Energy security and decarbonisation of spray drying in New Zealand

Heat supply pathways in a gas-constrained market

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Executive summary

New Zealand's dairy sector is facing a structural shift in how industrial heat is supplied. Declining natural gas availability, particularly in the North Island, combined with rising prices and increasing uncertainty of long-term supply, is forcing operators of energy-intensive processes such as spray drying to reassess their heat supply strategies.

Spray drying requires the continuous delivery of large volumes of heated air, typically in the range of 180–230°C, with thermal loads often exceeding several megawatts. Historically, natural gas has fulfilled this requirement either through direct-fired air heaters or via high-pressure steam systems used to heat air indirectly.

As gas supply becomes constrained, three principal pathways are emerging:

- Biomass-based systems (typically steam-based in dairy applications)
- Direct electric resistance heating (ERH)
- Electric boiler-based steam systems

Each pathway presents a different balance of cost, complexity, and operational performance.

Biomass systems currently offer the lowest operating cost but require significant capital investment and introduce operational complexity associated with fuel handling, combustion control, and maintenance.

Electric resistance heating provides a fundamentally different approach. By applying heat directly to the air stream, it eliminates intermediate energy conversion steps, resulting in a simple, compact, and highly controllable system. While operating costs are higher under current electricity pricing, ERH offers advantages in process stability, deployment speed, and long-term alignment with New Zealand's increasingly renewable electricity grid.

Electric boiler systems, which generate steam for indirect air heating, introduce additional complexity and efficiency losses and are generally not well suited to applications where steam is not inherently required.

The selection of an appropriate heat supply pathway is therefore not solely an economic decision. It must consider system complexity, reliability, site constraints, and long-term energy strategy.

Problem definition

Spray drying is one of the most energy-intensive operations in the New Zealand dairy sector. The process depends on the continuous delivery of large volumes of heated air, typically raised from ambient conditions to inlet temperatures in the range of 180–230°C. For industrial-scale dryers, this corresponds to sustained thermal loads from approximately 1 MW to well over 10 MW.

In practice, this air heating duty is delivered using a range of configurations. Many installations utilise direct-fired natural gas air heaters, where combustion gases heat the process air either directly or via a heat exchanger. Others use high-pressure steam systems (typically up to ~40 barg), where steam generated in central boilers is used to heat air via coils.

These different approaches reflect historical design choices rather than inherent process requirements. From a thermodynamic perspective, spray drying requires only the delivery of clean, temperature-controlled air, there is no fundamental requirement for steam within the drying process itself.

Historically, natural gas has been the preferred primary energy source due to its availability, energy density, and relatively simple system integration. However, the New Zealand energy landscape is now undergoing a structural shift. Gas availability in the North Island is declining, prices have risen to over NZD $40/GJ, and long-term supply is increasingly uncertain.

For assets such as spray dryers (where heat supply is critical to production) this introduces both operational and strategic risk.

The challenge is therefore not simply to replace gas, but to do so in a way that maintains:

- process stability
- product quality
- operational reliability

> Spray drying requires heated air - not steam.

Heat transfer basis

Spray drying is fundamentally a sensible air heating process, governed by: $Q = m \cdot Cp \cdot \Delta T$

Where energy demand is determined by airflow, specific heat capacity, and temperature rise.

Large airflow rates combined with a significant temperature rise result in high energy demand, and the process requires only sensible heating of air.

At multi-megawatt scale, system efficiency becomes a significant economic driver. Even relatively small efficiency differences - in the order of 5–10% - translate into substantial energy consumption. For example, at a 3 MW continuous load:

- 10% inefficiency ≈ 2,400 MWh/year
- At NZD $200/MWh → approximately $480,000 per year

This highlights the importance of minimising unnecessary energy conversion steps and selecting the most direct heating pathway where possible

Technology pathways

Electric resistance heating (ERH)

Electric resistance heating converts electrical energy directly into heat within the air stream. From an engineering perspective, this represents the most direct and simplest approach to air heating, with no intermediate fluids or combustion processes.

This simplicity delivers several advantages. Electrical-to-thermal conversion efficiency is effectively 100% at the point of use, and thermal response is rapid, enabling precise control of inlet air temperature. This is particularly valuable in spray drying, where even small temperature fluctuations can impact product quality and yield.

Operationally, ERH systems eliminate the need for fuel handling, combustion air systems, and emissions management. Maintenance requirements are relatively low and typically limited to electrical components and periodic inspection of heating elements.

At higher capacities, ERH systems can be implemented using medium voltage (MV) electrical infrastructure. This allows multi-megawatt installations to be delivered without excessive current levels associated with low-voltage systems, improving overall system efficiency and reducing distribution losses.

While MV systems introduce additional electrical design considerations, they are well established in industrial environments and enable electric heating to be applied at the scale required for large spray drying applications.

The primary limitation is operating cost. At current New Zealand electricity pricing (~NZD $200/MWh), ERH is more expensive to operate than both gas and biomass. In addition, electrical infrastructure requirements - particularly at higher loads - may require upgrades.

Biomass systems

Biomass-based heat systems can be configured in different ways depending on how heat is transferred to the process. The two principal approaches are direct hot gas systems and indirect systems based on steam generation.

- **Direct biomass (hot gas systems)**
  In direct biomass systems, heat from combustion is transferred to the process air either directly or via a primary heat exchanger. From a thermodynamic perspective, this approach minimises energy conversion steps and can achieve relatively high efficiency.
  However, in dairy spray drying applications, this configuration is generally not adopted.
  This is primarily due to:
  - stringent air quality requirements
  - risk of particulate or volatile contamination
  - food safety and audit constraints

  For these reasons, while direct biomass heating is technically feasible and used in other industrial sectors, it is not typically considered for dairy spray drying applications.

- **Biomass boiler & high pressure steam systems**
  In practice, biomass in dairy processing is almost exclusively deployed via steam generation. In this configuration, biomass is used to produce high pressure steam, which is then used to heat air via coils or heat exchangers.

This approach provides:

- clear separation between combustion and process air
- compliance with food safety requirements
- compatibility with established plant design practices

However, it introduces additional energy conversion steps:

- combustion → steam
- steam → air heating

Each step reduces overall efficiency and increases system complexity. Steam systems also require additional infrastructure, including boilers, pressure systems, piping, and condensate handling.

From a process perspective, these systems tend to exhibit slower thermal response compared to direct heating methods.

Electric boiler & steam systems

Electric boiler systems follow a similar architecture to biomass steam systems, but use electricity as the primary energy source. In this configuration, electricity is used to generate steam, which is then used to heat air via coils or heat exchangers.

From an engineering standpoint, this approach introduces multiple energy conversion steps:

- electricity → steam → air heating

Each step introduces efficiency losses and additional system requirements compared to direct electric heating. In addition to these fundamental limitations, practical considerations further constrain the use of electric boilers at the scale required for spray drying.

Traditional low-voltage resistive electric boilers, while relatively simple in design, become increasingly challenging at higher capacities. Large-scale installations require substantial electrical infrastructure and can become physically large and capital-intensive when sized for multi-megawatt thermal loads.

The use of medium-voltage (MV) electrical systems can extend the practical capacity of electric resistive boilers by reducing current levels and improving the efficiency of power distribution. This enables higher thermal outputs to be achieved without the same degree of scaling constraints associated with low-voltage systems.

However, MV systems introduce additional electrical complexity, including specialised switchgear, protection systems, and integration requirements. While MV infrastructure improves scalability, it does not eliminate the broader system considerations associated with steam generation, including additional conversion steps, increased operational complexity, and overall system footprint.

Electrode boilers, which are often used for higher-capacity applications, introduce further operational considerations. Their performance is highly dependent on boiler feedwater conductivity, requiring tight control of water chemistry. This typically necessitates:

- continuous monitoring and adjustment of water quality
- specialised water treatment systems
- increased operator oversight

These requirements add both operational burden and system risk, particularly in facilities where steam is not already a core utility.

For spray drying applications, where steam is not inherently required, electric boiler systems introduce additional complexity and constraints without providing a clear process advantage.

Fuel and operating cost comparison

The following comparison is primarily based on direct energy input cost. Steam-based systems also require auxiliary utilities including boiler feedwater pumps, condensate return systems, water treatment, and associated balance-of-plant equipment, which increase both operating cost and overall system complexity. Direct electric resistance heating does not require these auxiliary utility systems, simplifying operation, maintenance, and overall plant integration.

For a representative 3 MW spray dryer operating 8,000 hours per year (~24,000 MWh annual heat demand), the relative economics are as follows:

Technology	Cost ($/MWh)	Annual Cost
Biomass (steam-based, typical dairy application)	~45–50	~$1.1–1.2M
Natural Gas	~160	~$3.8M
Electric Resistance Heating	~200	~$4.8M
Electric Steam	~217	~$5.2M

ERH values are based on direct electrical energy converted at the point of use with no intermediate thermal transfer fluid.

Capital cost comparison (relative to gas = 1.0):

Technology	CAPEX Index
Electric Resistance Heating	0.9 – 1.8
Electric Steam	2.5 – 4.0
Biomass (steam-based)	3.0 – 6.0

While biomass systems offer a clear operating cost advantage, this must be considered in the context of significantly higher capital investment and infrastructure requirements. Steam-based biomass installations in particular require extensive plant, including boilers, fuel handling systems, and associated utilities, resulting in higher upfront cost and longer project timelines.

Electric resistance heating systems, by contrast, are comparatively compact and modular, resulting in lower initial investment for decarbonisation and simpler integration into existing facilities. This difference in capital intensity can be a key factor in project feasibility, particularly where timelines, space constraints, or capital allocation are limiting.

Emissions profile comparison

Technology	Typical emissions profile	Notes
Natural Gas	High Scope 1 emissions	Direct combustion emissions at site
Biomass (steam-based)	Low / biogenic Scope 1 emissions	Dependent on sustainable fuel sourcing and supply chain
Electric Resistance Heating (NZ grid)	No Scope 1 emissions	Scope 2 emissions reduced by NZ's highly renewable grid (~80–85%)
Electric Steam	No Scope 1 emissions	Similar grid dependency but with additional conversion losses

For many industrial operators, future technology selection is increasingly influenced not only by operating cost, but also by emissions profile, reporting obligations, and alignment with long-term decarbonisation targets. In New Zealand, the high proportion of renewable electricity generation materially improves the emissions performance of electrified heating technologies.

System-level trade-offs

Efficiency vs complexity

Direct heating systems such as ERH minimise energy conversion losses and simplify system architecture. In contrast, steam-based systems introduce additional conversion steps, increasing both losses and complexity.

Control and process stability

Spray drying performance is highly sensitive to inlet air temperature stability. ERH systems offer rapid response and precise control, enabling tighter temperature bands and improved process consistency.
Steam-based biomass systems, by contrast, are slower to respond due to thermal inertia and heat exchanger limitations, making fine control more challenging.

Reliability and downtime risk

Spray dryers are high-value assets, and unplanned downtime can result in significant production losses. Biomass systems introduce multiple mechanical components and dependencies on fuel supply and quality. ERH systems are inherently simpler, reducing the number of potential failure points.

Operational overhead

Biomass systems require continuous fuel logistics, including procurement, handling, storage, and ash disposal. This adds an operational layer that does not exist in electric systems. ERH systems eliminate this requirement entirely, simplifying plant operation. As a result, lifecycle operating cost should be considered on a total system basis rather than fuel cost alone.

Size and footprint considerations

Physical footprint and integration requirements are important practical constraints, particularly for brownfield installations where available space is limited.

Biomass systems - particularly steam-based configurations - require substantial infrastructure, including fuel storage areas, handling systems, boiler plant, and associated auxiliaries. These installations often involve significant civil works and can be challenging to integrate into existing plant layouts.

Electric resistance heating systems, by comparison, are typically compact and modular. Heating elements are installed directly within ductwork or air handling systems, requiring minimal additional footprint. This enables easier integration into existing facilities and can reduce both installation complexity and overall project timelines.

New Zealand-specific considerations

Technology selection must be evaluated in the context of local conditions:

- Gas supply constraints, particularly in the North Island
- A largely renewable electricity grid (~80–85%)
- Regionally variable biomass availability

In addition, the dairy sector is under increasing pressure to reduce emissions, particularly in export markets.

These factors suggest that long-term decisions should consider not only current fuel cost, but also supply security and alignment with future energy systems.

Practical technology selection

In practice:

- Biomass (steam-based) is best suited to large, stable baseload applications where fuel supply is secure
- ERH is best suited to applications requiring high control precision, fast deployment, or minimal operational complexity
- Hybrid systems can combine biomass baseload with electric trimming to balance cost and performance

Conclusion

The transition away from natural gas in New Zealand spray drying is both inevitable and already underway, driven by declining supply, increasing cost, and growing uncertainty around long-term availability.

Biomass and electrification represent fundamentally different approaches to industrial heat supply. In practice, both biomass and electric boiler systems typically rely on steam generation and indirect air heating, introducing additional energy conversion steps, infrastructure, and operational complexity. Electric resistance heating, by contrast, applies heat directly to the air stream, offering a simpler, more controllable, and increasingly future-aligned solution.

> **Engineering principle:**
> Each additional energy conversion step increases both cost and complexity.

Spray drying is fundamentally a sensible air heating process. The process requires the delivery of heated air - not steam. As a result, the most efficient and operationally simple systems are typically those that minimise intermediate energy conversion steps and apply heat as directly as possible to the process air stream.

The appropriate pathway is therefore not determined by fuel cost alone. It must also consider:

- Overall system architecture
- Operational complexity
- Process control requirements
- Site constraints
- Reliability
- Long-term energy security

As New Zealand's electricity system continues to decarbonise, and as industrial operators place greater emphasis on flexibility, reliability, and simplicity, electric resistance heating is likely to play an expanding role - either as a primary heat source or as part of hybrid system configurations alongside biomass.

Electrification also enables greater alignment with increasingly dynamic electricity markets, including future participation in flexible energy and demand-response strategies.

Ultimately, the most effective solutions will be those that minimise complexity, maximise process efficiency, and align with the direction of New Zealand's future energy system.

> The most effective solutions will be those that minimise complexity while aligning with the direction of the future energy system.

About the Author: Andy Wells is the Business Development Director for Vulcanic, focused on the electrification of industrial process heat. He brings extensive experience in steam system design from his time with Spirax Sarco and now supports industrial clients in transitioning from fossil fuels to electric heating solutions.
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