Technology scan

New technology opportunities for coffee manufacturers

May 2024

Produced by CS Russell Engineering Services

Introduction and methodology

Introduction

New Zealand Specialty Coffee Association Incorporated (NZSCA), with support from EECA (the Energy Efficiency and Conservation Authority), commissioned a report as a global scan, that focuses on coffee roasting processes and exhaust air emission reduction.

EECA's Sector Decarbonisation Programme offers New Zealand coffee roasters access to tools and resources that help them take positive action towards emissions reduction and adapt for a low-carbon future.

In New Zealand, fossil fuels used to produce an average batch of beans is responsible for an estimated 80% of process related emissions. A survey by EECA suggests coffee roasting likely contributes about 4kT CO2e primarily from the use of natural gas during the roasting process. In a coffee roastery gas used within the drum roaster and thermal afterburners is responsible for most of the emissions.

This global technology scan provides recommendations for decarbonisation, energy efficiency, high-impact opportunities and additional technologies for consideration.

Methodology

Fuel switch alternatives for drum roasting

Demand reduction opportunities for air quality equipment

Heat recovery retrofit possibilities

The focus of this report was on the stationary energy use. Whilst exploring alternatives for emissions reductions it is recommended that good energy practices are followed first.

A key focus was on limitations with sizing and application to larger coffee roasters and the ability to retrofit technologies to current assets. The process of analysis took on the following stages and considerations:

- An investigation of available coffee roasting, odour and particulate matter emissions reduction technologies
- Collation and analysis of representative NZSCA members coffee roasting energy consumption data
- Identification of the coffee roasting processes, mass balances and heat balances
- Review of current coffee roasting processes to comply with local Territorial Authorities' air quality consent requirements
- Review of coffee roaster technologies
- Review technologies available to address the requirements for odour and particulate emission reduction (contaminant discharge)
- A summary of the main benefits and limitations of the available options
- A criteria has been used to score each opportunity. Please refer to Appendix (pg 31) for more information on this

Overview of the roasting process

Starting with a selected batch of green coffee beans, the coffee roasting process involves three successive coffee roasting phases. These are: -

1. **Coffee bean drying** - Drying aims to eliminate moisture inside the bean. The bean temperature rises, moisture turns to water vapour within the beans and diffuses out, then the coffee beans begin to change colour (yellowing). The internal steam pressure causes the coffee bean to expand, and the chaff is released.

2. **Maillard reaction or pyrolysis reactions** - The coffee roasting Maillard reaction stage triggers a series of physical, physicochemical, and chemical processes that influence the sensory properties of roasted coffee beans (colour, taste, and aroma). During this stage, the coffee bean experiences a rapid rise in temperature due to exothermic reactions within the bean. The commonly recognised coffee bean roasting stages are referred to as the 'first crack' and the 'second crack'.

3. **Cooling** - The cooling stage is primarily to rapidly halt the roasting process and avoid over development of the coffee aromas. Cooling the roasted beans can be initiated by injection of water into the roaster environment (quenching) and/or dumping the roasted beans onto an agitated cooling tray with ambient forced air to create a fluidised bed of roasted beans.

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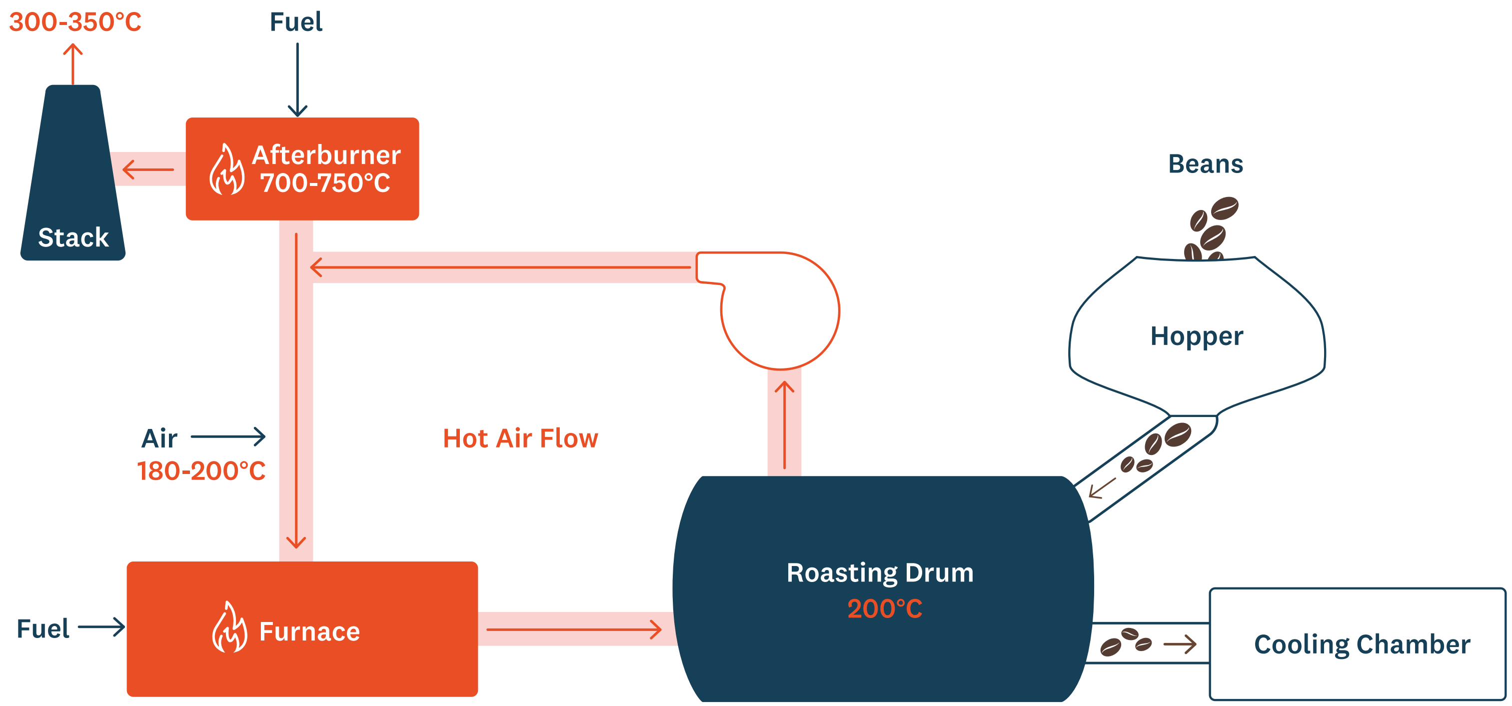
Overview of the roasting process



Sourced from sciencedirect.com

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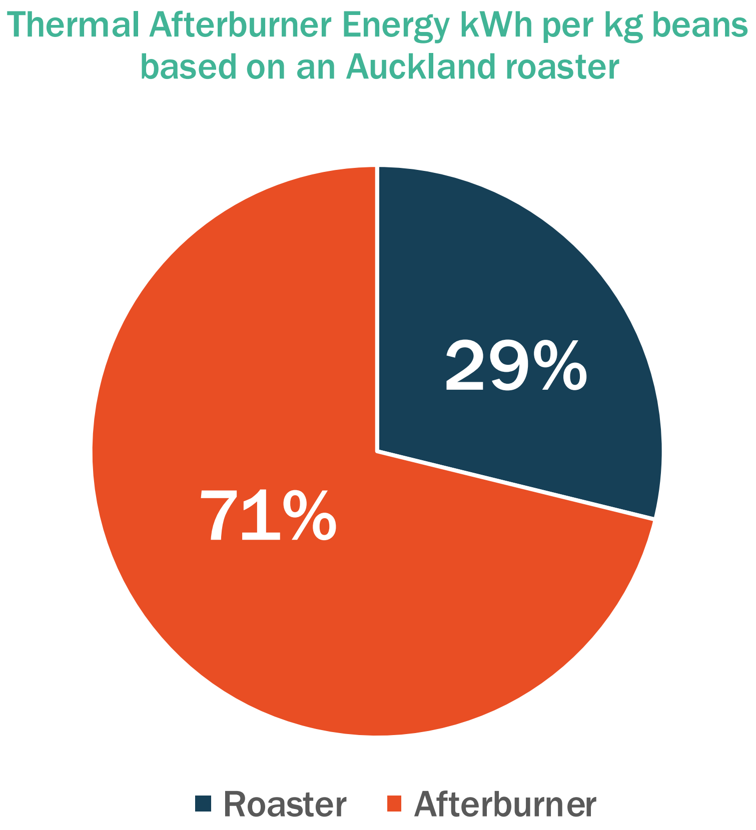
Thermal energy use in coffee roasting

This research undertook a collation of New Zealand coffee roaster's data, including a range of sizes and regions across the country. This was found to be comparable to overseas data concluding that New Zealand's roasting processes are reflective of the international market.

The energy consumption chart includes thermal incineration afterburner data. This is reflective of Auckland Council (where this roaster is located) requirements for discharge of contaminants into the air, which requires rigorous thermal heating demands to meet air quality for consent. Every region currently has differing requirements for businesses to meet for air discharge consent.

The two key roasting processes that have the potential for new technologies to be applied are roasting and afterburners. These processes are where most coffee roasting energy demand takes place.



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Fuel switching

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Fuel switch alternatives for drum roasting

Drum roasting - overview

Coffee drum roasters are the most common type of coffee roasters. The drum roasters feature a solid drum that rotates with a gas flame to heat the coffee beans. The beans receive conductive heat transferred by making direct contact with the surface of the drum and convection heat transferred from the heated air inside the drum. Paddles inside the drum mix the beans as the drum rotates, ensuring the beans receive the right blend of conductive and convective heat.

In small coffee roasters, the heated air may pass through the roaster as a single pass. For larger commercial coffee drum roasters, a percentage of the roaster is exhausted and hot air is recycled back into the drum to improve the roasting energy efficiency. The exhausted air typically requires an air quality system added to the coffee roasting process in the form of a thermal afterburner.

Fuel switching explores alternative fuel sources to natural gas and LPG such as the use of electricity and hydrogen drum roasters.

Electric heated roasters

Summary

New Zealand has a highly renewable electricity grid which makes transitioning to electricity as the energy source a low emissions opportunity. Electrically heated coffee roasters eliminate the need for gas. Currently the philosophy of heating the beans via either/ or conductive and convective heating remain the same. However, for an electric roaster the heating medium is via an electric element rather than the alternative gas fired furnace.

There is potential for a temperature lag if requiring change to unique profile step changes and this must be considered (i.e., electric roasting isn't as responsive as traditional roasting). In addition, maintenance requirements include heating element replacement is recommended every 5-6 years. This is relatively similar cost to preventative maintenance of a standard gas fired roaster.

Case Study - Beyers Koffie and the construction of the first industrial-scale, fully electric coffee roasting line was announced in 2023

[Sustainable roasting tech: Industrial Scale | Beyers]

Suppliers

- Giesen coffee-roasters
- Probat
- Beyers – Taking coffee further
- Bellwether Coffee

Electric roaster score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
5	2	3	3	1	14

Refer to appendix for rating information

Hydrogen roasters

Summary

Hydrogen is an alternative gas that can be used for drum roasting. When combusted, hydrogen does not release the same carbon dioxide (CO2) and carbon monoxide (CO) as LPG or natural gas fired coffee roasters. Therefore, is considered a low carbon alternative fuel source.

How hydrogen combusts within a burner is different to conventional natural gas and therefore requires another heating furnace. The gas route of hydrogen also requires an upgrade as valves and materials used must be those appropriate for hydrogen.

Probat, a supplier of these roasters, notes that the installation of the hydrogen roaster is quite easy for customers to implement with existing infrastructure. Retrofitting hydrogen heating is currently possible for <12kg roaster built after 2021.

Case Study - [Probat unveils its first hydrogen-powered shop roaster - Global Coffee Report (gcrmag.com)]

Suppliers

PROBAT

Hydrogen roaster score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
5	3	1	2	2	13

Near infra-red roasters

Summary

The primary difference from an electric roaster is that near infra-red (NIR) utilises radiation heating in addition to just convective and conducive heating of the beans and drum. NIR heating uses a central heating element positioned within the drum roaster which provides the radiative heat to the drum and coffee beans. The air is introduced and controlled through a centre core where the NIR element is positioned. This results in approximately 50% less energy consumption due the effective heat method.

Advantages:

- Low comparable energy consumption
- Primarily radiation heating of beans
- Low roaster exhaust temperatures
- 6kg roaster in development
- Ability to develop unique flavour profiles
- Short roasting cycle times (9-10 minutes)

Limitations

- Currently available in 600g, 1kg or 3kg roaster

Case Study - Frank Hsu, - Frank's uses infrared technology in its roasting process [Frank's Wellington]

Suppliers

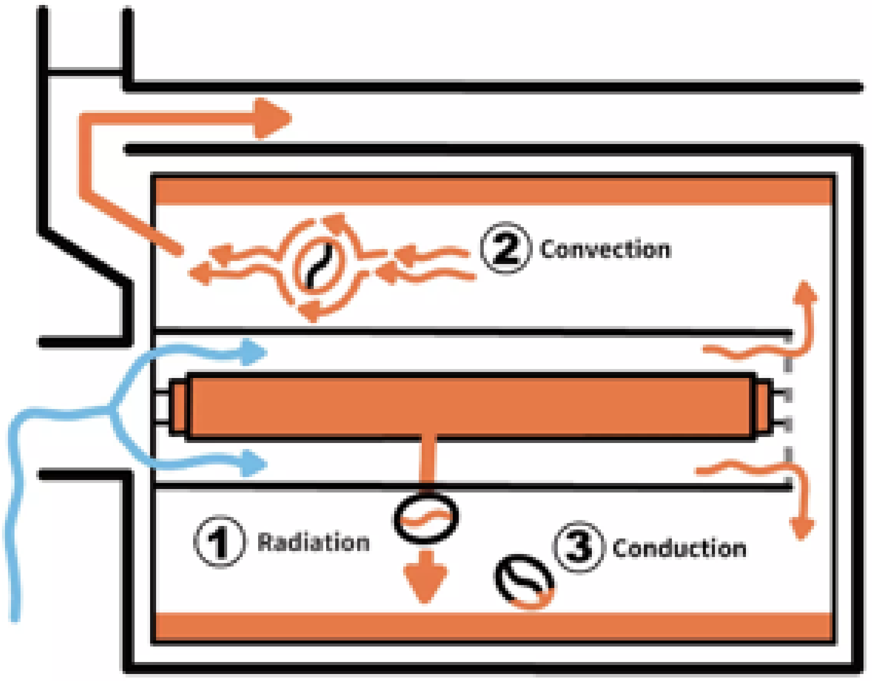
RUBASSE

NIR roaster score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
5	5	5	4	1	20

Near infra-red roasters

Example



Comparative energy requirements and budget cost of alternative drum roasters

Notes of comparisons

Energy requirements and costs

- The table shows the cost differential is minor for alternative fuel options compared with the conventional natural gas models.
- However, NIR demonstrates significantly reduced energy requirements than the alternative electric models.
- Alternative fuel roasters (other than NIR) require currently a 1 for 1 heating. Therefore, consideration into local fuel pricing and availability must be considered.

Emergent technologies

- Technologies that use lower emissions fuel sources such as electricity and hydrogen are under development
- Technologies that are suitable for larger scale roasting operations are expected to become available on the market soon.

Comparative costing

- Probat is renowned for high quality resulting in a reflective higher prices then alternative brands

Roaster Nominal Heat Loads

Model and Roaster Size	Natural Gas Burner	Electric Heating	Hydrogen burner
Probat P01 – 1kg batch		11 kW	
Probat P05 – 5kg batch	14 kW	14 kW	14 kW
Probat P12 – 12kg batch	28 kW	28 kW	28 kW
Probat P25 – 25kg batch	60 kW		
NIR 3kg Professional		6 KW	

Comparative Budget Costs of Coffee Roasters (NZD CIF)

Model and Roaster	Natural Gas Burner	Electric Heating	Hydrogen Burner
Probat P05	$65,000	$70,000	$65,000
Probat P12	$75,000	$87,500	
NIR 3kg Professional		$38,500*	

Cost comparison:
CIF (cost, insurance, freight) – quoted based on landed at NZ port dated April 2024 *Exchange rate at time of report USD 1:1.69 NZD

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Demand reduction

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Demand reduction opportunities for air quality equipment

Thermal incinerator afterburners overview

Thermal incinerator afterburners are the most common type of air quality solution within traditional coffee roasters. They are relatively simple and cost-effective. Thermal afterburners operate by heating the roaster exhaust air to burn off the volatile organic compounds (VOCs) and pollutants produced during the roasting process. A straight thermal incinerator afterburner has a combustion chamber and does not include any heat recovery of exhaust air.

The Ministry for the Environment Good Practice Guide for Assessing Discharges to Air From Industry discusses thermal incineration as a possible management option for VOC removal and as such some of the New Zealand councils have included minimum coffee roaster exhaust air discharge temperature (for example Auckland Council requires some size roasters to meet 700°C to 760°C).

Currently the high temperatures in the thermal afterburner chamber are typically achieved using fossil gas or LPGs as a fuel source and are energy intensive.

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Catalytic converter afterburner

Summary

Catalytic converter afterburners work like the standard thermal incineration, whereby the exhaust gases pass through an open flame area. Where they differ is that in addition to this, the exhaust gas then enters a catalyst bed. The catalyst bed increases the oxidation reaction rate and enables conversion of VOCs at lower reaction temperatures and particulate removal than in thermal afterburner. This can be achieved at a lower exhaust to air temperature (315°C to 400°C) resulting in energy demand reduction.

The catalytic converter afterburner is mounted downstream of the chaff collecting cyclone. The system raises the temperature of the exhaust gases from the coffee roaster to the required operating temperature, to maximise destruction of the vapours and particulate matter in the exhaust stream.

Advantages:

- Neutralises smoke, odours & VOC
- Energy demand is 33% less
- Can be retrofitted to existing roasters
- Compact systems
- Monitoring of process temperature quarterly

Limitations:

- Still requires the input of gas to reach initial temperature
- Energy demand is more than the energy to roaster
- Replacement of the catalyst every 3 years
- Council consent considerations and discussions

Suppliers

Model	Batch Size (kg)	Capacity (Nm³/h)	Cost (NZD)*
ReiCat 100	5	100	$ 17,500
ReiCat 450	5 – 30	450	$ 29,750
ReiCatino 600	30 – 60	600	$ 46,850
ReiCat Ind 1600	75	1,600	$ 137,850
Clean Stream CSA-200-CAT	25	340	$ 33,800
Clean Stream CSA-400-CAT	30	680	$ 40,500

CAT afterburner score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
4	2	4	5	3	18

*Freight, Insurance and installation additional costs to be considered. Exchange rate at time of report USD 1:1.69 NZD, EURO 1:1.81 NZD

Catalytic converter afterburner

Example

Wet scrubber system

Summary

Wet scrubber systems use water to scrub the exhaust gases. The gas is passed through a series of spray nozzles, which apply a fine mist of water to the gas stream. The water removes the VOC's and particulates. The water from the wet scrubber process is collected in a holding tank. This system means open flame thermal incineration is not required and therefore provides the largest resulting energy and demand reduction.

The unit has the capacity to reduce the temperature of the incoming air to below 50C, well below the point of condensation of coffee VOCs. Centrifugal forces within the cyclone forces the particulate matter and VOCs to the side wall to be entrained in water and washed out.

Advantages:

- Produces no CO2, CO or NOx
- Captures CO2 from the roaster itself
- Significantly lower energy demand to remove the coffee odours and particulate matter
- Stack and cyclone are warm to touch; no risk of injury, no need for double wall ducting

Limitations:

- Only one quality supplied identified - VortX
- Space required at floor level
- Handling and finding an alternative use of the water exiting the system

Suppliers

VortX Kleanair Systems

Model	Batch Size (kg)	Capacity (Nm³/h)	Cost (NZD)*
VortX EcoFilter	60	1,360	$ 27,000
Retrofit VortX EcoFilter to Giesen W15a	15	765	$ 34,000
Retrofit VortX EcoFilter to Probat P12	12	260	$ 42,190

Wet afterburner score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
5	5	5	4	3	22

*Freight, Insurance and installation additional costs to be considered. Exchange rate at time of report USD 1:1.69 NZD, EURO 1:1.81 NZD

Wet scrubber system

Example

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Electrostatic precipitators

Summary

Electrostatic precipitators (ESP) are a filtering process for combustion gases, using an electrical charge to remove VOCs and particulates from the exhaust gas stream from the drum roaster. ESP systems work by passing the exhaust gas through a series of plates, which are charged with a high voltage. These plates then use electrical current to break down VOCs and particulates to remove them from the combustion gas.

The optimal performance of the plates occurs when the exhaust air is cooled below 60-70°C. Therefore, additional stack cooling processes are required. If exhaust air is not cooled, the hot particulates within the exhaust gases will coat the electrostatic plates reducing effectiveness.

Advantages:

- ESP media is low cost
- Can be retrofitted and positioned above ground level.
- Systems available for coffee roaster (1-200kg batch).
- No gas required to operate

Limitations:

- Exhaust air needs to cool down below 60-70 °C for optimal performance prior to entry into EPS – additional cost
- ESPs reportedly less effective than other emission reduction systems.
- Electrostatic precipitator media requires regular replacement
- Multiple ESPs required for larger roasters, connected in parallel, increasing cost
- Pressure water cleaner required to clean the collector plates before re-inserted into the ESP.
- ESP acts like a resistor in the exhaust air which requires higher roaster fan operating speed – roaster fan speeds must be considered as fan may require upgrades

Suppliers

DUSTEX THE DUST EXTRACTION EXPERTS

DR. AIRE Ruihe

ESP modules	Roaster size	Cost (NZD)*
Retrofit to Giesen W15a	Roaster batch size 15 kg	$16,400
Replacement elements	Mesh Filters, Ionizer & Collector	$8,190
Retrofit to Giesen W15a	Roaster batch size 15 kg	$16,400

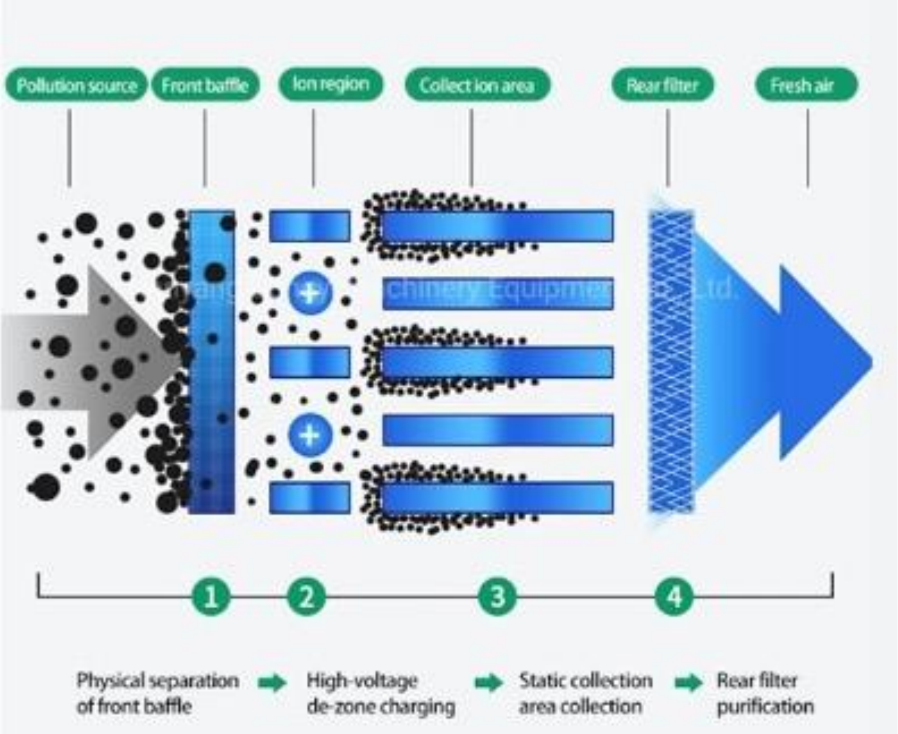
ESP afterburner score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
5	4	2	3	2	16

*Freight, Insurance and installation additional costs to be considered. Exchange rate at time of report AUD 1:1.09 NZD – Air cooling equipment not included

Electrostatic precipitators

Example



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Heat recovery

Heat recovery and retrofit opportunities

Heat recovery overview

Heat recovery is the method of capturing waste heat from the roaster exhaust and reusing this heat in the roasting process for the purpose of energy efficiency gains and reduction in fuel spend.

Currently, most roasters in New Zealand do not have heat recovery mechanisms in their roasting process in place.

Heat recovery provides opportunity to optimises the energy demand of the coffee roasting process by using waste heat to pre-heat either incoming air or beans, and substantially reducing energy demand of the site in the process.

[Heat Recovery - Reduce Heat Waste | Gen Less]

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Heat recovery

Summary

Air pre-heating uses a heat exchanger to extract heat energy from the roaster exhaust gases to pre-heat the incoming process air (fresh air or combustion air). This could save up to 30% on energy costs.

Pre-heating green beans - the exhaust gases heat can be used to pre-heat the green coffee beans before dropping the beans into drum. This could save up to 15% on energy costs.

Advantages:

- Heat exchangers can save on energy demand by reusing heat from the roaster
- Pre-heating the coffee beans can provide up to a 15% energy saving for the roaster

Limitations:

- Pre-heating green beans requires an additional process vessel to the coffee roasting process.
- Capital costs
- Building space requirements to be considered.
- Suitable only for large roastery processes

Case Study - [A landmark for the coffee industry | Inspiration Hub | Bühler Group (buhlergroup.com)]

Suppliers

BÜHLER exodraft BRAMBATI PROBAT

ESP Modules	Roaster Size	Costs NZD*
Retrofit to Giesen W15a	Roaster batch size 15 kg	$16,400
Replacement elements	Mesh Filters, Ionizer & Collector	$8,190

Air pre-heating score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
3	2	4	3	3	15

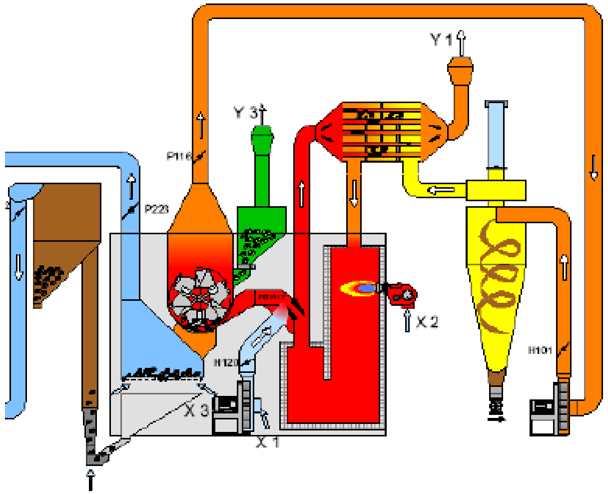
Bean pre-heating score

GHG	Capex	Opex	Technical maturity	Plant modifications	TOTAL
4	1	5	3	3	16

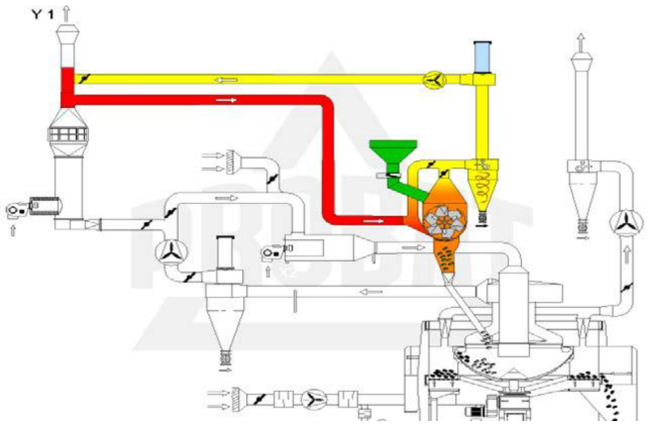
*Freight, Insurance and installation additional costs to be considered. Exchange rate at time of reportAUD 1:1.09 NZD – Air cooling equipment not included

Heat recovery

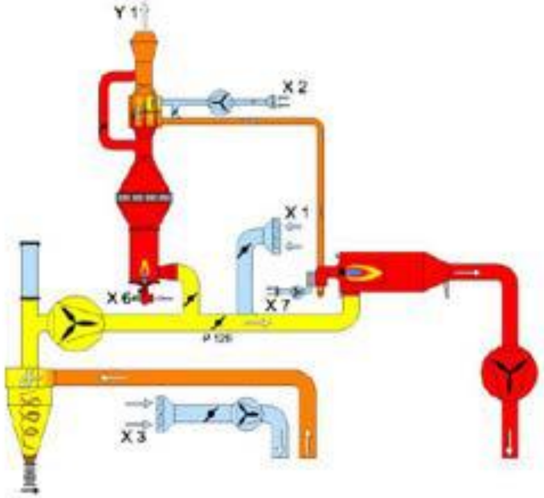
Example



Pre-heating fresh air



An additional mixing chamber required



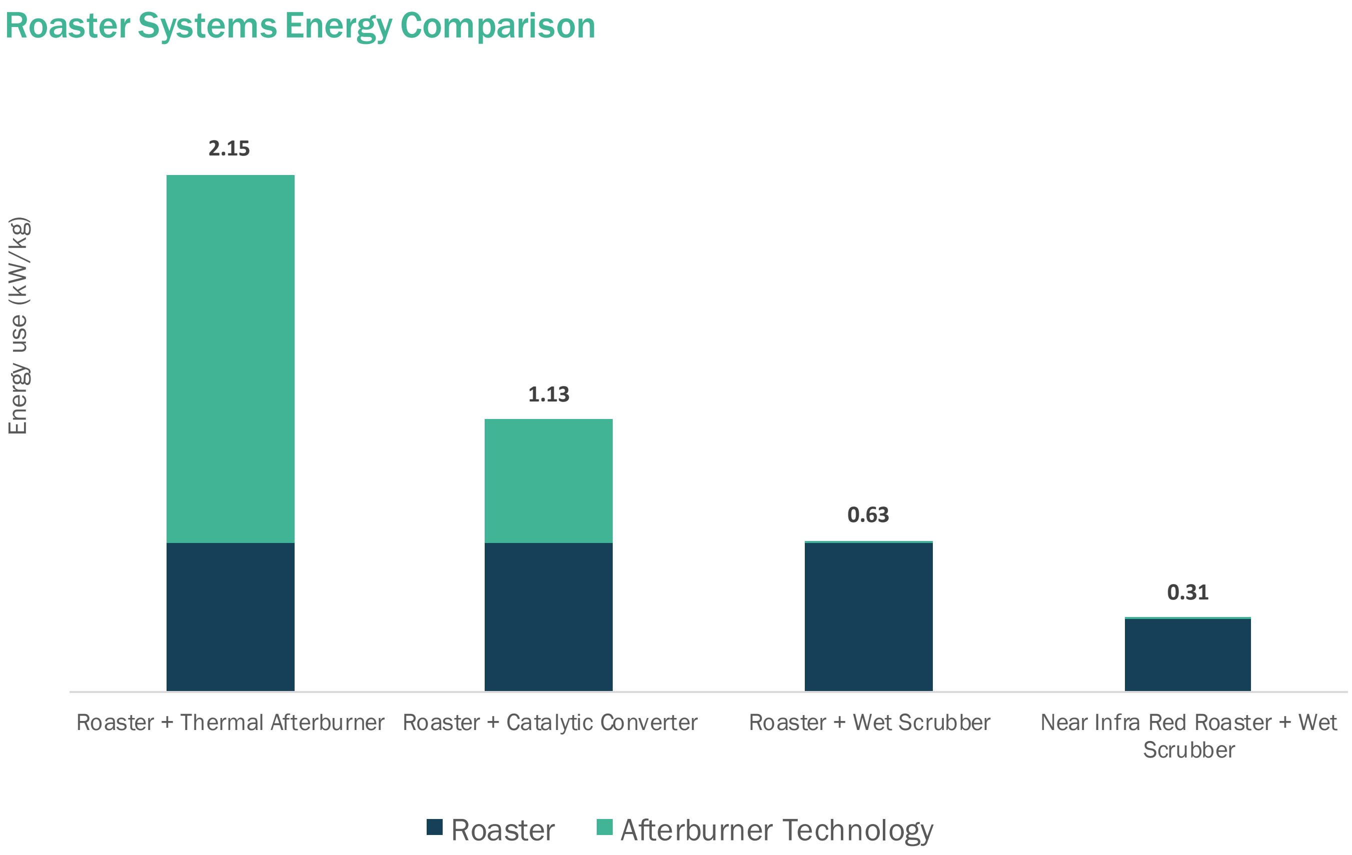
Pre-heating primary combustion air (up to 250°C)

Summary and recommendations

Summary and recommendations

This technology scan demonstrates there are opportunities for coffee roasters to reduce their energy and emissions. Technologies that use lower emissions fuel sources such as electricity and hydrogen are under development and equipment suitable for larger scale roasting operations are expected to become available on the market soon.

NIR has been found to rate as the optimal fuel switching selection. However, it is currently limited to smaller scale roasters. Whereas alternatives such as hydrogen are emerging yet constrained by local fuel supply availability.



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Summary and recommendations

Across New Zealand, local councils have different regulations for air quality discharge which include VOCs and particulate released during roasting. For sites with stricter regulations, afterburners have become necessary. Afterburners account for up to 71% of total thermal energy use in the roaster process. As such, changing afterburner technology presents the best opportunity to reduce energy consumption for these roasters. The wet scrubbing system has rated as the highest opportunity for not only energy greenhouse gas emissions reduction but also for both operating and capital costs, whilst also meeting air quality requirements.

The roaster systems energy consumption chart demonstrates three alternative selections to the traditional technology. The chart highlights the reduced energy use associated with alternatives. To take advantage of energy reduction and cost savings (opex) is dependent on commercial considerations and scale of the process.

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Appendix

Appendix – technology rating

Information to guide scoring was collected from suppliers. Each item was given a 1 - 5 score relative to several factors:

- Greenhouse gases emission reduction (GHG emissions)
- Site operating costs including both maintenance and comparable cost of energy (OPEX)
- Purchase and installation price relative to standard equipment (CAPEX) being a gas drum roaster and thermal incineration afterburner
- Technical maturity

Complexity of modifications to existing plant.

Scoring is based on 1 being relatively poor compared to 5 being relatively good. These scores were aggregated to give the technology an overall score for comparison purposes.

	GHG site emissions		OPEX
1	<1%	1	<30%
2	1-5%	2	10-30%
3	5-15%	3	-
4	15-30%	4	10-30% savings
5	>30%	5	>30% savings

	CAPEX relative to standard		Technical Maturity		Plant modifications
1	>20%	1	Novel	1	Complete change
2	1 - 20%	2	Some commercial application	2	Significant change
3	0%	3	Proven tech internationally	3	Extra equipment
4	1 - 20%	4	Proven tech in New Zealand	4	Simple change
5	<20%	5	Standard practice	5	No change

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Technology rating summary

	Roasting component	GHG	Capex	Opex	Technical Maturity	Plant modifications	Total
Electric	Roaster	5	2	3	3	1	**14**
Hydrogen	Roaster	5	3	1	2	2	**13**
NIR	Roaster	5	5	5	4	1	**20**
Cat	Afterburner	4	2	4	5	3	**18**
Wet	Afterburner	5	5	5	4	3	**22**
EPS	Afterburner	5	4	2	3	2	**16**
Air pre heating	Heat recovery	3	2	4	3	3	**15**
Bean pre heating	Heat recovery	4	1	5	3	3	**16**

Abbreviations:
GHG – greenhouse gas emissions | **Capex** – capital expenditure | **Opex** – operating expenditure