Final Report

Trim Cooling

Efficiency opportunities in rapid cooling of trim - A cost and environmental comparison of CO_2, N_2, and a new mechanical chiller system.

Project code
2025-1040

Prepared by
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Date submitted
09/05/2025

Published by
AMPC

Date published
09/05/2025

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1.0 Abstract

The ultimate aim of the project is a techno-economic analysis and GHG emissions estimation to provide recommendations around trim cooling technologies, with a specific emphasis on comparing CO_2 / N_2 solutions with a mechanical cooling system. A levelised cost of cooling metric enables a direct comparison between the different technologies on a $ / kWh of cooling basis inclusive of capital expenditure and ongoing energy, operating and maintenance costs. This metric was also converted into a $/tonne trim cooled from +10DegC to +2 DegC. Mechanical refrigeration has a larger upfront capital expense, but delivers cooling at a lower cost over the life of plant. A heat transfer model was developed and used to identify efficiency opportunities. CO_2 and N_2 are routinely purchased by RMPs from third parties – it is technically viable to produce CO_2 and N_2 onsite, however the cost is generally prohibitive.

2.0 Executive summary

Mechanical cooling is a relatively new technology, hence its application for beef trim cooling was tested as part of this project. After extensive site visits and data discovery, the following Levelised Cost of Cooling ($/kWh) was generated.

	CO2					N2			Mechanical	Mechanical
Parameter	UPPER - H2 2024 CO2 Pricing	With CO2 subcooling from -40 to -53DegC	High efficiency CO2 pellets replacing snow	CO2 recovery from vents; 30% recovery.	CO2 recovery from existing biogas	LN2 Delivered, includes CAPEX.	LN2 made onsite incl. new Trim Management System.	LN2 Onsite Production	UPPER: +$2mil civils	LOWER: simple installation
Available cooling per tonne CO2 or N2 kWh/tonne	175.8778	175.8778	175.8778			112.5436	112.5436	112.5436		
Procurement / Production $/tonne	$ 990	$ 990	$ 990	$ 754	$ 329	$ 750	$ 515	$ 963		
Basis: Mass Trim tpa	10,000	10,000	10,000			10,000	10,000		10,000	10,000
Trim start T	10.0	10.0	10.0			10.0	10.0		10.0	10.0
Trim end T	2.0	2.0	2.0			2.0	2.0		2.0	2.0
Specific heat "animal mixed tissue" kJ/kg.K Ref: on	3.20	3.20	3.20	3.20		3.20	3.20	3.20	3.20	3.20
Cooling requirement kJ pa	256,000,000	256,000,000	256,000,000			256,000,000	256,000,000		256,000,000	256,000,000
Convective ventillation losses / inefficiency factor	1.498187	1.498187	1.498187			1.2500	1.2500	1.2500	1.0500	1.0500
Total cooling allowing for losses	383,535,789	383,535,789	383,535,789			320,000,000	320,000,000	320,000,000	268,800,000	268,800,000
Cooling requirement kWh pa	106,538	106,538	106,538			88,889	88,889	88,889	74,667	74,667
CoP (R717 to -10 DegC evap)									***3.00***	***3.00***
Power kWh p.a.		175,200	113,863				2,913,296	2,913,296	***42,169***	***42,169***
Power $/kWh		0.1500	0.1500				0.15	0.15	0.3	0.15
Power $ pa		26,280.00	17,079.38	52,560.00	63,090.79		436,994.35	436,994.35	12,650.67	6,325.33
% conversion liquid CO2 to snow	0.4000	0.5500	0.7700			1	1.00			
Maintenance @ 3% CAPEX pa	$ 142,500	$ 157,500	$ 18,325	$ 90,000	$ 277,500	$ 127,500	$ 229,822	$ 96,622	$ 288,871	$ 228,871
Equipment leasing $ pa	$ 80,000	$ 80,000	$ 80,000			$ 80,000				
Gas OPEX useful cooling $/kWh	21.0829	15.3330	10.9522			8.3301	5.7214			
Gas tonnes pd (averaged)	4.149	3.017	2.155			2.164	2.164	2.164		
Gas tonnes pa	1,514	1,101	787	454	2,906	790	790	790		
Snow / pellets per operational day	2.5240	2.5240	2.5240	1.893	7.962					
Gas OPEX $ pa	$ 2,246,123	$ 1,633,544	$ 1,166,817			$ 740,454	$ 508,573			
TOTAL OPEX $ pa	**$ 2,468,623**	**$ 1,897,324**	**$ 1,282,222**	**$ 142,560**	**$ 610,591**	**$ 947,954**	**$ 738,396**	**$ 533,617**	**$ 301,522**	**$ 235,197**
CAPEX	**$ 4,750,000**	**$ 5,250,000**	**$ 718,350**	**$ 3,000,000**	**$ 9,250,000**	**$ 4,250,000**	**$ 7,660,745**	**$ 3,410,745**	**$ 9,629,049**	**$ 7,629,049**
Life of plant - years	15	15	15	15	15	15	15	15	15	15
Lifetime cost of entire system (CAPEX & OPEX)	$ 41,779,347	$ 33,709,861	$ 19,951,677	$ 5,138,400	$ 18,408,862	$ 18,469,304	$ 18,736,679	$ 11,414,996	$ 14,151,881	$ 11,157,001
Lifetime gross cooling kWh	1,598,066	1,598,066	1,598,066			1,333,333	1,333,333		1,120,000	1,120,000
LCoC - Lifetime Gross Cooling $/kWh	$ 26.14	$ 21.09	$ 12.48	$ 16.06	$ 6.54	$ 13.85	$ 14.05		$ 12.64	$ 9.96
Lifetime useful cooling kWh	1,066,667	1,066,667	1,066,667			1,066,667	1,066,667		1,066,667	1,066,667
LCoC - Lifetime Useful Product $/kWh	**$ 39.17**	**$ 31.60**	**$ 18.70**			**$ 17.31**	**$ 17.57**		**$ 13.27**	**$ 10.46**
PAYBACK ON CAPEX			**0.67**		**4.08**			**N.A.**	**4.44**	**2.20**

Figure 1: Levelised Cost of Cooling (LCoC) comparison between technology options.

The results of the analysis suggests that using CO2 snow is 3.7 times more expensive than mechanical cooling and that, for 10,000 tpa, a saving of over $2mil pa could be made by shifting to mechanical cooling.

The above information was then used to calculate a $/tonne for trim cooling over a 15 year life of plant with the results presented in the table below.

	Scenario	CO2			N2			Mechanical	
Parameter	Units	BASE CASE: Q4 2024 Liquid CO2 Pricing	CO2 subcooled (from -40 to -53DegC)	CO2 pellets replacing SHOVELLED snow	LN2 Delivered, includes CAPEX.	LN2 made onsite incl. new Trim Management System.	Production plus new Trim Management System	UPPER: +$2mil civils	LOWER: simple installation
Basis: Mass Trim tpa	tpa trim	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Trim start T	Deg C	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Trim end T	Deg C	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Maintenance @ 3% CAPEX pa	$ pa	$ 142,500	$ 157,500	$ 18,325	$ 127,500	$ 229,822	$ 229,822	$ 288,871	$ 228,871
Equipment leasing $ pa	$ pa	$ 80,000	$ 80,000	$ 80,000	$ 80,000				
Gas OPEX useful cooling $/kWh	$/kWh	21.0829	15.3330	10.9522	8.3301	5.7214			
Gas tonnes pd (averaged)	tpa	4.149	3.017	2.155	2.705	2.164	2.705		
Gas tonnes pa	tpa	1,514	1,101	787	987	790	987		
Snow / pellets per operational day	tpd	2.5240	2.5240	2.5240					
Gas Procurement Costs $ pa	$ pa	$ 2,246,123	$ 1,633,544	$ 1,166,817	$ 740,454	$ 508,573			
TOTAL OPEX $ pa	**$ pa**	**$ 2,468,623**	**$ 1,897,324**	**$ 1,282,222**	**$ 947,954**	**$ 738,396**	**$ 666,817**	**$ 301,522**	**$ 235,197**
CAPEX		**$ 4,750,000**	**$ 5,250,000**	**$ 718,350**	**$ 4,250,000**	**$ 7,660,745**	**$ 7,660,745**	**$ 9,629,049**	**$ 7,629,049**
Life of plant - years	Years	15	15	15	15	15	15	15	15
Lifetime cost of entire system (CAPEX & OPEX)	$	$ 41,779,347	$ 33,709,861	$ 19,951,677	$ 18,469,304	$ 18,736,679	$ 17,662,996	$ 14,151,881	$ 11,157,001
Specific Cost of Cooling $/tonne lifetime	**$/tonne**	**$ 278.53**	**$ 224.73**	**$ 133.01**	**$ 123.13**	**$ 124.91**	**$ 117.75**	**$ 94.35**	**$ 74.38**

Figure 2: Specific cooling cost per tonne of trim from +10 DegC to +2 DegC.

A summary of LCA findings shows the opportunity for moving away from dry ice to a "mechanical system" (plate freezers were considered in detail for this analysis) is approximately 1519 tpa CO2-e Scope 1 emissions reduction for a 10,000 tpa facility, which at the current ACCU spot price of $AUS 33.85 equates to $51,418 pa, which over a 7 year crediting period is worth $360,420. At these amounts, it may be preferable for a site to not generate credits but rather The overall Life Cycle Assessment GHG emissions reduction (Scope 1/2/3) of 1350 tpa CO2-e for a 10,000 tpa facility at the current ACCU spot price of $AUS 33.85 equates to $45,698 pa.

Scenario	Trim Process Rate	Electricity consuption	GHG	GHG / tonne trim cooled
Units	tonnes per day	kWh per day	kg CO2-e / day	kg CO2-e / tonne trim
Trim cooling via "Plate freezer"	74.7	1,355.7	1,265.0	16.9
LN2 tunnel	51.0	1,161.7	1,045.6	20.5
CO2 Snow	48.0	24.0	7,288.8	151.9

Figure 3: Life Cycle Implications of Different Cooling Methods.

This Final Report also specifically considers:

- on-site production of N2,
- on-site production of CO2,
- Efficiency gains via sub-cooling CO2 and lagging,
- Life Cycle Assessment approach to GHG emissions,
- efficiency improvements to dry-ice production.
- Future opportunities for other tissues, in approximate order of interest:
    - Body fat
    - KPH fat [kidney, pelvic, heart]

- Tongue root fillets
- Head meat
- Lips
- Throat trim
- Neck trim
- Presentation offals:
  - Cheeks
  - Heart
  - Lungs
  - Kidney
  - Liver
- 1m^3 nude trim blocks.

3.0 Introduction

The preservation of meat is a critical aspect of the meat industry, ensuring food safety, extending shelf life, and maintaining product quality from slaughter to consumption. Amongst the most widely used and effective methods for preserving meat is cooling or freezing, which involves the use of refrigeration systems or direct contact with cold gases/liquids/solids to lower and maintain meat at safe temperatures.

Solid CO2 (“snow” or pellets) and liquid N2 are direct contact options, whilst mechanical cooling utilises non-direct contact with meat on one side and, normally, a closed loop thermal transfer medium (e.g. a refrigerant such as ammonia or CO2) on the other that extracts heat from the meat products through refrigeration technologies requiring compressors, condensers, and evaporators. This process inhibits the growth of spoilage microorganisms and pathogenic bacteria, particularly those that thrive at higher temperatures. By maintaining meat at low temperatures, mechanical cooling significantly slows down enzymatic activity and microbial proliferation, both of which are responsible for deterioration.

The adoption of mechanical cooling has revolutionized meat handling, storage, and distribution. From cold rooms in slaughterhouses to refrigerated transport and retail storage, this technology plays a vital role in modern food supply chains.

The rising costs of industrial gases and, at times, supply chain limitations has resulted in RMPs looking for alternate solutions to direct contact cooling. Onsite gas production is technically viable but has historically been a more expensive option at the lower scales available.

Additionally, RMPs tend to be capacity limited with freezing / plate freezing / storage, hence have a keen interest in de-bottle necking the existing plate freezers to avoid investment in additional capital.

Another area for exploration is the shelf life for red meat tissues at different temperatures (i.e. frozen or “fresh” at -1 DegC or higher) and the associated value.

4.0 Project objectives

The outputs of the project are:

- Model heat transfer/convective parameters to determine cooling rates (i.e. incoming trim temp; target trim temp; etc). Evaluate the model against real plant situations.
- Assess current practices - specifically improving efficiencies for CO2 use (i.e. thermodynamically optimised bins; manual v automated, and optimised dry ice; capture & re-use of sublimated dry ice, dry ice pellets v snowing), and on-site production of N2 (via direct air capture).
- Evaluate feasible efficiency improvements to dry-ice production using food grade CO2, and gas contact rapid cooling using Nitrogen Tunnel.
- Model alternative tube plate contact rapid cooling technology; fit for purpose use or adaptation within current plant, product quality and cost requirements. industry plate contact rapid cooling system i.e. Hive.
- Design of a CO_2 re-use system (e.g. pressure swing adsorption and CO_2 liquefaction) detailed cost-benefit analysis.
- Evaluate environmental impact of the various cooling solutions using ISO 14040:2006 LCA framework.
- Final report; Processor applications; Detailed business case: CAPEX / OPEX; Levelised Cost of CO2 and N2 (comparing efficiency with production options).
- "Levelised Cost of Cooling", including $ / kWh metrics, and environmental impact comparisons.
- Two appropriate retailers will be consulted for feedback around the recommendations proposed by the project team.
- Six individual short form reports will be issued to participating members, with each covering rapid cooling recommendations supported by a pre-feasibility.

5.0 Methodology

The project methodology is as follows:

- Six consultation meetings with varying types of member participants end-users to defined scope analysis.
- Workshops with two retailers / six members.
- Obtain analysis software.
- Initial model development.
- Review scientific and R&D literature, and relevant case studies.
- Collected data for the Lifecycle Assessment (LCA).
- Conduct LCA on options.
- Model thermo / fluid dynamics and techno-economics for options.
- Analyses of techno-economic and environmental impact outcomes.
- Complete short form recommendations with pre-feasibility study for each member participant.
- Submission of manuscript including comparisons and recommendations for each participant.
- Final member participant end-user workshop, seminar and final reporting.

One key item to define is what the target temperature and associated timing is for each site. Different "Approved Arrangement" at each RMP means that temperatures and timing could vary. From "AS 4696" (extract below) it appears that the target temperature is "5 DegC on any of its surfaces" by being “placed under refrigeration without delay and is rapidly chilled” with no mention of internal temperatures or the exact timing required.

12.3 During the time the processing of the meat occurs the time and temperature requirements specified for its processing or packaging in the approved arrangement are complied with.

12.4 If the processing of meat removed from refrigeration is likely to result in a temperature of warmer than:

(a) for a carcase, side, quarter or bone-in major separated cut, 7°C on any of its surfaces; and

(b) for any other meat, 5°C at the site of microbiological concern; then the processing takes place in a temperature controlled environment of no warmer than 10°C.

12.5 After the process is completed the meat:

(a) undergoes a further process without delay; or

(b) is placed under refrigeration without delay and is rapidly chilled until it reaches a temperature of no warmer than:

(i) for a carcase, side, quarter or bone-in major separated cut, 7°C on any of its surfaces; and

(ii) for any other meat, 5°C on any of its surfaces

6.0 Results

6.1 Site Visit Findings - Thermal Imaging Examples

The following are a selection of images from site visits providing snap shots of temperatures for activities throughout RMPs.

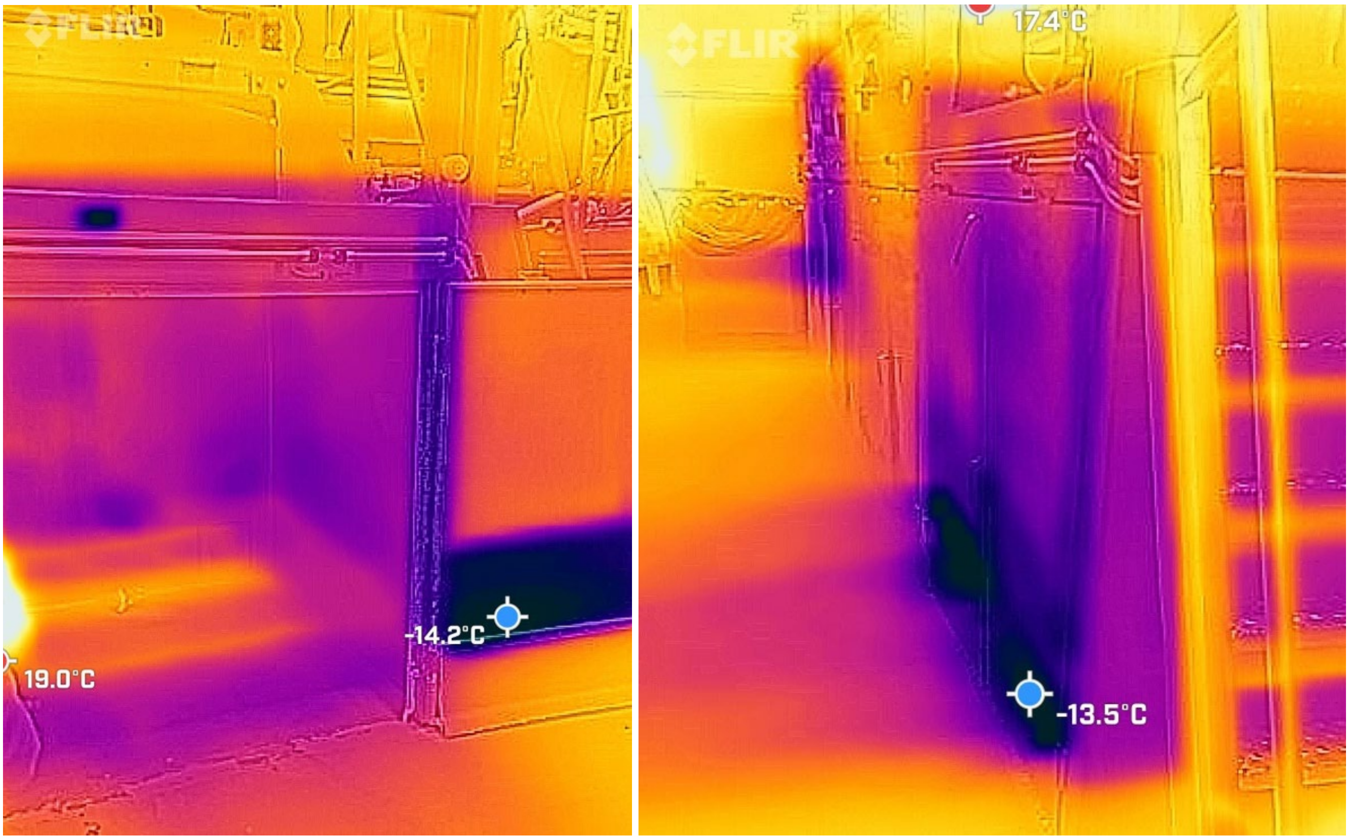


Figure 4: Front view (left) and side view (right) of trim snow cabinets showing large amounts of cooling loss from walls, sides and in particular through the base of the cabinets.

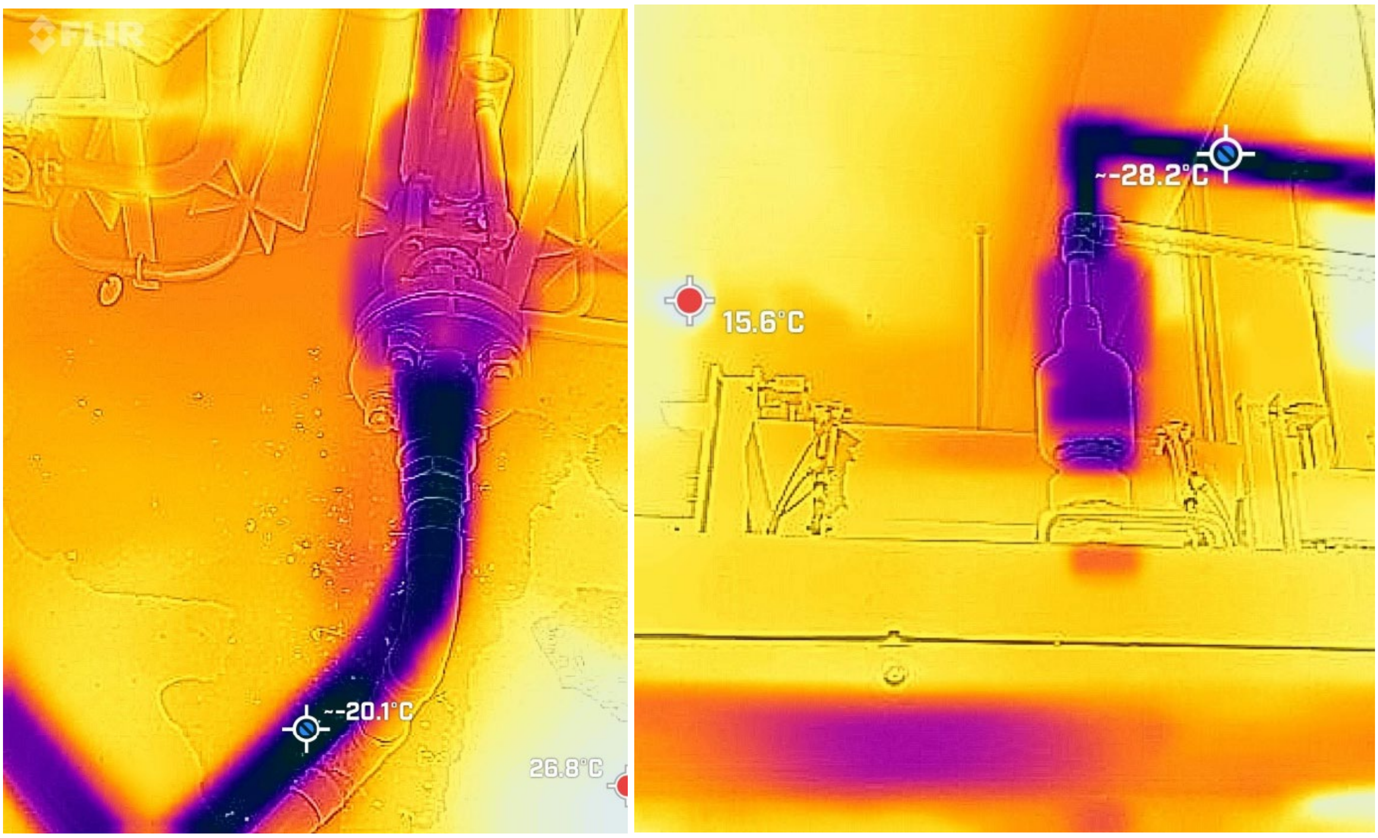


Figure 5: Evidence of the requirement for lagging on LCO2 from storage tanks (left) and LCO2 line within the boning room (right).

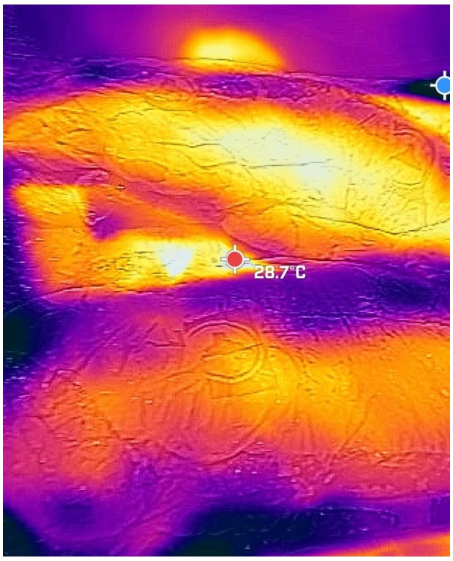


Figure 6: High temperatures of cartons about to be sent to the plate freezer of offal at 28.7 DegC after water bath (left) and trim at 10.1 & 10.4 DegC (centre and right).

6.3 Basis of Design

Selecting a Basis of Design enables a clearer “apples with apples” comparison.

For determination of a $/kWh cooling, the following was assumed:

- 10,000 tpa trim (40.82 tonnes trim per day for 49 weeks pa, 5 days per week).
- Start Temp 10 DegC (out of boning room).
- Target Temp 2 DegC (this is the target temperature after 24 hr freezer storage).
- Trim particle size of 50 mm (may require cubing / grinding)
- Bins of 800 kg trim.
- $0.3 or 0.15 / kWh power costs.

Additionally, this basis of design was utilised by the mechanical cooling vendor to generate a generic CAPEX / OPEX estimate.

6.4 High Efficiency CO2 Pellet Production

6.5.1 High Efficiency Dry Ice Production

Snow is created by flashing off some liquid CO2 which drops the temperature of the remaining liquid CO2 below the freezing point there by converting some CO2 from a liquid to a solid. A CO2 Recovery Systems captures and recycles CO2 that is otherwise vented (during snow production). Within the close loop recovery unit, the gaseous CO2 is cooled and compressed to create liquid CO2 that is then piped back to the dry ice pelletizer. Key questions on pellets are:

(1) are 3mm pellets acceptable for trim cooling, and

(2) do pellets provide a materials handling issue (compared to snow horns).

The pelletisation with flash recycling reduces liquid CO2 consumption by ~half in most installations. This process in simplified in the image below.

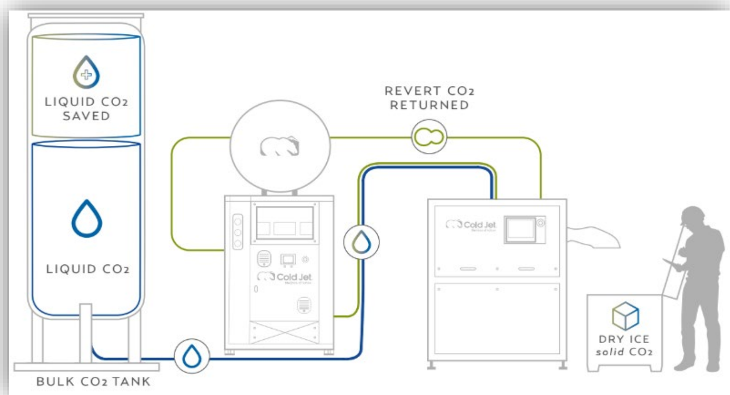


Figure 11: CO2 pellet system with flash gas recycle.

For the define "base case" of 10,000 tpa trim, the vendor recommended the PR350H pelletizer and the RE320 CO2 recycle system, shown in the images below. Pellets from 3 to 16mm can be produced (most beef processers use the 3mm dye), with a power draw of 5.5 kW (whilst the system can produce 350 kg/d, the recommended operational setting is 266 kg/h to match the recycle system, the system would operate for 10.4 hpd), <75 dB, compressed air of 10 Bar Class 3 required. The recycle system draws 45 kW (to recycle 320 kg/h of CO2). Total system footprint (Figure 12) is approx. 4.1m length, 1.35m width, 3.8m high (excluding pipework and switch board).

Figure 12: CO2 pellet system.

6.5.2 CO2 Pellets and Flash Recycle TCI

Client	AMPC Trim Cooling Project							
Author	All Energy Pty Ltd							
Revision	RevA							
By	GMF							
Checked	MCB							
Date	6/02/2025							
	Aggregated Total Capital Investment (TCI) incl. contingency	$ 718,350						
EXCLUSIONS:	"Owner's Costs" - Refer below incl. approvals, insurance, land access.							
	All items outside battery limits of project - Refer Below and PFD.							
FX:	1 AUD [Ref XE.COM 23/1/25]:	0.604126	EURO	Note: No FX contingency applied.				
	1 AUD [Ref XE.COM 23/1/25]:	0.628071	USD	Note: No FX contingency applied.				
KEY VENDOR PACKAGES	**Sub-System**	**Equipment / Material**	**Quantity**	**Unit**	**Unit Cost $AUS**	**Item Contingency**	**Item Cost**	**Info**
BoP ESTIMATE	**All Energy Pty Ltd estimates for site integration / local subcontractor scope**						$ -	
		Equipment / Material	**Quantity**	**Unit**	**Unit Cost**	**Item Contingency**	**Item Cost**	
	Pressure vessel design verification; Pressure vessel registration.		1	1	Assume vendor			
	Freight			**Euros**				
	Freight - Shipping (assume 40' from Denmark to PoB)		1	4550	$ 7,531.54	20%	$ 9,037.84	Freight Rate Calculator | 20 / 40 Ft Sea Container Shipping
	Freight - domestic		1	2000	$ 1,300.00	20%	$ 1,560.00	
	Import duty	Percentage of equipment FOB CAPEX	5%		$ 30,542.03		$ 30,542.03	
	Civil / structural / enabling	**Equipment / Material**	**Quantity**	**Unit**	**Unit Cost**	**Item Contingency**	**Item Cost**	
	Civil / Structural Design		EXCLUDED				$ 2,000.00	
	Ground surface leveling and compaction		EXCLUDED					
	Concrete apron and equipment slabs	Assume suitable available (25 Mpa 152mm thickness concrete)	EXCLUDED	m2	$ 300.00	20%	$ -	
	Site drainage & underground services			m	$ 50.00	20%	$ -	Drainage perimeter
	Telephone and Internet Services		EXCLUDED				$ 200.00	
	Monitoring Equipment (e.g. cameras)						$ 300.00	
	Signage		EXCLUDED				$ 200.00	
	Anchoring	Per container					Part of mechanical works	
	Plant perimeter fencing		EXCLUDED	m	$ 100.00	20%		Assumed square root of NH3 and N2 synthesis areas
	Electrical connection	**Equipment / Material**	**Quantity**	**Unit**	**Unit Cost**	**Item Contingency**	**Item Cost**	
	Power conduit and cable to connect MSB to Vendor Package SB. Including trenching, conduit/cable laying, reinstate fill, compaction.	3 phase connection, 480V 50 HZ. 4C+E wire	50	m	$ 353.34	15%	$ 20,317.05	
	Quality check of power cables (megger test, continuity etc according to local specs)		1		$ 3,000.00	15%	$ 3,450.00	
	Labour estimate (assuming all equipment pre-fabricated offsite)		80	hours	$ 200.00	15%	$ 18,400.00	
	Site Sundries - Electrical (Test & Commission; Site establishment & prelims; Administration, supervision, project management & QA)		1		$47,900	15%	$ 5,000.00	
	Mechanical / Plumbing connections	**Equipment / Material**	**Quantity**	**Unit**	**Unit Cost**	**Item Contingency**	**Item Cost**	
	CO2 supply - connection from battery limit to plant		10	m	$ 127.49	30%	$ 1,657.37	Utilise existing
	Fire water pipe incl. install	Galvanised steel pipe	EXCLUDED - UTILISE EXISTING	m	$ -	30%		
	Fire water pipe elbows		EXCLUDED - UTILISE EXISTING	Quantity	$ -	30%		
	Pipe supports		6	Quantity	$ 47.50		$ 285.00	Assumed same as other metric fittings cost
	Valves, vents, fittings	TBA	EXCLUDED - UTILISE EXISTING	Multiplier on straight cost	$ -	10%	$ -	
	Installation labour assuming equipment prefabricated off site where possible		80	Hours	$ 140.00	30%	$ 14,560.00	
	Spare parts	Allowance in vendor package.					BoP Excluded from TIC - account for in annual opex figure	
PELLETIZER	PART NUMBER	ITEM	QTY		$US		$AUS	
	2A0512-PKG	Pelletizer Unit, PR350H UL/CE, 380-480 V; 2A0512	1		$116,850	5%	$ 195,348.21	
	2D0606	3 MM (1/8 IN) Die Plate, PR350H/PR750H; 2D0606	1		INCL	5%		
	501327	10 mm Die Plate; 501327	1		INCL	5%		
	515536	Warm Weather Kit, PR350H; 515536	1		$7,850	5%	$ 13,123.52	May not be required if within production area
	2K0305	Armstrong Kit, PR350H & PR750H; 2K0305	1		$4,645	5%	$ 7,765.45	
	2K0261	Packaging, PR350H/PR750H, Wooden Box 2K0261	1		$680	5%	$ 1,136.81	
	Commissioning & Training	Commissioning & Training incl. Travel & Lodging expenses	1		$4,700	5%	$ 7,857.39	
	503005	Spare Parts, Standard, PR350H; 503005	1		$2,095	5%	$ 3,502.39	
	503030	Spare Parts Kit for 2000 hours service, PR350H; 503030	1		$2,270	5%	$ 3,794.95	
RECYCLE SYSTEM	**PART #**	**DETAILS**	**QTY**		**EURO**			
	2A0692	RE-CO2 320 Recovery Unit, 400 to 480 V, 50/60 HZ; 2A0692	1		€ 185,950	5%	$ 310,868.64	
	2C0363	RE-CO2 320, Buffer Tank, Revert Gas Receiver, 1600 L; 2C0363	1		19100	5%	$ 31,931.12	
	4K0070	KIT, WARM WEATHER, RE-CO2 320	11		€ 5,195	5%	$ 8,684.93	
	81526-001	SPARE PARTS, STANDARD, RE-CO2 320	1		€ 4,097	5%	$ 6,849.31	
	2C0298	Check Valve, Assembly, Recovery; 2C0298	1		€ 1,620	5%	$ 2,708.29	
	2C0312	External Hose Connection, Recovery; 2C0312	1		€ 2,775	5%	$ 4,639.21	
	Commissioning & Training	Commissioning & Training excl. travel & living	1		€ 6,450	5%	$ 10,783.02	
	2K0574	Packaging, 1600 L Buffer, Wooden Box; 2K0428	1		€ 490	5%	$ 819.18	
	2K0493	Packaging, RE-CO2 320, Wooden Box; 2K0493	1		€ 615	5%	$ 1,028.15	

OWNER'S COSTS		
	OWNERS COSTS	
	Land Purchase / Lease	EXCLUDED
	Owners Project Management Team	EXCLUDED
	Legal Advisors	EXCLUDED
	Insurance Consultant	EXCLUDED
	Industrial Relations Consultant	EXCLUDED
	Project Insurance	EXCLUDED
	All Statutory Requirements incl. Permits & Approvals (refer below)	EXCLUDED
	Technology Licenses	EXCLUDED
	PRE-PRODUCTION COST	EXCLUDED
	Frent End Engineering Design / Detailed Design not included in TCI	EXCLUDED
	Staff & labour costs	EXCLUDED
	Administration expenses	EXCLUDED
	Training (safety, etc)	EXCLUDED
	Recruitment & relocation	EXCLUDED
	Reagents & consumables	EXCLUDED
	Power during commissioning (gen set hire)	EXCLUDED
	Insurance spares	EXCLUDED
	Consumables spares	EXCLUDED
	Commissioning spares	EXCLUDED
	Safety supplies & Training	EXCLUDED
	Maintenance Tools & Equipment	EXCLUDED
	Office Equipment & Furniture	EXCLUDED
	Computing Hardware & Software	EXCLUDED
	CONTINGENCIES	EXCLUDED
	Package Contingency - Supplers & Contractors	EXCLUDED
	EPC Contingency	EXCLUDED
	Project Contingency	EXCLUDED
	Escalation	EXCLUDED
	Force majeur	EXCLUDED
		EXCLUDED
	Power supply	EXCLUDED
	Panels	EXCLUDED
	Panel support - ground mount	EXCLUDED
	Transformer (Pad Mounted Transformer(s) at battery limit)	EXCLUDED
	Inverter	EXCLUDED
	Monitoring	EXCLUDED
	Meter	EXCLUDED
	Installation	EXCLUDED
Statutory Requirements		
	Planning & Approvals: main requirements are expected to be:	
	Development application (incl. Material Change of Use),	Expected to come in under existing Eas
	Major Hazards Facility (MHF) submissiondetermine whether they should be an MHF.	Not expected to change from existing plant
	Work Health and Safety (WHS) Regulation 2011 notification of a Manifest Quantity Workplace (MQW) for chemical storage / handling to Hazardous Industries and Chemicals Branch (HICB). Note: normally occurs after detailed design abd before "Issued for Construction".	Not expected to change from existing plant
	Quantitative Risk Assessment (for WorkSafe & MHF) including HAZOPs.	May be required
	Copy of the emergency plan, prepared under Part 3.2, Division 4 (section 43) of the Work Health & Safety Regulation 2011 (section 361) for the workplace to the Queensland Fire & Emergency Services (QFES). QFES may then communicate the emergency plan with the Queensland Police Service.	May require updating
	Pressure vessel design verification and registration for Hazard level A,B,C vessels under the WHS Regulation (Schedule 5, Part 2 – Items of plant requiring registration).	Likely required for liquid CO2 vessel as operatnig at up to 18 Bar.
	Hazardous Area Audit (for compliance with AS3000, IECEx, etc).	May require updating
	State Level Env Relevant Activities (ERAs)	Not expected to change from existing plant

Figure 13: CO2 pellet system Total Capital Investment estimate.

6.5.3 Case Study – High efficiency pellets

A beef plant in Europe replaced a "Snow Horn" with a PR750H and reduced CO_2 usage by 50%.

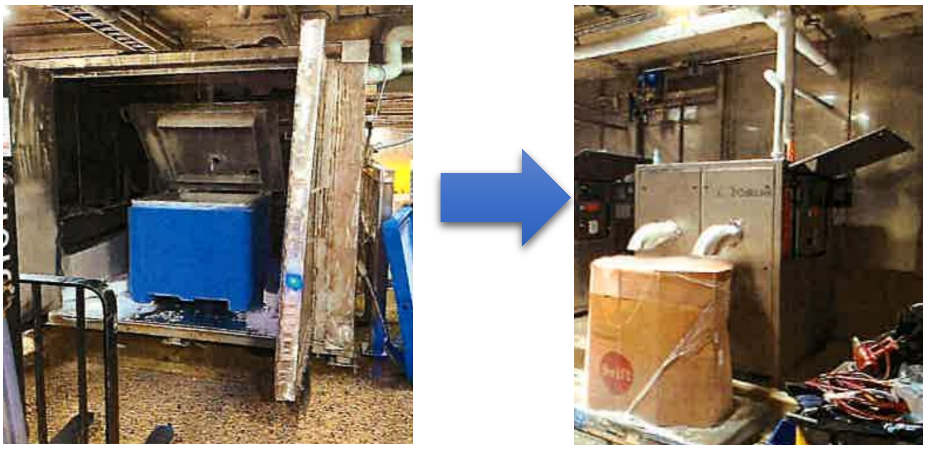


Figure 14: Images of a snow system on the left (before) and a pellet system on the right (after).

6.5.4 CO2 Recovery from Vent Gas

A specific opportunity considered in detail is to recover CO2 from vent gas, which could include CO2 flashed during snow production and sublimated CO2 during the cooling process, both of which would require dedicated extraction systems. Due to the need to ventilate within operational areas, CO2 is diluted rapidly by ventilation air, hence a CO2 hood or capture system, particularly during the early stages of trim cooling would be required (which is when the greatest amount of sublimation is expected) The CO2 recovery opportunity relies upon:

(1) Having a source of, ideally, >70% CO2. Otherwise, the CAPEX increases and recovery drops.

(2) A method to capture a high percentage of available CO2.

Around 6.9 tpd CO2 is available from flash gas and sublimation. However, it is assumed that does to losses and inefficiencies in the purification system that 40% of total CO2 is recovered.

A Pressure-vacuum swing adsorption (PVSA) system has been recommended. This system would be sized to recover ~2 tons CO2/day, which is relatively small for this type of technology. A compressor would be required to pressurise the CO2 for the PVSA inlet (2 bar feed to reduce the volume flow and 0.2 bar vacuum) and a second compressor for the liquid CO2 production. A Y-type zeolite is recommended. CAPEX estimated at $3mil.

A schematic of a PSA process is shown below[1].

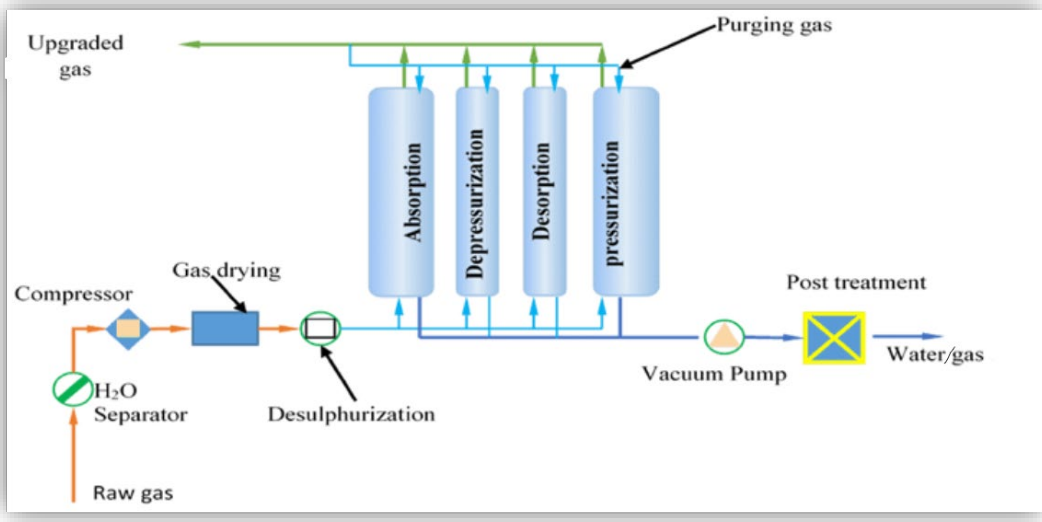


Figure 15: CO2 recycling system.

[1] Ogunlude, P et al., WEENTECH Proceedings in Energy, DOI:10.32438/WPE.8319, 2019.

By way of example, a skid mounted PSA system for the production of CO_2 is shown below[2].

Figure 16: Pressure Swing Adsorption (PSA) system for CO_2 recycling.

[2] Large Industrial CO_2 Generator, Xuzhou Huayan Gas Equipment Co., Ltd, accessed 6th Feb 2024.

6.5 CO2 Recovery From Biogas

Biogas is a complex mixture, in approximate order, of CH4, CO2, water, N2, H2, H2S, NH3 and other trace volatile organic carbon molecules. Methane purification is routinely via scrubbing, PSA, or amine scrubbing. However there exists the opportunity for

Assuming a large RMP facility processing 1200 beef cattle per day (108,000 tHSCW pa), it is estimated that 88,641 GJ/annum of biogas could be produced which equates to approx. 4,432,050 Sm^3 pa or 12,142 Sm^3 pd. At 42.6mol% CO2, this equates to 10.83 tpd CO2. Hence, sufficient CO2 is present in the biogas from a RMP to meet trim cooling requirements. A liquid CO2 system rated to 7.926 tpd (74% recovery) was selected with CAPEX assumed at $9.4mil[3].

By way of example, a skid mounted amine scrubber for the production of bio-methane with CO2 as a by-product[4].

Figure 17: Skid mounted system to separate CO2 from CH4 in a biogas stream.

3 "Feasibility Study into Resource Recovery Facility in the Red Meat Sector", AMPC Project 2024-1019, 2024.
4 "Amine Scrubber", americanbiogascouncil.org/processing-aminescrubber/, accessed 6 Feb 2025.

6.6 On-site production of N2 for rapid cooling using Nitrogen Tunnel.

Onsite production of N2 is technically straight forward. The analysis for this project would suggest that the economics of onsite N2 is marginal due to:

- RMPs use a comparatively small amount of N2, hence onsite N2 production technologies at a suitable scale are designed for medical and imaging applications.
- Industrial N2 production, routinely via cryogenic distillation, enjoys economies of scale and is effectively a by-product from the manufacture of O2, hence the relatively low cost of N2 compared to CO2.
- Small scale N2 production, routinely via pressure swing adsorption or molecular sieves, is very energy intensive (i.e. kWh / kg liquid N2) due to the need for small scale air separation and liquefaction equipment.

A block diagram for a cryogenic production system is shown below.

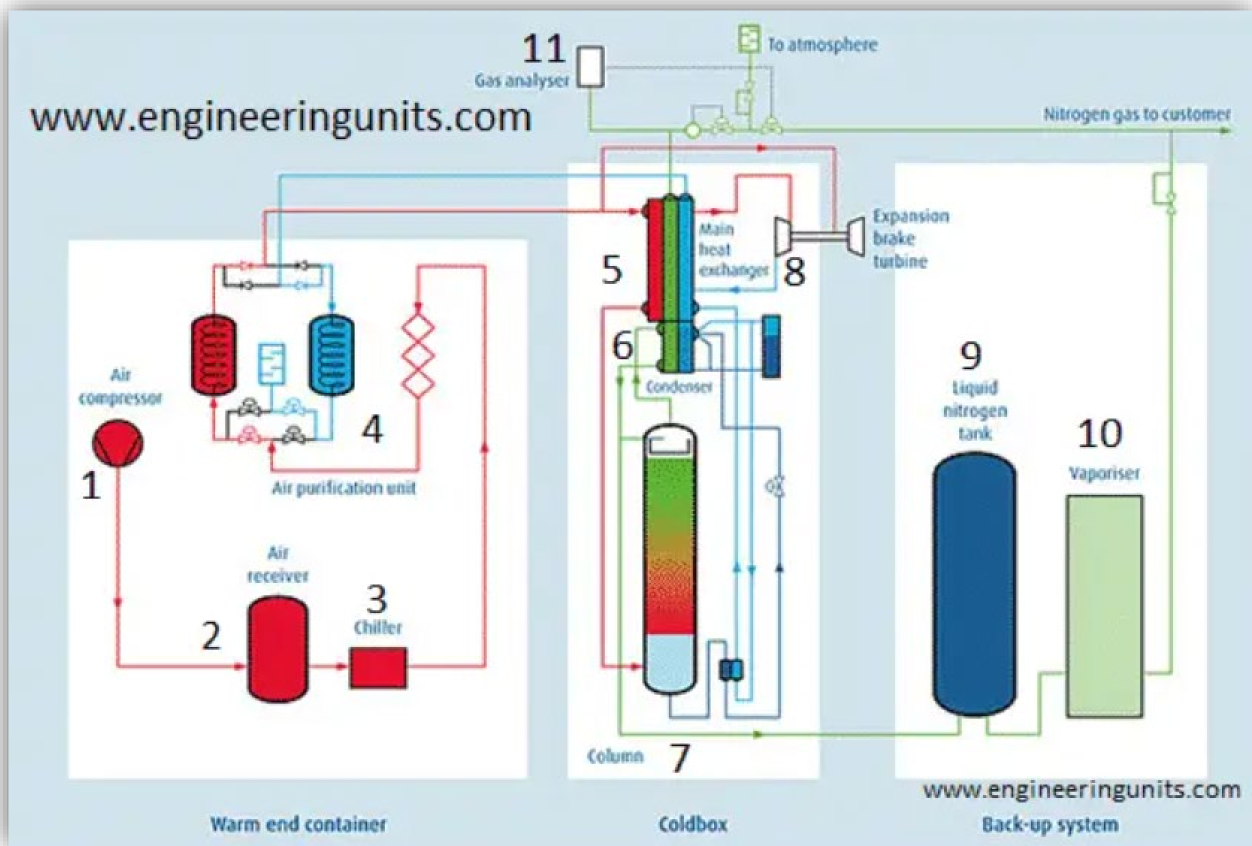


Figure 18: Liquid N2 production system.

A submission for onsite N2 production was received from Peak Scientific[5] for onsite N2 production as per the flow diagram below. The detailed economic analysis for LN2 is presented below.

	Scenario	N2	
Parameter	Units	LN2 Delivered, includes CAPEX.	LN2 made onsite incl. new Trim Management System.
Heat of vaporisation / sublimation kJ/kg (up to 593.2)	kJ/kg snow	199.64	199.64
Heat of vaporisation / sublimation kWh/kg	kWh/kg snow	0.0555	0.0555
Heat of vaporisation / sublimation kWh/tonne	kWh/t snow	55.4563	55.4563
Specific heat kJ/kgK [CO2: -78 to 2; N2: -195.8 to +2 DegC (77.35K to 275.15K]	kJ/kgK CO2	1.0390	1.0390
Specific heat per tonne [-78 to target] kJ/t	kJ/t CO2	205,514.2000	205,514.2000
Specific heat per tonne [-78 to target] kWh/tonne	kWh/t CO2	57.0873	57.0873
Available cooling per tonne CO2 or N2 (kWh/t)	kWh/t CO2	112.5436	112.5436
Procurement $/tonne	$/t	**$ 750**	**$ 515**
Basis: Mass Trim tpa	tpa trim	10,000	10,000
Trim start T	Deg C	10.0	10.0
Trim end T	Deg C	2.0	2.0
Specific heat "animal mixed tissue" kJ/kg.K Ref: omnicalculator	kJ/kg.K trim	3.20	3.20
Cooling requirement kJ pa	kJ pa	256,000,000	256,000,000
Convective ventillation losses / inefficiency factor	factor	1.2500	1.2500
Total cooling allowing for losses	kJ pa	320,000,000	320,000,000
Cooling requirement kWh pa	kWh pa	88,889	88,889
CoP (R717 to -10 DegC evap)			
Power kWh p.a.	kWhe pa		2,913,296
Power $/kWh	$/kWhe		0.15
Power $ pa	$ pa		436,994.35
% conversion liquid CO2 to snow	%	1.00	1.00
Maintenance @ 3% CAPEX pa	$ pa	$ 127,500	$ 229,822
Equipment leasing $ pa	$ pa	$ 80,000	
Gas OPEX useful cooling $/kWh	$/kWh	8.3301	5.7214
Gas tonnes pd (averaged)	tpa	2.705	2.164
Gas tonnes pa	tpa	987	790
Snow / pellets per operational day	tpd		
Gas Procurement Costs $ pa	$ pa	$ 740,454	$ 508,573
TOTAL OPEX $ pa	**$ pa**	**$ 947,954**	**$ 738,396**
CAPEX		**$ 4,250,000**	**$ 7,660,745**
Life of plant - years	Years	15	15
Lifetime cost of entire system (CAPEX & OPEX)	$	$ 18,469,304	$ 18,736,679
Lifetime gross cooling kWh	kWh	1,333,333	1,333,333
LCoC - Lifetime Gross Cooling $/kWh	$/kWh cooling	$ 13.85	$ 14.05
Lifetime Product Cooling kWh	kwh cooling	1,066,667	1,066,667
LCoC - Lifetime Product Cooling $/kWh	**$/kWh**	**$ 17.31**	**$ 17.57**
CAPEX	$AUS		
CO2 bins	500000		
Vacuum insulated pipes	150000		
TMS Marel	2320000		
Installation	1780000		

Figure 19: Liquid N2 LCoC estimate.

[5] Personal communication, Todd Linford (E: tlinford@peakscientific.com), Peak Scientific Instruments, 2 / 5 Phillip Court, Port Melbourne 3207, 25 Nov 2024.

6.7 Mechanical Cooling

Detailed communications were held with the Staughton Group on their HIVE cooling system. Additional options include Vacuum Chilling and Spiral freezers (note: these are being considered in other projects; hence it is proposed that a full life cycle assessment be completed as the next phase of work to compare technology options in terms of energy, emissions, water, packaging / materials and resources).

Hive is an innovative refrigeration technology developed by and installed at Staughton's Albury pet food processing plant, and involves a pumpable product being frozen via continuous[6] extrusion. This technology was investigated during the site visits for applicability to trim. The primary identified concern was any size specifications by trim offtakers that would prevent the 50 mm pre-grinding necessary for this system's material transfer. Another area for consideration is the materials handling, specifically feeding tissue into the mono-pump.

The uniform dimensions of the frozen block may be an attractive feature for logistics, and enable either a much larger mass to be packed per pallecon, or reduce the size and hence packaging material for fixed mass 60lb / 27.2 kg boxed trim. The frozen blocks have a higher density than loosed packed tissue hence reduces bulging.

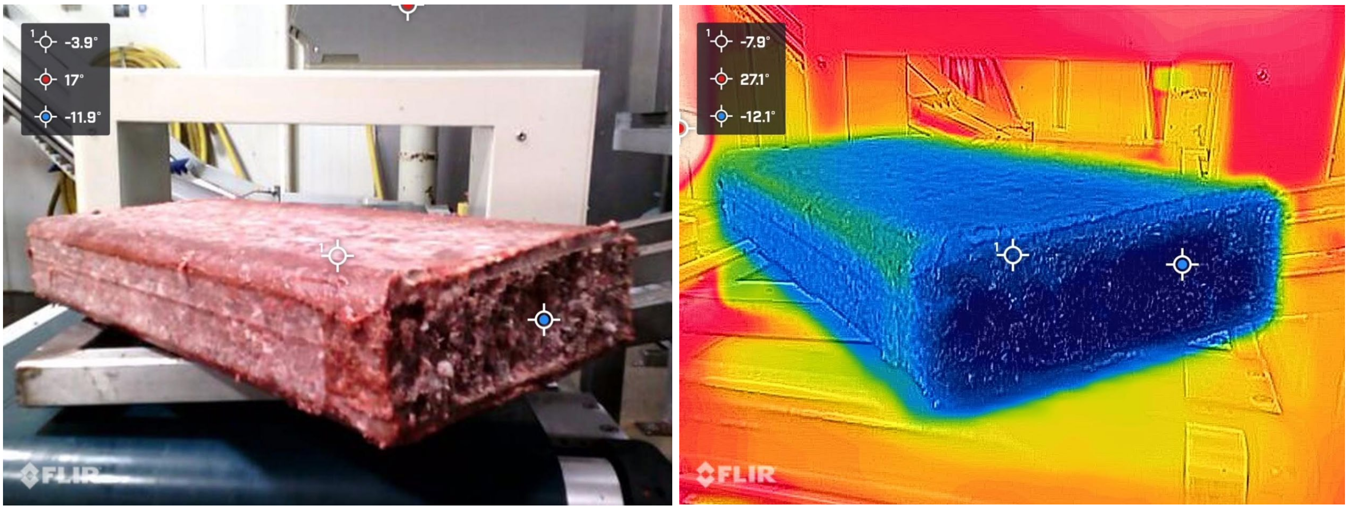


Figure 22: Thermal images of frozen mince processed through the HIVE system.

[6] In contrast to the batch operation of standard vertical or horizontal plate freezers.

6.8 Impact of the various cooling solutions on GHG emissions

The following summarises a life cycle assessment (LCA), where the plate freezer and LN2 tunnel LCAs were completed by the University of the Sunshine Coast and CO2 Snow was based on available site data for a RMP case study.

Scenario	Trim Process Rate	Electricity consuption	GHG	GHG / tonne trim cooled
Units	tonnes per day	kWh per day	kg CO2-e / day	kg CO2-e / tonne trim
Trim cooling via "Plate freezer"	74.7	1,355.7	1,265.0	16.9
LN2 tunnel	51.0	1,161.7	1,045.6	20.5
CO2 Snow	48.0	24.0	7,288.8	151.9

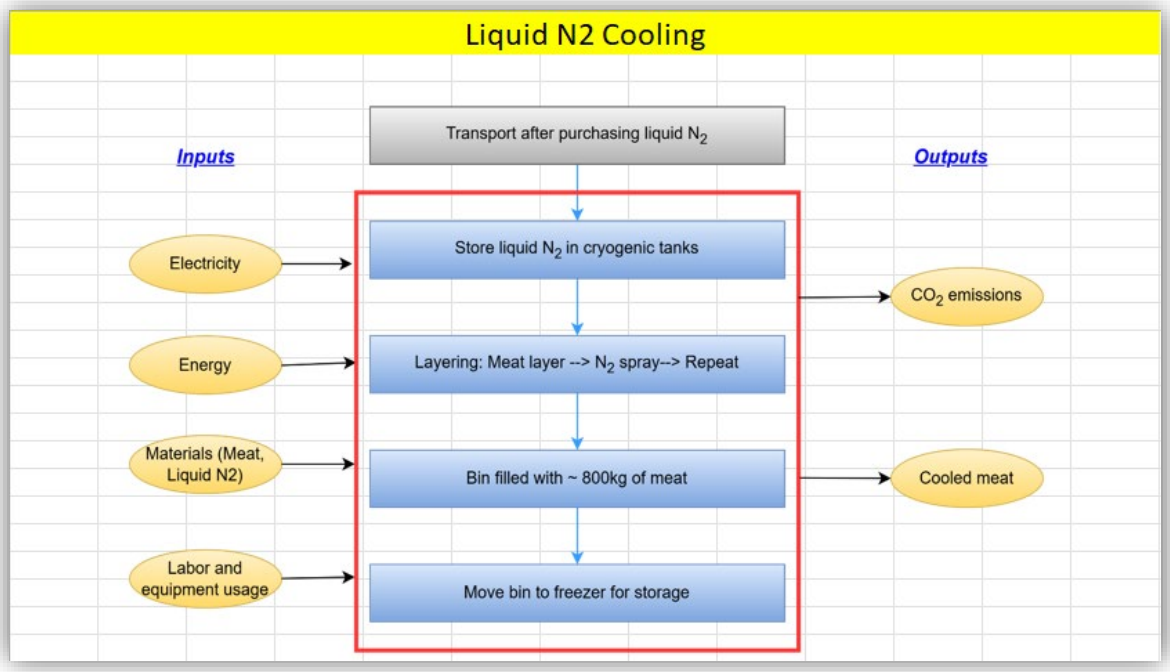


Figure 25: Life Cycle Assessment results for cooling technologies.

Task description		
This **Life Cycle Assessment (LCA) analysis** focuses on evaluating the **greenhouse gas (GHG) emissions** of the **N2 cooling process** using a **Gate-to-Gate approach.** The assessment considers key process stages, including storage of liquid N2 , Cooling via N2 spray and layering with meat, and freezing for storage. The goal is to quantify the inputs and outputs for each stage, enabling a clear understanding of environmental impacts. By systematically mapping the material and energy flows, this analysis provides insights into emission hotspots and potential efficiency improvements, supporting data-driven decision-making for reducing the carbon footprint of the cooling process. This analysis is conducted based on the four key phases defined in the ISO 14040:2006 to ensure systematic evaluation of environmental impacts.		
Key phases of ISO 14040	**Description**	**Key activities**
Goal and Scope Definition	Defines the purpose, system boundaries, and functional unit of the LCA.	Establish functional unit Define system boundary Select impact categories Identify assumptions
Life Cycle Inventory (LCI)	Collects data on energy, material flows, and emissions for each process.	Identify inputs Quantify outputs Use data sources
Life Cycle Impact Assessment (LCIA)	Translates inventory data into environmental impact categories.	Select impact categories Calculate based on the data
Interpretation	Evaluates results, identifies hotspots, and makes recommendations.	Identify major contributors to impacts

Goal		
1. Evaluate the full environmental impact of the liquid N2 cooling process		
2. Compare different cooling scenarios		
3. Identify key emission contributors and recommend optimizations.		

Scope		
Activities	**Approach**	**Description**
LCA Type	Attributioanal LCA	This study only assesses the environmental impact of the beef cooling process using liquid N2 (Gate-to-Gate), without modeling changes in production or market effects
System Boundary	Gate-to-Gate	Analysis only focuses exclusively on the cooling process based on the available data.
Unit of Analysis	Cooling 1 kg of meat using liquid N2	This referes to the functional unit, which defines the quantitative basis for comparison of environmental impacts. For this study selected fuctional unit describes all inputs and outputs are calculated based on the per 1 kg of meat cooled.
LCA Stages	1. Storage liquid N2 2. Cooling via N2 spray 3. Bin filling 4. Freezing and storage	Based on the process flow of liquid N2 cooling

	Quantity	Units	Resources	Additional Notes			
Data							Units
Latent heat of sublimation	199	kJ/kg	Available data from trim cooling master file	1kwh	=	3600	kJ
Specific heat of Beef	3.44	kJ/kg		1 kg of CO_2 used	=	1 kg CO_2-e emitted	
Temperature difference	22	°C					
Total mass	850	kg/bin					
Electricity grid emission factor	0.9	kg CO2-e per kWh	Brander, M., Sood, A., Wylie, C., Haughton, A., & Lovell, J. (2011). Technical Paper| Electricity-specific emission factors for grid electricity. Ecometrica, Emissionfactors. com.				
Bins per day	60	bin/day	Assumption				
Cooling rate used in N2 tanks	0.05		Assumption				
Working hours	24	hr	Assumption				
Power estimate for freezer	1.5	kW/hour	Assumption				
Calculations							
Energy Calculations							
Energy required for cooling per bin	64328	kJ/bin					
N2 liquid requirement	323.2562814	kg/bin					
Energy required for cooling per day	3859680	kJ/day					
Convert energy to kWh							
Q per bin	17.86888889	kWh/bin					
Q per day	1072.133333	kWh/day					
GHG Emissions							
GHG emissions from electricity usage per day	964.92	kg CO2-e per kWh					

System Boundary Assumptions		
Category	**Assumption**	**Justification**
LCA Type	Gate-to-Gate (only considers cooling)	Excludes liquid N2 production & transport in this stage due to the lack of data
Functional Unit	Cooling 1 kg of meat using liquid N2	Provides a standardized basis for comparison
Energy Consumption Assumptions		
Process	**Assumption**	**Justification**
Latent heat of liquid N2	199 kJ/kg	Based on thermodynamic data at atmospheric pressure
Cooling rate used in N2 tanks	5%	Represents LN_2 usage as proportion of cooling mass or loss allowance
Emission Factor Assumptions		
Factor	**Assumption**	**Justification**
Electricity Emission Factor (Australia)	0.9 kg CO2-e per kWh	Based on literature
CO2 Sublimation Emission Factor	1 kg CO2-e per kg CO_2 used	Each kg of CO2 sublimated is considered a direct emission (Scope 1)
Bins per day	60	Operational assumption based on plant capacity
Process Efficiency & Material Loss Assumptions		
Factor	**Assumption**	**Justification**
Meat Cooling Efficiency	Assumes uniform heat transfer from meat to liquid N2	Ignores minor temperature variations within meat bins.
Annual Operational Assumptions		
Factor	**Assumption**	**Justification**
Plant Operational hours	24 hours/day	Full day operation assumed
Power Estimate for Freezer	1.5 kW	Estimated continuous power draw of freezer equipment

		Quantity	Units
1. Storage of liquid N2			
Database	EcoInvent		
Inputs	Energy	53.60667	kWh/day
	Grid emission factor	0.9	kg CO2-e per kWh
Outputs	Total GHG emissions	48.246	kg CO2-e/day
2. Layering of N2 and Meat			
Database	EcoInvent		
Inputs	Energy required	1072.133	kWh/day
	Grid emission factor	0.9	kg CO2-e per kWh
Outputs	Total GHG emissions	964.92	kg CO2-e/day
3. Freezing Process for Storage			
Database	EcoInvent		
Inputs	Electricity for Freezing	36	kWh/day
	Grid emission factor	0.9	kg CO2-e per kWh
Outputs	Total GHG emissions	32.4	kg CO2-e/day

Global Warming Potential (GWP) and energy consumption		
Process Step	GHG Emissions (kg CO_2-e/day	Energy Use (kWh)
Storage liquid N2	48.246	53.60666667
Cooling via N2 spray	964.92	1072.133333
Bin filling	0	0
Freezing Process	32.4	36
Total	1045.566	1161.74

6.9 Efficiency Gains for CO2

6.10.1 Pipe Lagging

As highlighted by the thermal imaging, considerable cooling is lost when pipes are not lagged. The images below show an unlagged section of pipe in the outlet of the CO2 liquid tank where even after ice crusting the temperature is -17 DegC.

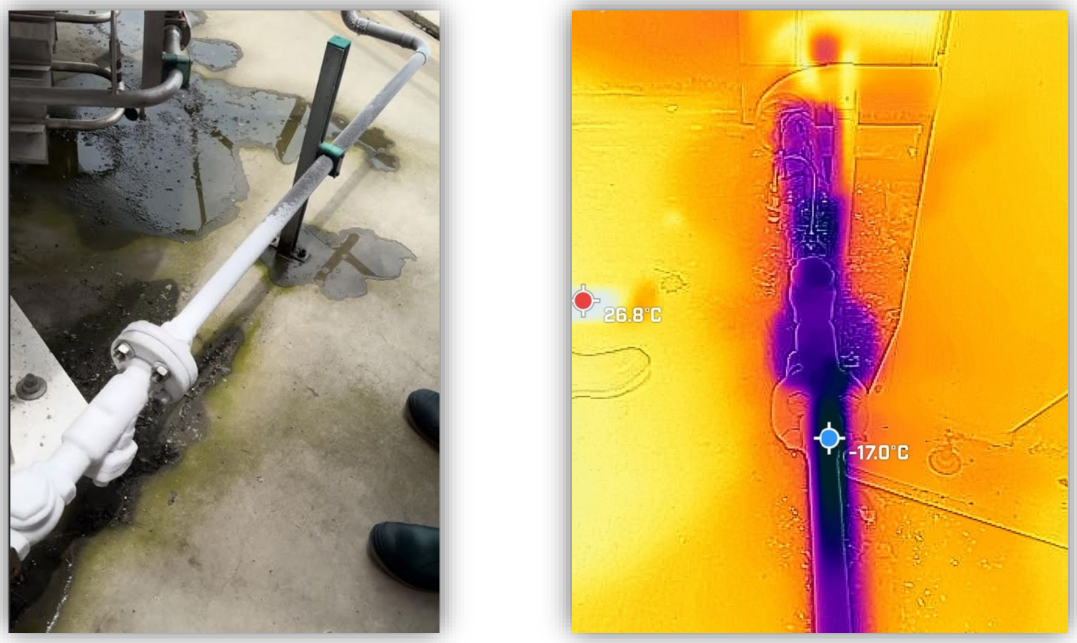


Figure 26: Liquid CO2 supply pipe from storage to plant.

The next images shows the CO2 liquid pipe to the snow horns within the production area. Whilst these pipes do not ice up due to the low humidity, there is considerable cooling loss due to the ambient air being 10 to 15 DegC.

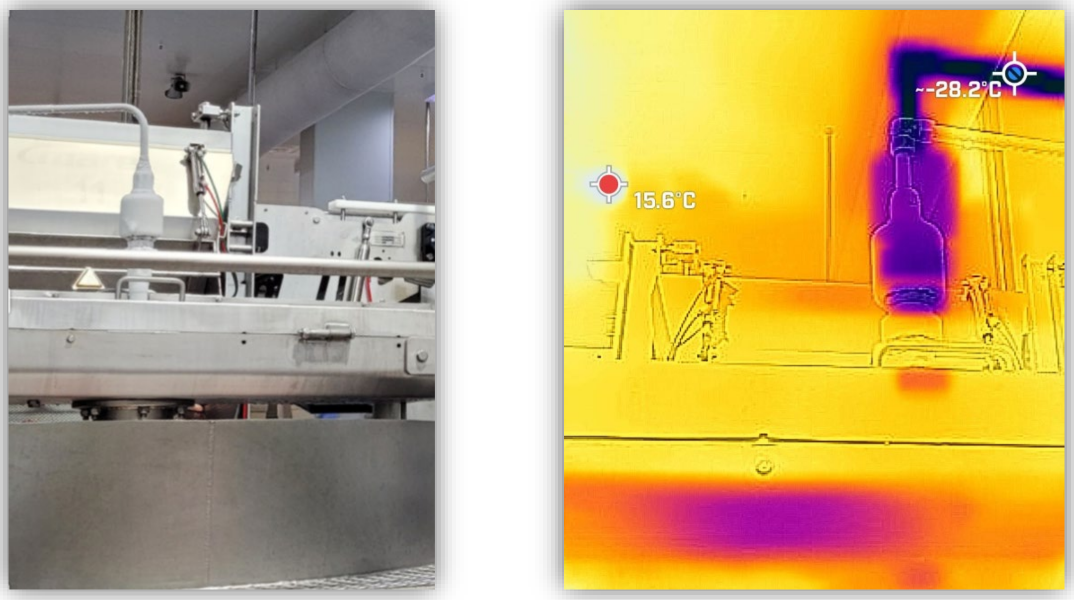


Figure 27: Liquid CO2 supply within the trim cooling area.

Modelling a 1.0m length of unlagged 2" pipe in 25DegC ambient conditions (pipe surface temperature -19.9DegC): assuming pressure remains constant, some of the LCO2 entering the pipe exists as gas. This results in a reduction of CO2 snow production where 3.1% less snow is produced per metre of unlagged pipe, noting that an ice crust creates some lagging effect, but the infrared still shows considerable energy losses. As per the image below.

Payback estimate:

Lost snow production value: ~$64,449 pa (at 2.1mil kg pa consumption of LCO2).

$27.49 per meter (ref: https://insulationeasy.com.au/product/thermotec-4-zero-thermal-wrap-pipe-insulation/) + $100 installation and fixings.

Payback: $127.49/32890 = 0.7 days (excluding impact of ice crusting).

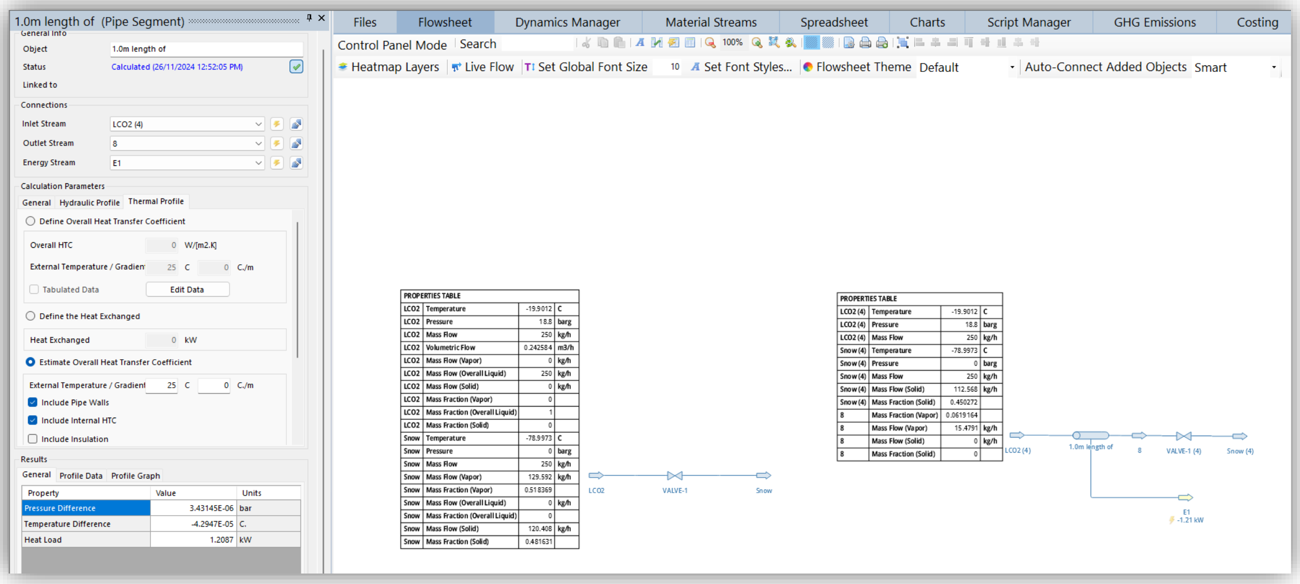


Figure 28: Thermodynamic model confirming opportunity to lag liquid CO2 supply lines.

Modelling a 1.0m length of unlagged 2" pipe in 10DegC (i.e. boning room) ambient conditions: assuming pressure remains constant, 4.12275% of LCO2 entering the pipe exists as gas. This results in a reduction of snow production down to 46.075% i.e. 2.08% less snow per metre of unlagged pipe.

Noting: the ice crust creates some lagging effect, but the infrared still shows considerable heating impacts.

Lost snow production value: ~$43,243 pa (of 2.1mil kg CO2 pa).

$27.49 per meter (ref: https://insulationeasy.com.au/product/thermotec-4-zero-thermal-wrap-pipe-insulation/) + $100 installation and fixings.

Payback: $127.49/43243 = 1.1 days (excluding impact of ice crusting).

6.10.2 Advanced Process Model – Production of Snow from Subcooled LCO2

LCO2 sub-cooling idea: Using an equation of state model (DWSIM), in a perfectly lagged system, CO_2 at 18.8 Barg (pressure in the Kilcoy tanks) is a liquid at -19.9012 DegC. When expanded to atmospheric pressure in a perfectly lagged system, 48.1% of the CO_2 is converted into solid CO_2. If the temperature of the LCO2 is reduced to -40 DegC, then 55.1% of the CO_2 is converted into solid CO_2.

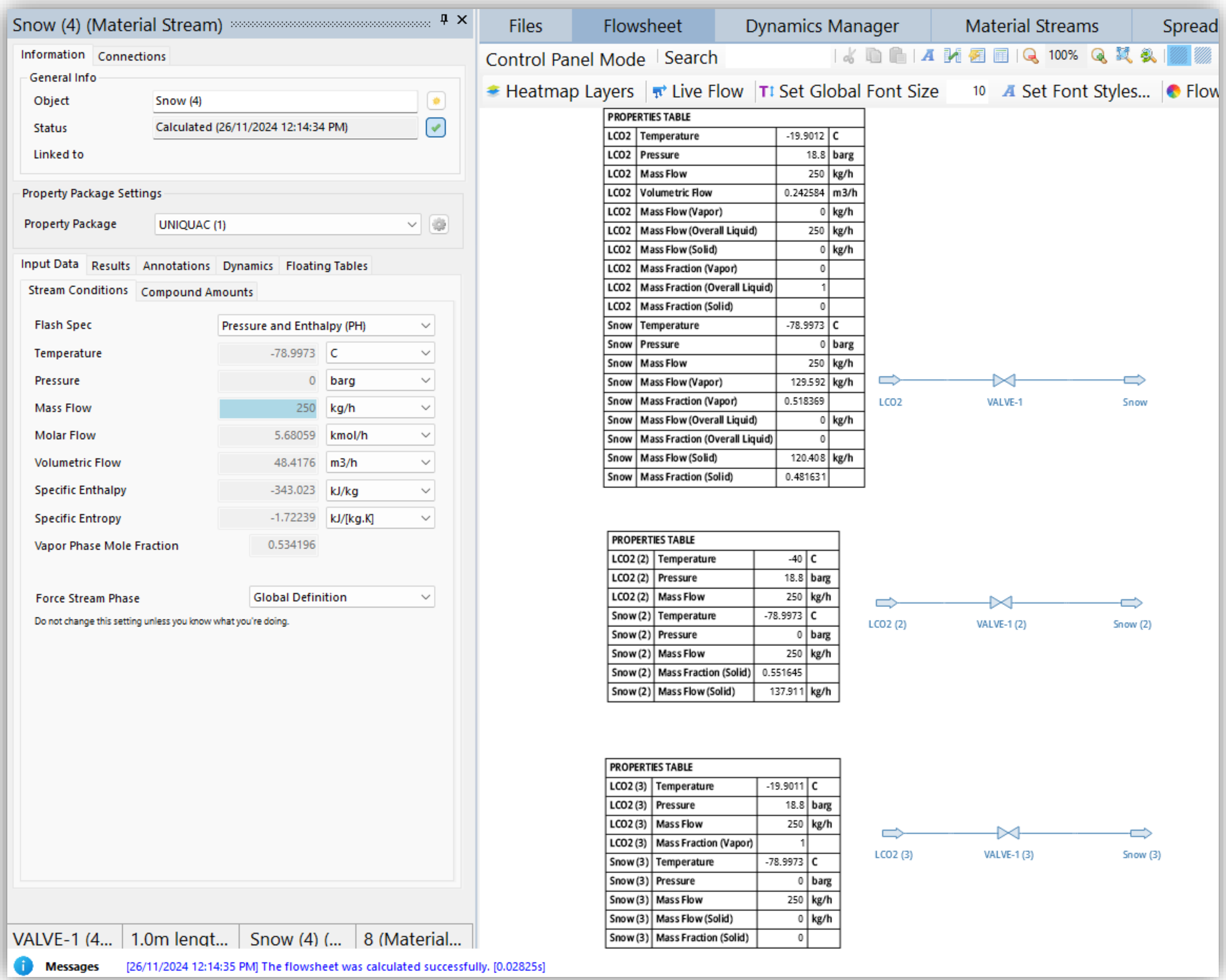
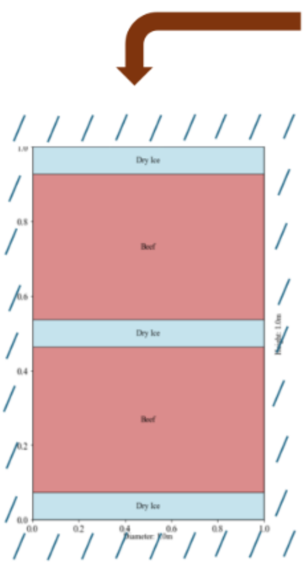


Figure 28: Thermodynamic model confirming opportunity to sub-cool liquid CO_2 before snow production.

6.10.3 Insulation of Large Containers / Pallecons

Thermodynamic modelling by the University of the Sunshine Coast (USC) estimates a 58% reduction in snow requirements where a pallecon / trim holding vessel is “perfectly” insulated.

Comparison (Study of Insulation effects)



Study 3 (Optimum layer thickness and with insulation)	Results from simulation	Study 02 (Optimum layer thickness and no insulation)
643.24 kg	Beef cooling capacity	643.24 kg
269.5 kg	Initial Dry Ice Capacity	269.5 kg
110.48 kg (40.99%)	Dry Ice usage (%)	262.80 kg (97.5%)
41.2 mins	Time to cool down entire beef	44.1 mins
Heat Transfer Characteristics		
31.53 MJ	Beed to Dry Ice	33.74 MJ
0 MJ	Dry Ice to Environment (Waste)	41.27 MJ
0 MJ	Beef to Environment (Waste)	2.22 MJ

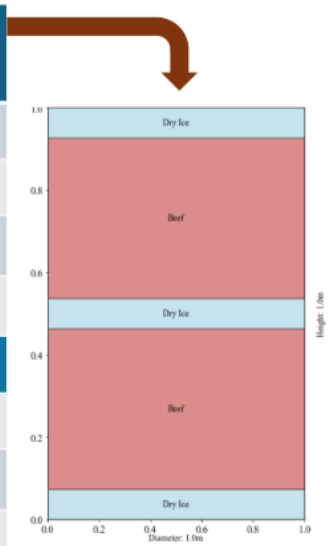


Figure 29: Thermodynamic considerations for using solid CO2 for cooling.

8 Discussion

8.1 Food Grade Gas Specification

A review of "food grade" specification is that the only legal requirement is that the gas should not leave residues in the product that would present a risk to health.

The following table outlines food additives gases specifications in EU legislation.

Component Impurity	Standard	Carbon dioxide E 290	Nitrogen E 941
Assay (v/v)	EC	>99%	>99%
	JECFA	>99%	>99%
Odour	EC		
	JECFA		
Moisture	EC		<0.05%
	JECFA	<52 vppm	
CO_2	EC		
	JECFA		
CO	EC	<10 vppm	<10 vppm
	JECFA	<10 vppm	<10 vppm
NO/NO_2	EC		<10 vppm
	JECFA		
Total hydrocarbons	EC		<100 vppm
	JECFA	<50 vppm	
Residual Gases (O_2, N_2, H_2)	EC		<1% O_2
	JECFA		
Oil	EC	<5 mg/kg	
	JECFA	<10 vppm	
Acidity & Reducing Substances	EC	pass test	
	JECFA	pass test	

Figure 30: Summary of current food additives gases specifications in EU legislation and JECFA[7].

[7] Doc_126_20_Minimum_Specifications_for_Food_Gas_Applications

Of high interest is "Food processing aids": From EUROPEAN INDUSTRIAL GASES ASSOCIATION, MINIMUM SPECIFICATIONS FOR FOOD GAS APPLICATIONS Doc 126/20 Revision of Doc 126/18: "Food processing aids are legally defined as "Any substance not consumed as a food by itself, intentionally used in the processing of raw materials, foods or their ingredients to fulfil a certain technological purpose during treatment or processing, and that can result in the unintentional but technically unavoidable presence of residues of the substance or its derivatives in the final product, provided that these residues do not present any health risk and do not have any technological effect on the finished product", see Regulation EC 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives [2]. Gases are processing aids when used during the processing of a food, for example liquid nitrogen or carbon dioxide for freezing, chilling and temperature control or inerting of bulk materials during processing but they are not themselves consumed as part of the food. In this case the only legal requirement is that the gas should not leave residues in the product that would present a risk to health."[8]

A specific example to consider is gases used for carcass splitting, hence there provides the opportunity for recycling N2 tunnel off gas.

Component	Formula	Unit	Bulk 744 Food grade	750 Hospitality grade	Packaged 082 Food grade
Carbon dioxide	CO_2	%	> 99.9	> 99.9	> 99.9
Moisture	H_2O	ppm	< 50	< 20	< 100
Oxygen	O_2	ppm	< 50	< 30	-
Total hydrocarbon as CH_4	-	ppm	< 50	< 50	-
Inerts	N_2 + Ar	ppm	< 100	< 100	-
Nitrogen oxides	NO_x	ppm	< 2.0	< 2.0	-
Sulphur dioxide	SO_2	ppm	-	< 1.0	-
Total other sulphur (H_2S, COS, mercaptans)	-	ppm	< 0.5	< 0.1	-
Total non-methane hydrocarbon as CH_4	-	ppm	-	< 20	-
Non-volatile organic residue	-	ppm(w)	-	< 5	-
Non-volatile residue	-	ppm(w)	-	< 10	-
Methanol	CH_3OH	ppm	-	< 10	-
Carbon monoxide	CO	ppm	< 5	< 5	-
Ammonia	NH_3	ppm	-	< 2.5	-
Hydrogen cyanide	HCN	ppm	-	Not detected	-
Phosphine	PH_3	ppm	-	< 0.3	-
Acetaldehyde	C_2H_4O	ppm	-	< 0.2	-
Total aromatic hydrocarbon (benzene/toluene)	-	ppm	-	< 0.02	-
Taste / odour / appearance in water	-	-	-	Nil	-
Odour and appearance of solid	-	-	-	Nil	-

Figure 31: Example of food grade CO2 specification which exceeds the requirements for food grade gas (BOC grades of CO2 in Australia[9]).

[8] Doc_126_20_Minimum_Specifications_for_Food_Gas_Applications, accessed 29 Nov 2024.
[9] www.boc-gas.com.au

NITROGEN FOOD GRADE BULK

Product Code: 223901

This is to certify that quality verification tests have been performed on representative samples of Nitrogen Food Grade from Coregas' approved production plants and the results of the tests comply with the requirements of the Nitrogen Food Grade specification.

Component	Chemical Formula	Specification	Unit
Nitrogen	N_2	≥ 99.5	%
Moisture	H_2O	≤ 67	ppm
Oxygen	O_2	≤ 50	ppm
Total hydrocarbons		≤ 100	ppm
Carbon monoxide	CO	≤ 5	ppm

Cylinder connection as per AS2473 n/a
Cylinder pressure at 15°C n/a
Package content at 15°C, 101 kPa n/a

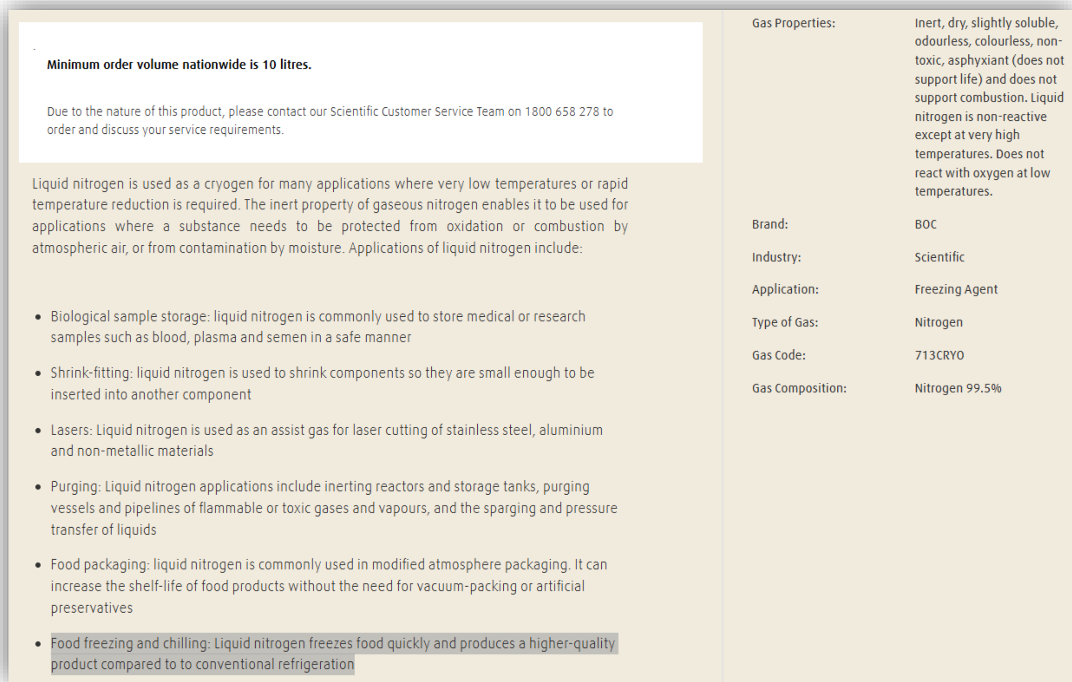
Remarks: Product complies with Australian Food Code Standard and EIGA IGC Doc 126/11/E (Minimum Specifications for Food Gas Applications).

Figure 32: Example of food grade N2 specification which exceeds the requirements for food grade gas[10].

BOC makes the qualitative claim on its publicly available website that LN2 "produces a higher-quality product compared to conventional refrigeration" without any evidence or third party research.

Only one of the visited sites used an N2 tunnel for cooling of trim. The site reported the gas consumption of 1 refill per week.

[10] www.coregas.com.au/images/downloads/COC-223901-nitrogen-food-grade-bulk.pdf, All-certs-0918, accessed



Minimum order volume nationwide is 10 litres.

Due to the nature of this product, please contact our Scientific Customer Service Team on 1800 658 278 to order and discuss your service requirements.

Liquid nitrogen is used as a cryogen for many applications where very low temperatures or rapid temperature reduction is required. The inert property of gaseous nitrogen enables it to be used for applications where a substance needs to be protected from oxidation or combustion by atmospheric air, or from contamination by moisture. Applications of liquid nitrogen include:

- Biological sample storage: liquid nitrogen is commonly used to store medical or research samples such as blood, plasma and semen in a safe manner
- Shrink-fitting: liquid nitrogen is used to shrink components so they are small enough to be inserted into another component
- Lasers: Liquid nitrogen is used as an assist gas for laser cutting of stainless steel, aluminium and non-metallic materials
- Purging: Liquid nitrogen applications include inerting reactors and storage tanks, purging vessels and pipelines of flammable or toxic gases and vapours, and the sparging and pressure transfer of liquids
- Food packaging: liquid nitrogen is commonly used in modified atmosphere packaging. It can increase the shelf-life of food products without the need for vacuum-packing or artificial preservatives
- Food freezing and chilling: Liquid nitrogen freezes food quickly and produces a higher-quality product compared to to conventional refrigeration

Gas Properties:	Inert, dry, slightly soluble, odourless, colourless, non-toxic, asphyxiant (does not support life) and does not support combustion. Liquid nitrogen is non-reactive except at very high temperatures. Does not react with oxygen at low temperatures.
Brand:	BOC
Industry:	Scientific
Application:	Freezing Agent
Type of Gas:	Nitrogen
Gas Code:	713CRYO
Gas Composition:	Nitrogen 99.5%

Figure 33: BOC N2 gas property page[11]

[11] https://www.boc.com.au/shop/en/au/liquid-nitrogen-713cryo-p#product1, 26th Nov 2024.

9 Conclusions & Recommendations

Mechanical cooling is a relatively new technology, hence its application for beef trim cooling is being tested and reviewed as part of this project. Key considerations include the pumping system, materials handling (particle size / grinding requirements / hopper) and efficiency / time for cooling.

Due to the strong economics of mechanical cooling, one outcome could be for RMPs to consider low CAPEX efficiency gains pending availability of CAPEX for a mechanical system or executing a BOO agreement. It is difficult to see how, given the supply chain issues and costs of CO2 and N2, how a RMP could make a large investment into a system the relies upon the supply of gas from a third party. There are certain speed advantages of CO2 and N2, hence onsite generation and/or high efficiency system could be considered. The long term vision should be towards more consistent, effective, and cheaper mechanical refrigeration methods utilising renewable energy with an associated cooling storage system to progress towards zero emissions cooling.

Further research:

- Deployment and associated monitoring of the first HIVE system.
- Extension of mechanical cooling to other tissues, in particular offals.
- Increased shelf life and additional value by exporting frozen offals.

10 Project outputs

Key project outputs were:

- $/kWh cooling for CO2 snow, CO2 pellets, N2 tunnels, mechanical cooling.
- $ / tonne cooling.
- Onsite N2 production.
- Onsite CO2 production.
- CO2 recycling.
- Testing of mechanical cooling of trim and edible fats.
- Future program of works.
- Site visits, inspection and documentation of equipment.