Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Technical Information Document

# Direct Process Heating
## Microwave and Radio Frequency

Technical Information Document 2019

New Zealand Government

# Introduction

Dielectric heating uses electromagnetic waves and fields of varying frequencies to heat materials uniformly rather than applying heat from the outside. This means that the operation is more efficient. The most common use of dielectric heating is the domestic microwave oven.

In a dielectric oven, heat is generated when high frequency microwaves or radio frequency (RF) electric fields interact with the molecules within the product, causing them to move. The oscillations of the waves trigger oscillations in the molecules of the material, which causes a release of energy that heats the product. The heating occurs throughout the product rather than the heat needing to penetrate the material from its surface.

Strata ENERGY CONSULTING

Efficient Energy International
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EECA commissioned Strata Energy Consulting and Efficient Energy International to produce this document which is one of a series on electrical heating.

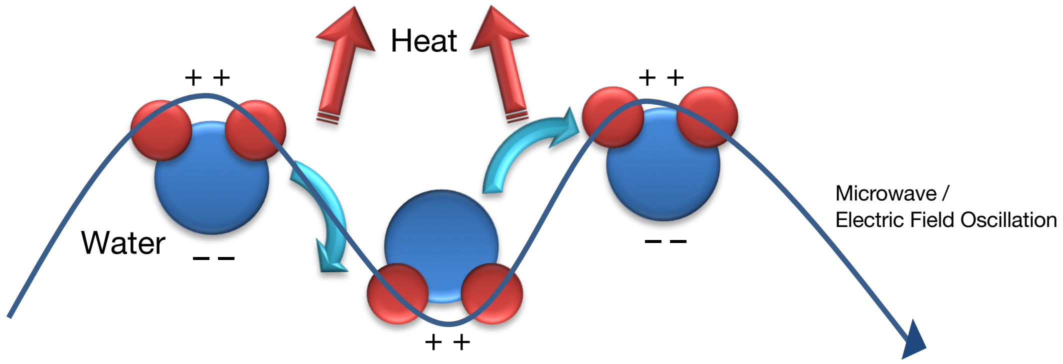



**Figure 1. Visual Representation of Microwave and Frequency Heating**
Source: Strata Energy

Microwaves are usually generated using a device called a magnetron. Radio frequency waves are usually generated by two or more electrodes producing an oscillating electric field that surrounds the material to be heated.

Radio frequency (RF) and microwave dielectric heating technologies differ in how they are generated and applied. Microwaves are transmitted from the magnetron to the target material via a 'wave guide' while for RF, the field is produced by electrodes placed on opposite sides of the target material. In general, RF fields have greater penetration than microwaves while microwaves can deliver higher power densities. RF fields are more commonly applied to high energy applications (up to 900 kW) than microwaves (up to 50 kW).

Dielectric heating has the potential to solve complex heating problems (for example, irregularly shaped, thick or sensitive materials) while contributing to an overall reduction in energy use and a more compact processing environment. However, capital investment costs can be high compared to other heating options.

## Typical applications of dielectric heating have included:

- Wood adhesive drying, where RF heating is used to reduce the drying and setting times of wood glues from hours to minutes
- Baking, where a combination of traditional oven convection heating and RF heating is used to ensure a uniform level of moisture removal while reducing the risk of burning or over drying the product
- Textile drying, where RF drying techniques can reduce the drying time of yarns and fabrics from around ten hours to under 40 minutes.

# Technical features

## Overview

Dielectric heating has already become essential for several industries and is becoming increasingly attractive to others. This is because dielectric heating can overcome some important limitations of conventional process heating methods. For example with dielectric:

- Heat is generated directly inside the product allowing for a more uniform heating profile than through other methods
- Results from dielectric heating are easily reproducible, allowing for greater uniformity in production and heating processes
- Heat transfer rates can be relatively high and can be generated within compact equipment which is easily designed to be compatible with production flowlines
- Some substances, such as water, absorb heat more easily than other materials which means that products may be dried very efficiently and to a uniform moisture profile through selective heating processes
- Very little thermal losses occur and toxic or noxious exhaust fumes are eliminated achieving cleaner, uncontaminated and higher consistency of product quality.

Dielectric heating can be controlled by methods including cycling the power output (e.g. switching off and on) using shields to protect sensitive areas of a workpiece, or by using heat sinks which are an introduced material that absorb the dielectric energy and heat the surrounding material through conduction and/or convection.

## Operation

In dielectric heating applications, the ‘loss factor’ of the target material is important. The higher the loss factor the better the material is at converting the RF and microwave energy into heat.

The table below shows how samples of materials heat when reacting to different RF and microwave frequencies. As a general rule, material with a loss factor of less than 0.02 will not be an ideal candidate for a dielectric process.

| Material | At 10MHz | At 2450 MHz |
|---|---|---|
| Tap / Salt Water | 100 | 18 |
| Pure Water | 0.36 | 12 |
| Wet Wood | 0.1 | 0.07 |
| Dry Wood | 0.04 | 0.01 |
| Pork Fat | 94 | 2.7 |
| Kidneys | 4.2 | 0.18 |
| Wool | 0.01 | - |
| Cotton | 0.03 | - |
| Polyester | 0.04 | 0.04 |
| PVC | 0.04 | 0.1 |
| Paper | 0.4 | 0.4 |

Industrial RF heating equipment generally operates between seven and 40 MHz. For industrial microwave heating, frequencies of 900 MHz and 2450 MHz are most commonly used.

## RF heating configuration options

The RF field is generated by connecting an oscillating power supply to electrodes in proximity to the material. The electrodes can be arranged in different configurations to optimise heating of the material, two typical configurations are show below.

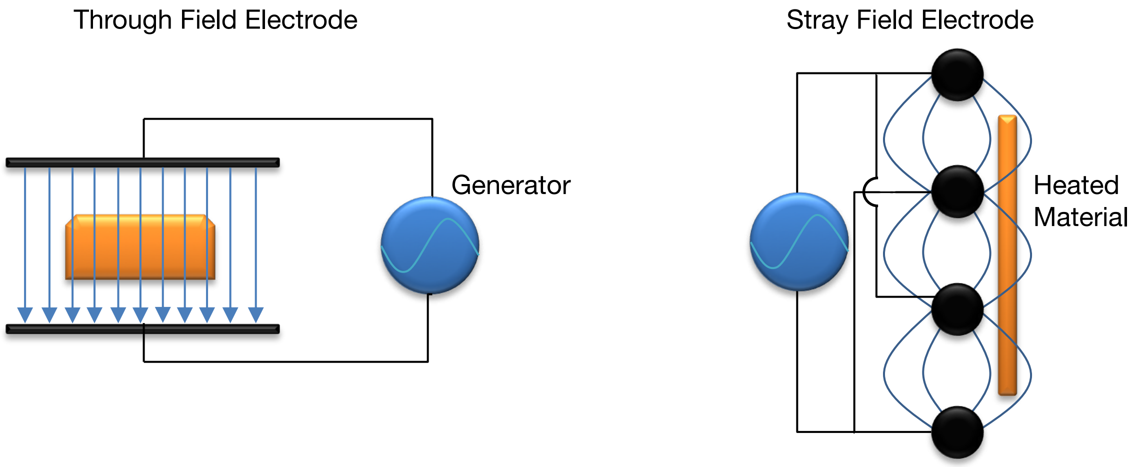



**Figure 2. Typical Electrode Configurations**
Source: Strata Energy

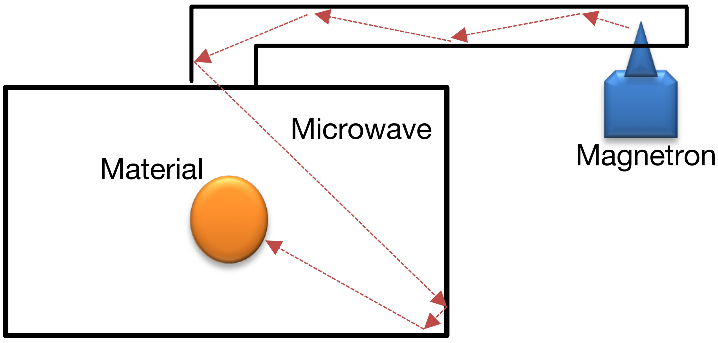
The average efficiency of conversion of electrical energy to RF energy is generally around 70%. The efficiency of RF to heat conversion depends on the type of material being heated (see figure 1 above)

**Figure 3. RF Glue Bonding and Plastics Welding**
Source: High Frequency Electronics Ltd, Auckland, New Zealand http://www.highfrequency.co.nz/wa.asp?idWebPage=18093&idDetails=106


**Figure 4. Radio Frequency Dryer**
Source: KERONE USA http://www.keroneindia.com/radio-frequency-heating.html

## Microwave heating configuration

Microwave frequencies are normally generated using a magnetron. A magnetron uses electric and magnetic fields to control the flow of electrons and generate microwaves. The microwaves are emitted from the magnetron and guided into a heating chamber bounded by metallic, reflective walls.




Techniques such as vacuum chambers, conveyor belts, multiple wave guide tubes or magnetrons, and the application of additional reflective techniques (e.g. mode stirrers, which are reflective fans used to disperse and distribute microwaves within the oven chamber) create increased efficiency.

Microwave technology is used in a broad range of food processing applications including drying, tempering, blanching, cooking, pasteurisation, sterilisation, dehydration, and baking. Other potential industrial applications for microwave technology include; asphalt curing, treatment of toxic substances, plastics and minerals processing.

**Figure 3. Example of Industrial Microwave Food Production Equipment**

Source: KERONE USA http://kerone.com/blog/kerone/microwave-heating-for-the-food-processing

# Selecting Equipment

Detailed technical appraisal of each situation is needed to determine both an estimate of the possible benefits and the optimum positioning of the equipment.

The information generally needed when making an enquiry includes:

1. A description of application e.g. heating, drying, curing, cooking
2. A description of the product or range of products
3. A description of the production process, such as:
   a. If, it is continuous flow or batch
   b. The product throughput – weight, volume, size
   c. Any input and output requirements e.g. the quantity of moisture to be removed
   d. Tolerable temperature range
   e. Any special features
4. A description of the product or range of products to be heated by the dielectric equipment;
5. A summary of the reasons for investigating a dielectric solution and the expected benefits;
6. Information about the current of process costs
7. Details of the existing process, if applicable
8. Process constraints or quality issues.

# Manufacturers, suppliers and installers of dielectric process heating systems

Radio frequency and microwave industrial process heaters are available from specialist manufactures and suppliers. For New Zealand applications, equipment is available from local suppliers and international manufactures and suppliers.

## New Zealand suppliers

**High Frequency Electronics Ltd**
Established in 1988, High Frequency Electronics Ltd ("HFE") supplies Radio Frequency Dielectric Heating Equipment, Hot Air Welders, Wedge Welders and Induction Heating equipment.

http://www.highfrequency.co.nz

## International suppliers

**Ferrite Microwave Technologies, LLC**
165 Ledge Street, Nashua, NH 03060 United States
Ferriteinc.com

**The Radio Frequency Company, USA**
http://www.radiofrequency.com/rftech.html

**Kerone, Mumbai, India**
http://www.keroneindia.com/radio-frequency-heating.html

**Shanghai Nasan Industry Co., Ltd**
http://www.nasan.com.cn

**Thermex Thermatron, 10501 Bunsen Way, Suite 102, Louisville, KY 40299**
https://thermex-thermatron.com/industrial-microwave-systems/

# Sources of additional information on dielectric process heating systems

**Pueschner, Schwanewede, Germany**
http://www.pueschner.com/en/microwave-technology/frequency-ranges

**Industrial Microwave Systems Inc. New Orleans**
http://www.industrialmicrowave.com/faqs.htm
https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/microwave-drying

# Benefits

### Time Reductions
Dielectric heating can provide significant reductions in heating and drying times, allowing for greater volumes of product to be manufactured.

### Energy Efficient
Dielectric heating has efficient energy to heat conversion and low heat losses. It has very fast heating times and has the ability to heat directly and selectively, again reducing heat losses.

### Uniform heating
Uniform heating can be achieved throughout the product. This reduces the risk of heat-damage to the product and lowers the exposure time required in drying or processing.

### Controlled and targeted heating
Dielectric heating methods can be altered to target specific areas and cross sections of a product allowing for selected heating or variable heating across the product's shape.

### Safe with a smaller unit size
Dielectric heating equipment can be compact. The equipment used in dielectric heating is not operated at a higher temperature, making all day use more comfortable and safer for operators.

### Unique solutions
Conventional thermal heating methods are inefficient at heating some materials (thick, insulative, non-uniformly shaped, thermally sensitive, powdered etc). In many applications, dielectric heating can be used to overcome these problems

# Challenges

### Materials must be compatible
Some materials respond well to RF and microwaves, others don't. Materials that do respond well may need to be matched or tuned with the frequency that produces the most efficient heating.

### Some hazardous equipment risks
Microwave radiation can be harmful to humans. Generally, shielding overcomes the risks. RF heating requires an electric field that, when operating at high energy levels, can create the risk of an electrical discharge (arcing).

### Capacity Requirements.
When switching to dielectric heating from fossil fuel heating, the site electrical capacity may need to be upgraded. For example, a typical 30kW drier can vaporise 34kg of water per hour and requires a 3 phase 40 kVA supply to operate.

### Investment costs.
Payback periods on capital investment in dielectric heating can be relatively long if energy savings alone are relied on. Strategic design and integration of dielectric heating with other systems has the potential to lower costs, increase production throughput, improve product quality and, through these benefits, improve payback periods.

# Application Notes

For industrial applications RF solutions are much more commonplace than microwave.

Radio frequency applications include plastics welding, drying biscuits, textiles and wood glue and thawing frozen foods. Microwave applications are typically used in the food processing industries for heating frozen foods, drying and cooking meat. There are also some pharmaceutical applications.

## Post-baking biscuits

Dielectric applications are widespread in the baking industry, particularly for the post-baking of biscuits, cereals and crackers as dielectric heating provides a convenient and safe way to remove excess moisture to achieve structure and colour after the initial baking has been done.

Often, in the final stages of baking, some moisture remains. RF and microwave energy are used to heat the excess water molecules without the risk of damaging the baked goods or creating unpredictable variations in temperature.

Also, RF is sometimes used to pre-heat dough and cake mixtures to increase production rates.

## Cooking and food preparation

Commercial microwave ovens often combine microwave heating with other convection heating methods, such as a hot air or steam system. This allows increased yields and superior quality products. Poultry, fish, bacon and meat patties cooked in commercial microwave ovens have reduced shrinkage with more flavour at shorter cooking times.

Rapid heating from within by use of dielectrics can also produce ‘puffed’ products (such as in cereals or snacks) as the internally heated steam bursts through to the product’s surface.

There is a strong market for using microwave heating to dry pasta, which, when combined with hot air drying, can reduce the moisture content to 12% for packaging at a much faster rate. Microwave heating has added benefits of a smaller drying set up, less energy and reduced cleaning requirements.

Juices can be dried using microwave heating in a vacuum, which reduces the boiling point and allows the resulting concentrate to retain more flavour and nutrient content.

Tempering and defrosting of meat products can be achieved using dielectric heating. The temperature of meat and other food products is raised to just below melting point using dielectric methods. This can reduce the defrosting time to under an hour, even when the product is sufficiently large and would require several days under normal conditions. An additional benefit is that the speed of defrosting can reduce spoiling and degradation of the product.

## Blanching, Sterilisation and Pasteurisation

The objective of these processes is eliminating microbial and enzyme activity to ensure that products or tools are safer for human consumption or use. Commercial solutions combining microwave sterilisation with steam can be extremely effective and can reduce the typical unused heat losses associated with hot water use.

Microwave and radio frequency dielectric heating is used on a commercial scale in the production of convenience foods and ready-made meals and the sterilisation of their packaging.

Microwaves have also been used to reduce the number of micro-organisms in foodstuffs such as grains and flour, one minute of microwave exposure is sufficient to effectively control the level of micro-organisms in a 25kg sack of rice.

Nutritional content and product quality are also significantly less likely to be impaired by microwave heating applications than with traditional heating methods.

## Other Applications

Dielectric heating has many other applications such as herbal & spice sterilisation, welding, preheating, drying and curing plastics, preform heating and continuous vulcanisation for rubber, drying wood and wood adhesives, pulp & fibre microwave drying, food sterilisation and heating. It can also be used for asphalt recycling where microwave energy melts the asphalt so that it can be restored and reused saving money, resources and landfill space.

Microwave is also used for disinfection systems in the treatment of hazardous waste in facilities like hospitals where untreated dumping or incineration could result in significant environmental impacts. Microwaves are also used to fuse low level nuclear waste into a substance similar to glass.

Radio frequency heating is used for moisture removal in the textiles industry where it can reduce energy consumption by over 50% while also reducing the risk of heat-damage to products.

## Is dielectric heating suitable for your business?

For many applications, industrial dielectric heating equipment can be purchased ‘off the shelf’. Where equipment is available, a manufacturer and supplier will provide advice on type, design and installation for specific situations.

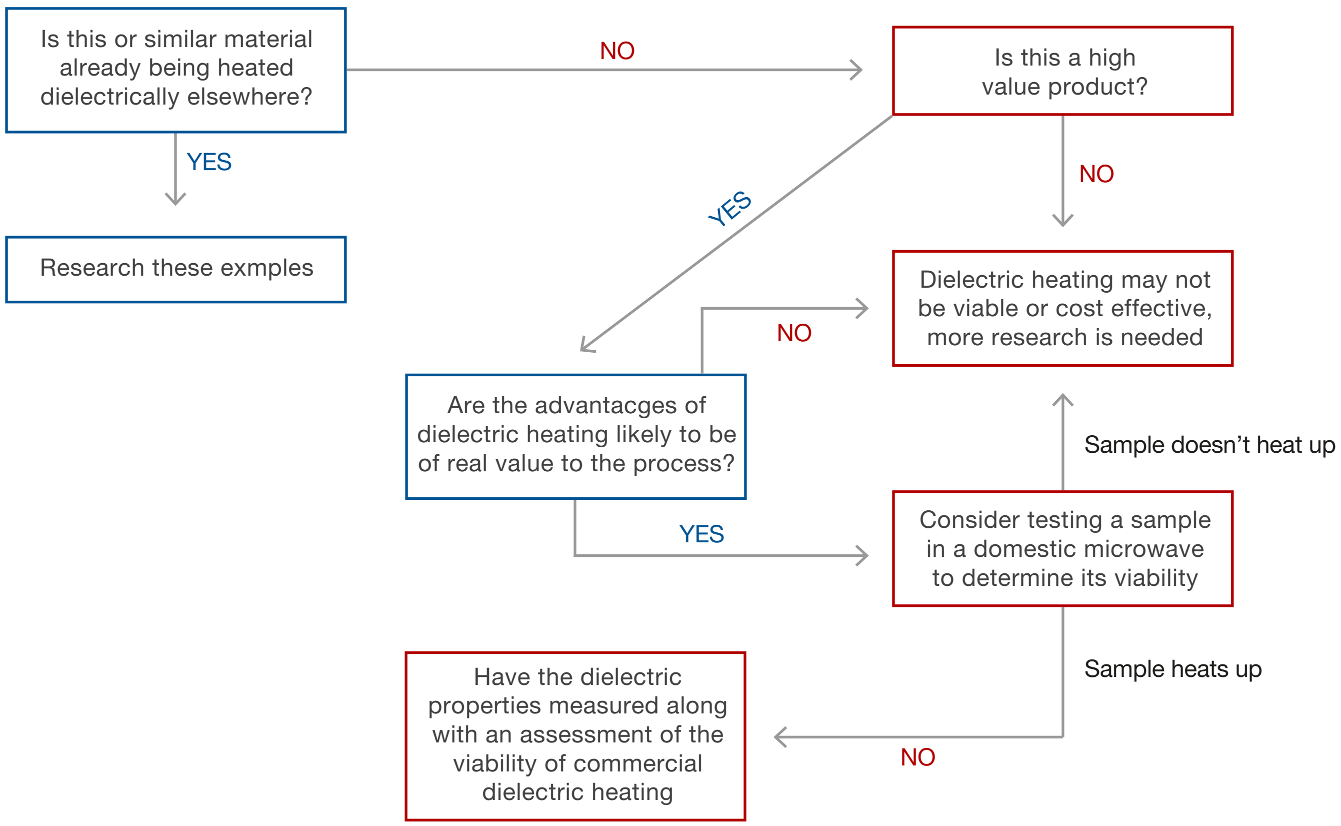
If the proposed application is new or no previous similar application has been completed, the development of a solution will be more difficult. In these cases, a specialist will be required to undertake research and testing to ensure that dielectric heating would be suitable.

A key question to consider is whether the potential benefits are sufficient to balance high capital costs. Dielectric processes can cost between $6,000 and $10,000 per kW capacity for complete units.

To address this question consideration should include the:

1. improvement of product quality.
2. value of increased product throughput and faster processing times.
3. release of space on a production line.
4. energy conversation efficiency and associated reduction in operating costs.
5. improvement in environment with reduced heating of the surrounding workplace.
6. value of the fast response to varying product demands.

The flow chart below provides a general guide to assessing the viability of dielectric heating.



# Indicative capital and operating costs of dielectric process heating

## Radio Frequency applications

RF drying is self-regulating as energy is only consumed if there is moisture present to heat and evaporate. This means that RF is very good at profile drying at the end of a production line or web. Even though the conversion from electricity supply to RF is around 50 – 70%, the highly efficient conversion from RF to evaporated moisture makes RF a good option for end of process drying or specialised profiling applications.

The following are rules of thumb for a rough estimate of RF equipment capacity:

- For moisture removal, 1.0 kWh RF output removes 1.0 kg water.
- For welding thermoplastics, 1.0 kW of RF output provides 25 cm of distributed weld area.

Table 1 provides indicative capital purchase costs for industrial RF heating equipment, and indicative operating costs. The costs are in 2018 New Zealand dollars.

| RF output | Purchase cost ($/100 kW) | Installation cost ($/100 kW) | Operating cost |
|---|---|---|---|
| 50kW RF post bake production line oven, | $360,000 | Variable | $90,000 |
| 5kW RF dryer for water based adhesives in paper and board | $56,000 | Variable | $3,500 |
| 12kW RF dryer for water based adhesives in paper and board | $77,000 | Variable | $12,000 |
| 20kW RF dryer for water based adhesives in paper and board | $120,000 | Variable | $21,600 |
| 4kW plastics welder | $25,000 | Variable | $2,700 |
| 20kW continuous feed plastics welder | $165,000 | Variable | $21,600 |

**Table 1. Indicative capital and operating costs for RF equipment**

Installation costs for small capacity RF units can be relatively low. For large, continuous production line units installation costs can be greater than the capital cost of the RF unit.

## Calculating RF running costs

To calculate the amount of energy required to evaporate water you need to use the specific heat capacity of water; 4.184 kilojoules (kJ) (which is the energy required to heat one kilogram of water by one degree Celsius) and then add a further 2600 kJ/kg to allow for the phase shift that transforms liquid water into steam.

Assuming the input water temperature is 15 Celsius, the energy required to evaporate 50 kg of water is:

$(4.184 \times 50 \times (100-15))+(2,600 \times 50) = 147,782$ kJ

1 kWh = 3,600 kJ so to find the energy required to evaporate the water, divide the kJ value by 3,600 = 41kWh.

As the moisture is to be removed over one hour, a minimum 41 kW output capacity RF unit will be required. Because the operating load factor of RF units is typically between 50% and 80%, the capacity of the RF unit should be greater than the calculated energy for moisture removal. In our example, an RF unit of approximately 70kW would be installed.

## Microwave applications

Indicative capital costs of industrial microwave can vary between $5,000 and $10,000 per kW installed (excluding international delivery cost). The cost will depend on availability of equipment in New Zealand, the power range required, the auxiliary equipment required (e.g. vacuum, injection of hot air or steam, microprocessor control, automation etc.).

## Calculating microwave running costs

Running costs will depend on the efficiency of the microwave equipment, load factor and cost of electricity. Indicative running costs can be calculated using the following assumptions:

For evaporation of moisture, the same calculation provided above for RF drying can be used to determine the energy required to evaporate the moisture. The same rule of thumb that 1.0 kW microwave output removes 1.0 kg water can also be applied as an initial guide to equipment capacity. However, the electricity supply to microwave conversion must also be considered. This is generally between 60% and 80%, so microwave capacity will need to be 20% to 40% higher than the 1.0 kW = 1.0 kg rule of thumb.

For an approximate estimate of running costs and comparison with a gas convection oven you will need to decide values for the following assumptions:

1. The capacity of the microwave unit installed (electrical rating in kW)
2. The capacity of gas equivalent (including for heat losses and lower efficiency). If this isn't known it can be estimated as gas kW = electric kW x 1.3
3. The annual operating hours so that electrical consumption can be calculated (electric kWh)
4. The annual operating hours for gas, including for warm-up, cool-down and reduced responsiveness (gas kWh). If you don't know the gas operating hours you can use, gas hours = electrical kWh x 1.3
5. The average unit price of electricity and gas ($/kWh)

The annual cost of electricity consumed = electrical kWh x electricity $/kWh

The annual cost of equivalent gas consumed = gas kWh x gas $/kWh.

## Climate change emissions reductions

Microwave and RF heating will not directly produce any greenhouse gas emissions; however, some of the electricity consumed may have been generated from non-renewable sources that produce greenhouse gases. Because the proportion of non-renewable generation in New Zealand is low, the climate change gas impact of microwave heating will be much lower than for gas or other fossil fuel ovens.

Climate change gas rule of thumb comparison:

### Electricity

$CO_2$ = kWh consumed x 0.1

For every 100 kWh of electricity used 10 kg of $CO_2$ is emitted.

### Gas

$CO_2$ = kWh of gas consumed x 0.216

For every 100 kWh of gas used 21 kg of $CO_2$ is emitted.

In summary, electrical microwave and RF heating is highly efficient in the appropriate applications. For drying applications, this is at the end of processes when the bulk of the moisture has already been removed. Because electricity emits approximately half the $CO_2$ of gas combustion, efficient electricity applications can reduce $CO_2$ emissions by more than 60%.

Remember each potential RF and microwave application will have specific operating conditions, operational efficiency opportunities and duty cycles. Because of this, capital and operating costs, and the potential benefits, will vary considerably.

# Case studies

**Case Study: Sugar Foods Corporation.**
Sugar Foods is a manufacturer of consumer snack products. The company is an innovator bringing new products to market and pushing the established production boundaries. Sugar Foods had been unable to achieve the desired product characteristics of a high demand, snack food product with conventional food processing ovens and equipment. An alternative process was needed to eliminate both front-end and back-end manufacturing complexities. Microwave technology was identified as a potential solution and equipment manufacturer Ferrite Microwave Technologies (FMT) was selected to partner in the development of the microwave option.

Initial testing was undertaken giving Sugar Foods confidence that the proposed snack system would deliver a product to their requirements. During the solution development, Sugar Foods gained knowledge of the materials that would absorb microwaves and, more importantly, those that would not. FMT worked with Sugar Foods using real-time production results to identify power and belt speeds that produced optimum product outputs. Initially, one system was installed as a test line.

The initial test line was targeted at a relatively small number of finished goods per hour and had a small 10m footprint. Within the first week, the system was producing at full targeted capacity. Meeting that level of production immediately after installation, with minimal discharge and loss, convinced the Sugar Foods team that they had found the solution. Within a year, second and third microwave systems were installed.

For more information contact:

Ferrite Microwave Technologies, LLC
165 Ledge Street, Nashua, NH 03060 United States
[Ferriteinc.com](Ferriteinc.com)

### Case Study: Foodcomm International MIP12 microwave tempering tunnel

Foodcomm International (Foodcomm) had seen microwave applications in operation at Nestlé and thought that the technology might be a good way of reducing yield loss in blocks of meat during its tempering process.

A MIP12 microwave tempering tunnel was purchased from Ferrite Microwave Technologies (FMT) for use in Foodcomm's cold storage operation. Foodcomm found that microwave reduced moisture loss and saved money. The microwave solution released floorspace in 400 locations previously used for tempering meat products and allowed the company to move product consistently, saving approximately 2% yield loss.

The microwave meat tempering solution exceeded Foodcomm's expectations allowing continuous refinement and improvement of its production process. Foodcomm is considering purchasing a further microwave system.

For more information contact:

Ferrite Microwave Technologies, LLC
165 Ledge Street, Nashua, NH 03060 United States

Ferriteinc.com