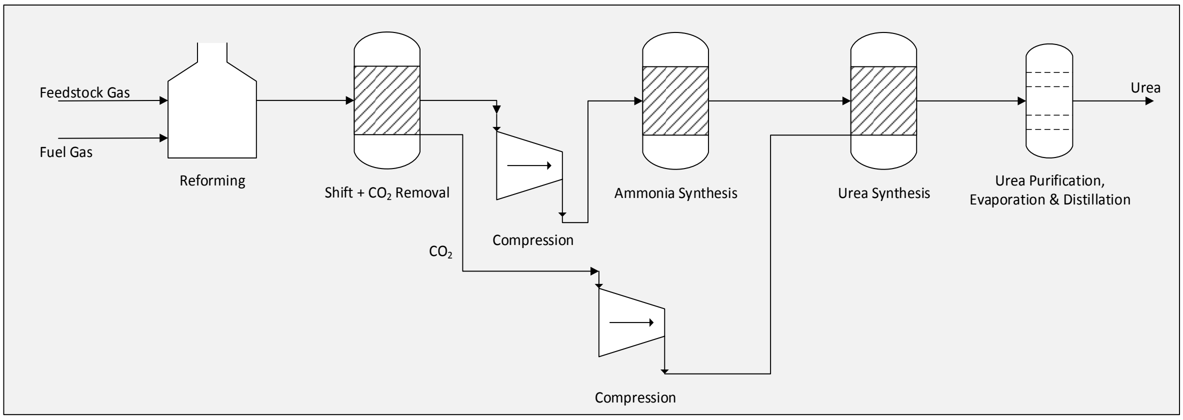

Figure 12. Simplified process flow diagram for urea production.

Carbon Capture, Storage and Utilisation

Stage of Availability: Pre-commercial

CO_2 from the fuel gas and combustion of fuel gas can be captured and reinjected into the process to increase production or for sequestration. Conventional Amine based capture technologies for Steam Methane Reforming (SMR) have been considered and extensively modelled[21]. A capture rate of 90% is assumed. Achieving a 100% capture rate is technically difficult and expensive. A 90% capture rate is an optimal rate for Amine based methods[22].

New Plant Efficiency Improvement

Stage of Availability: Commercial Pre-commercial,

Ballance had been considering investment in a new modern production facility with expanded production. The proposed plant was cost around $1 billion NZD[23]. At that cost it would have included a production increase from around 265 kt_{urea}/y to around 550 kt_{urea}/y. If the new plant meets the BAT emissions factor there would be a reduction in specific emissions per unit of product but an increase in overall emissions due to the increase of production. It is highly unlikely that the new plant included CCS technology. Ballance halted expansion plans in 2017 citing low urea prices and its inability to attract the required investment[24] and more recently has cited the recent ban on off-shore oil and gas exploration as another factor[25].

---

[21] IEA, 2017, Techno-economic evaluation of SMR based standalone (merchant) hydrogen plant with CCS. and Collodi et al., 2017, Demonstrating large scale industrial CCS through CCU – a case study for methanol production. Energy Procedia, 114, 122-138.

[22] IEA, 2017, Techno-economic evaluation of SMR based standalone (merchant) hydrogen plant with CCS. and Collodi et al., 2017, Demonstrating large scale industrial CCS through CCU – a case study for methanol production. Energy Procedia, 114, 122-138.

[23] https://www.newsroom.co.nz/2018/05/07/107731/urea-plant-upgrade-hangs-in-the-ballance

[24] https://www.stuff.co.nz/business/industries/96476275/ballance-agrinutrients-kept-waiting-for-investor-to-build-new-kapuni-plant

[25] https://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=12143888
http://www.scoop.co.nz/stories/PA1809/S00344/woods-rattled-as-ban-scares-off-investment.htm

Renewable Hydrogen Production

Stage of Availability: Commercial, Developing, Pre-commercial

Renewable electricity can be converted into hydrogen through the electrolysis of water, passing an electric current through water, to split into oxygen and hydrogen. Renewable hydrogen can also be combined with carbon to synthesise a range of chemicals such as ammonia, urea, etc. Large scale hydrogen production from electrolysis would require around 175 MW_{el} for the current production rate.

Dairy

The dairy sector is a significant user of industrial heat with an estimated 72% of thermal energy being used in the production of milk powder. A simplified process flow diagram for a typical New Zealand milk powder process is shown in Figure 13. For most modern milk powder plants approximately 80% of the water removal from raw milk is achieved with mechanical vapour recompression (MVR) driven using electricity. This is highly efficient and being predominantly grid sourced electricity is also relatively low in carbon emissions. The remaining water is removed in the spray drying process which has inherently low thermal efficiency. Alternative drying methods have been proposed for many years but are not used commercially for many reasons such as scale, product quality or practical considerations. New Zealand has the largest and most efficient milk powder spray dryers in the world, although there is opportunity for further reduction in demand and electrification[26].

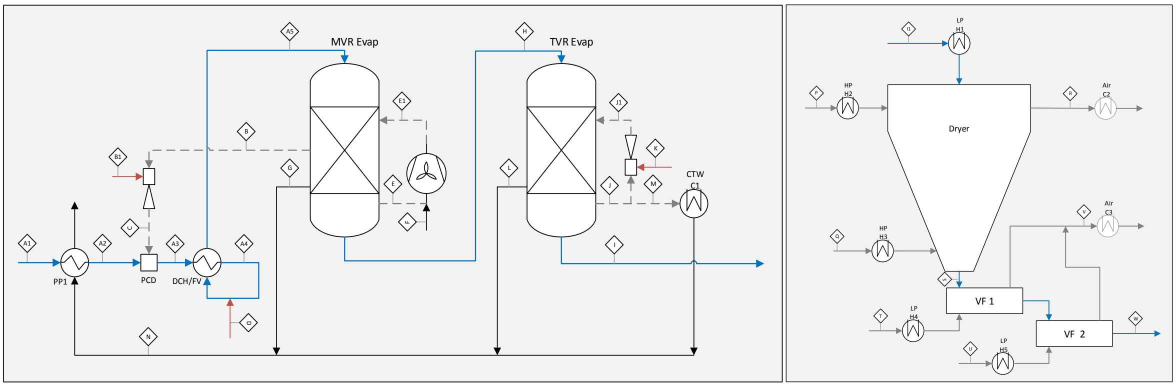

Figure 13. Simplified process flow diagram of a milk powder plant using MVR/TVR.

The remaining dairy processes include butter and cheese making, and ultra-high temperature processing (UHT) milk, amongst others. These have typically low temperature requirements (sub 100°C) and have much lower specific energy consumption values.

Milk Powder – MVR & DSE TVR

MVR Replacement (Finishers)

Stage of Availability: Commercial

---

[26] Walmsley, T.G., Atkins, M.J., Walmsley, M.R.W., Philipp, M., Pessel, R.H. (2018). *Process and utility systems integration and optimisation for ultra-low energy milk powder production.* Energy, 146:67-81.

This replaces the thermocompressor (TVR) in the Evaporator Finisher with a MVR fan to provide the temperature lift to the last evaporator stage. This removes need for live steam (K) and will eliminate condenser and cooling water requirement (Figure 14). Thermal duty is replaced with electrical duty at a much higher efficiency/COP. The MVR fans required are smaller, high-speed fans.

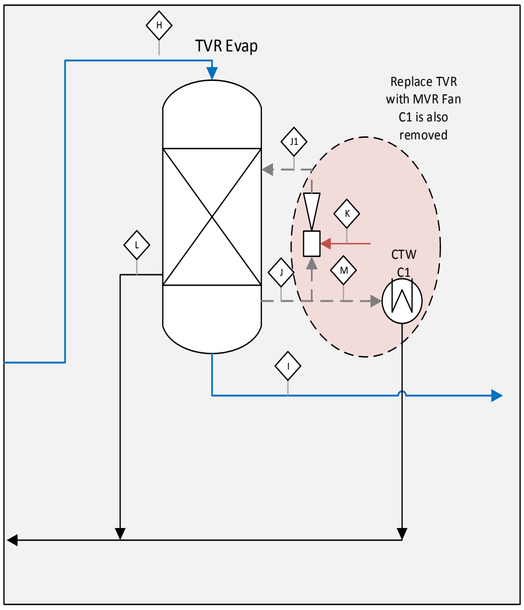

Figure 14. Replacement of TVR with MVR on final evaporator stage prior to the spray dryer.

MVR Replacement (Preheater PCD)

Stage of Availability: Pre-commercial

This replaces the thermocompressor (TVR) before the PCD pre-heater with a mechanical vapour recompression (MVR) fan to provide temperature lift to vapour entering the PCD. This removes the need for live steam (B1) (Figure 15). Thermal duty is replaced with electrical duty at a much higher efficiency/COP. Vapour flow to PCD is also reduced by B1 but the total evaporation load is also reduced by B1. The MVR fans required are smaller, high-speed fans.

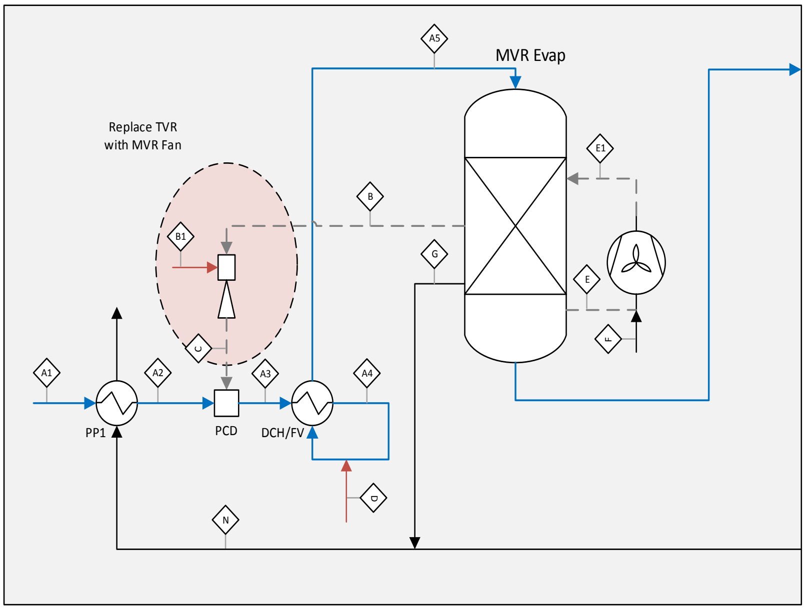

Figure 15. Replacement of TVR with MVR PCD pre-heater prior to evaporator.

MVR Replacement – DSI TVR

Stage of Availability: Commercial

This replaces the thermocompressor (TVR) at the start of the evaporator train with MVR fan(s) as required. Several configurations are possible depending on the number of evaporator effects. These types of evaporators typically have between three and seven effects and are configured as shown in Figure 16.

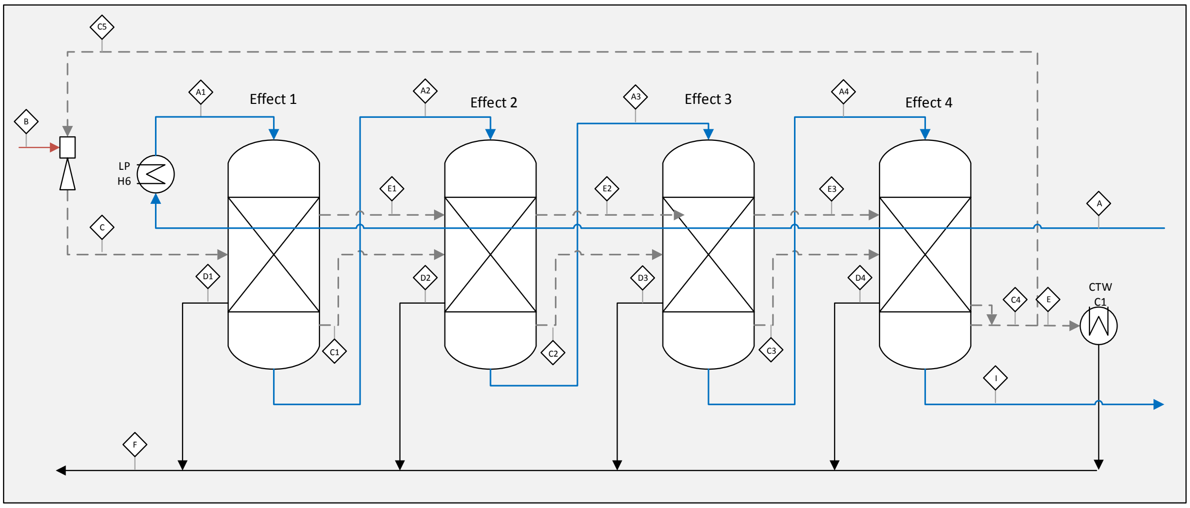

Figure 16. Simplified process flow diagram of a milk powder evaporator using DSE TVR.

Dryer Exhaust Heat Recovery

Stage of Availability: Commercial

Sensible heat is recovered from the exhaust air of the spray dryer and used to preheat the main dryer inlet air. Other heat sinks maybe used (Figure 17). Typically indirect heat exchange is preferred due to operational and space constraints. To avoid excessive powder fouling from sticky powder, bag houses on the dryer are required and the exhaust should not drop below around 50°C.

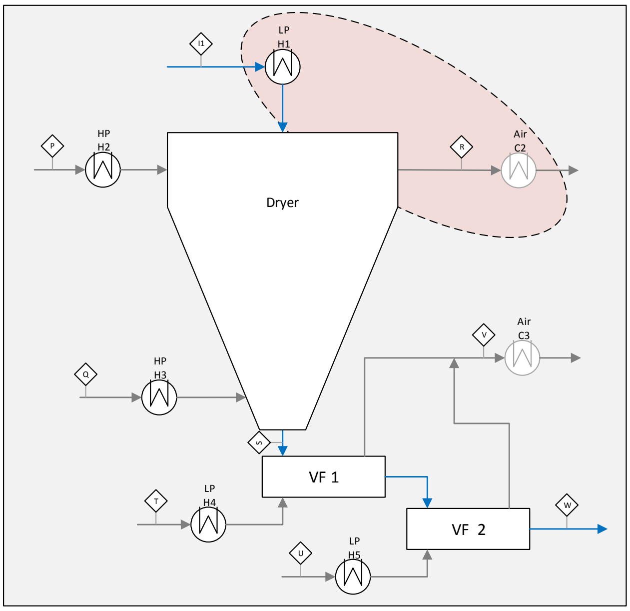

Figure 17. Spray dryer exhaust heat recovery with inlet air preheating.

Low Temperature Heat Pump (to secondary air)

Stage of Availability: Commercial

Heat pumps are used to produce hot water (≈90°C) which is then used to preheat secondary dryer air (Figure 18). It is assumed that there is suitable low temperature (<30°C) waste heat external to the powder plant that can be upgraded using a conventional vapour compression cycle.

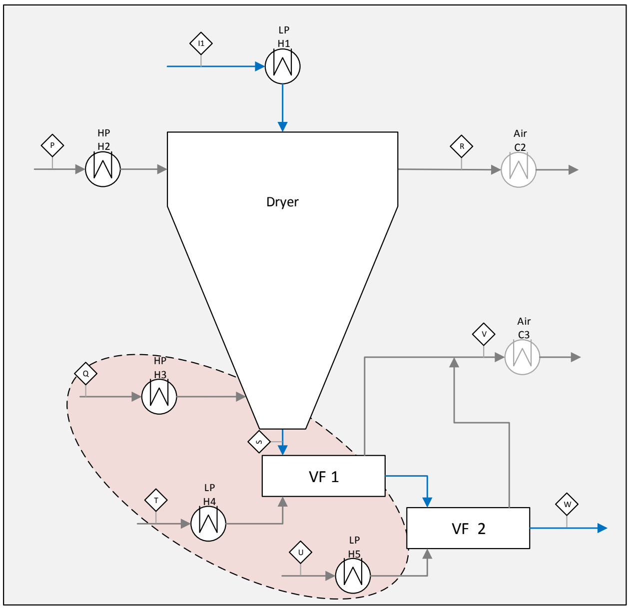

Figure 18. Secondary dryer air preheating using low temperature heat pumps.

Other Dairy Processes

Heat Recovery

Stage of Availability: Commercial

There is often opportunity for increased heat recovery in many other dairy processes. Typically a large amount of heat recovery is already performed although more can be achieved by reducing the minimum approach temperature by increasing heat exchanger surface areas. Factors such as heat exchanger fouling, hygiene and product quality need to be carefully considered before the approach temperatures are reduced. Approach temperatures of 2 – 3 °C can easily be achieved using a plate heat exchanger.

Food Processing

Electrotechnologies

A number of electrotechnologies exist that could be used for different aspects of food processing. These include for sterilisation, pasteurisation, thermal processing, cooking, and heating, and non-thermal processing alternatives[27]. Examples include pulsed electric field, microwave and radio-frequency heating, ohmic heating, and ultra-violet radiation[28]. The efficiency can be improved however it is important to note that the effects on other production aspects such as food quality and safety also need to be carefully considered.

Meat Processing

Slaughtering

The primary heat demand in a meat processing plant conducting slaughtering and carcass processing is for hot water at three main temperature levels:

- Knife sterilisation is a major hot water demand and must have hot water delivered at the point of use at a minimum of 82°C. This is both a regulatory requirement from the Ministry of Primary Industries (MPI) and a market expectation. Alternative methods for sterilisation are not allowed or acceptable to the market.
- Hot water between 55 – 65°C is used for cleaning and other purposes
- Hot water at 45°C for personal and hand wash.

Some sites also require a small amount of steam.

Efficiency – Meeting Benchmark Specific Energy Consumption

Stage of Availability: Commercial

---

[27] Knorr, D., et al., K. 2011, Emerging technologies in food processing. Annual Review of Food Science and Technology, 2, 203-235.

[28] Roohinejad, S., Parniakov, O., Nikmaram, N., Greiner, R., & Koubaa, M. (2018). Energy Saving Food Processing. In Sustainable Food Systems from Agriculture to Industry (pp. 191-243). Academic Press.

The major factor in the efficiency of a meat processing plant is the consumption of hot water, especially steriliser water use. Sensor technology exists to limit the water use as required or alternatively where sensors are unsuitable (such as for sheep processing) recommended flow rates can be met through the correct system set-up. Good house-keeping is also important to meet efficiency benchmarks. These measures require some alternations to current systems and in some cases hot water and storage distribution systems will required upgrading.

Heat Pumps

Stage of Availability: Commercial

Heat pumps can be used to provide a significant proportion of hot water demand by upgrading the waste heat from on-site refrigeration plant. The use of storage and the timing of the operations is an important consideration to enable this. Some sites will require additional (non-heat pump) hot water generation or temperature increases due to site-specific considerations. Integrating heat pumps into meat processing still requires following process integration principles to get appropriate integration into the system, but this is relatively straight forward due to the nature of the process.

Rendering

The rendering sector analysed here assumes that rendering occurs at integrated rendering plants (i.e. includes the slaughtering and carcass processing described in the slaughtering section). There are also standalone rendering facilities however the specific energy consumption data is for integrated plants. Rendering converts waste animal tissue and blood into commercially valuable products such as tallow, bone meal, etc.

Efficiency – Meeting Benchmark Specific Energy Consumption

Stage of Availability: Commercial

Aside from implementing the efficiency measures outlined in the slaughtering section above, high efficiency can be achieved through heat recovery for hot water production supplied to the slaughter house operations, good housekeeping, process control, etc.

Electrification of Meal Drying

Stage of Availability: Pre-commercial

The drying of protein meal (meat and bone meal etc.) can be performed using electrically based drying technology such as microwave or infrared. This would represent a major change in the sector although currently these are unproven or have not had widespread application[29].

---

[29] Zhang, L., Yin, B., Rui, H. 2013, Effects of microwave rending on the yield and characteristics of chicken fat from broiler abdominal fat tissue. Journal of Food Science and Technology, 50:1151-1157.

Wood Processing

The wood processing sector can be divided into two main subsectors, sawmills and board mills (e.g. medium density fibreboard, particleboard, plywood, etc.). Typically the wood processing sector utilises wood residues and wastes to provide energy. Geothermal heat is used in the central North Island for timber drying. There approximately 2.9 PJ (10% of the sector primary energy demand) of fossil fuel used for wood drying operations across the main subsectors. This also occurs across both North and South Islands. The drivers for this are somewhat unknown although it will be most likely due to a lack or imbalance of processing residues, energy cost, or assets legacy issues on site.

Continuous Drying Kilns

Stage of Availability: Commercial

A major improvement in the drying of sawn lumber is from the use of continuous drying kilns. These operate in a counter-flow type fashion and with two charges being dried and air and heat being transferred/recovered between the charges. This can significantly improve efficiency and can improve quality. There is a major supplier of these kilns internationally located in Porirua, Wellington[30].

---

[30] Windsor Engineering. www.windsor.co.nz