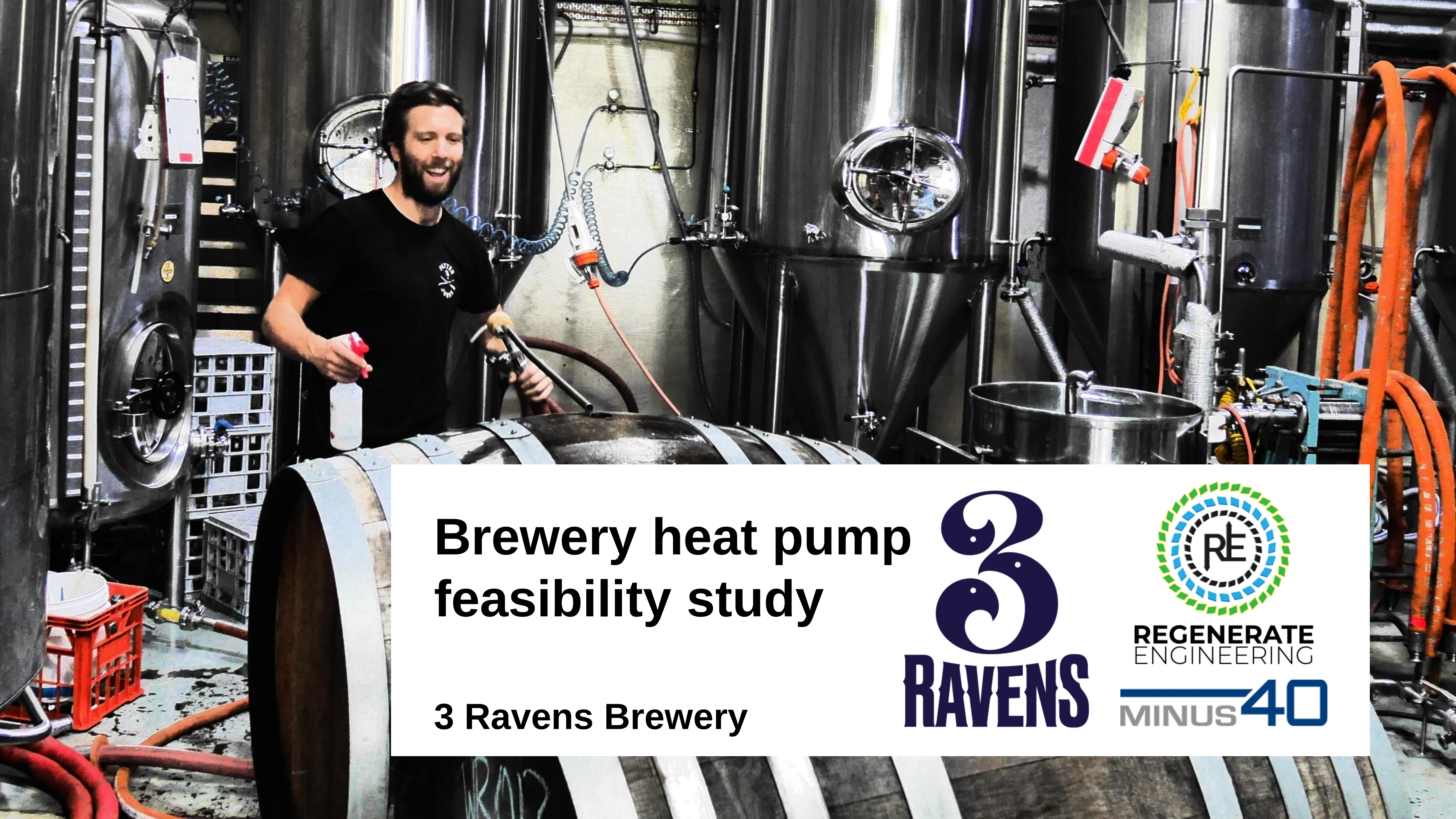

Brewery heat pump feasibility study

3 Ravens Brewery

3 RAVENS

REGENERATE ENGINEERING

MINUS 40

Brewery Process

- Significant heating and cooling typically separated by a few hours + constant loads
- Chiller waste Heat > Chiller Coolth but serves no useful purpose
- All processes except boil can be improved using the renewable heat system we have developed.
- Despite the boil still using resistive heating we still can achieve 50% energy save over the complete brewing process

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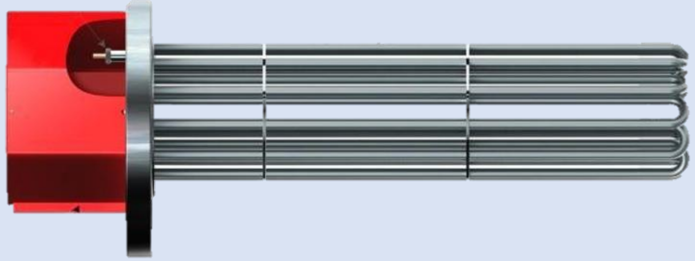
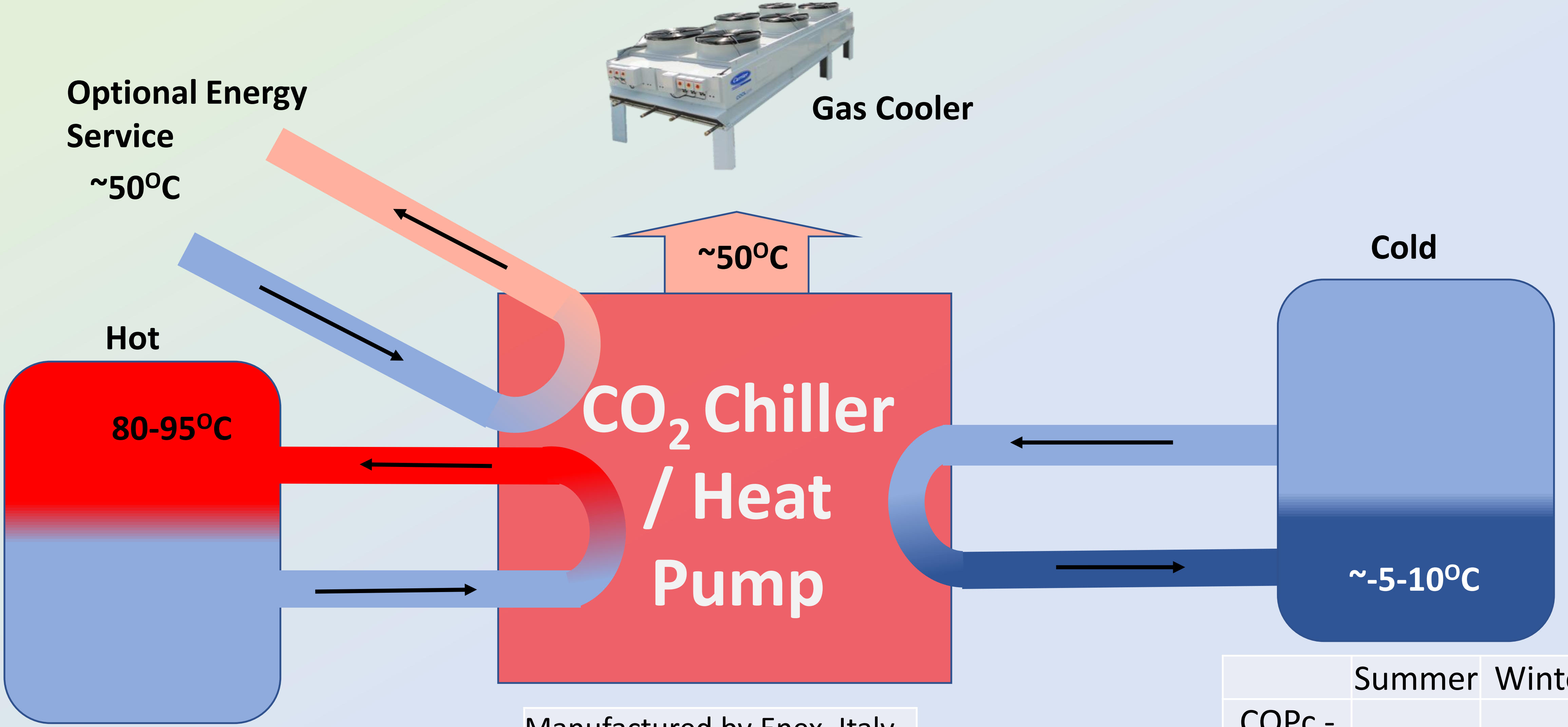
Freon Chiller – COP_C ~2.5



Electric Heating element – COP_H ~0.95

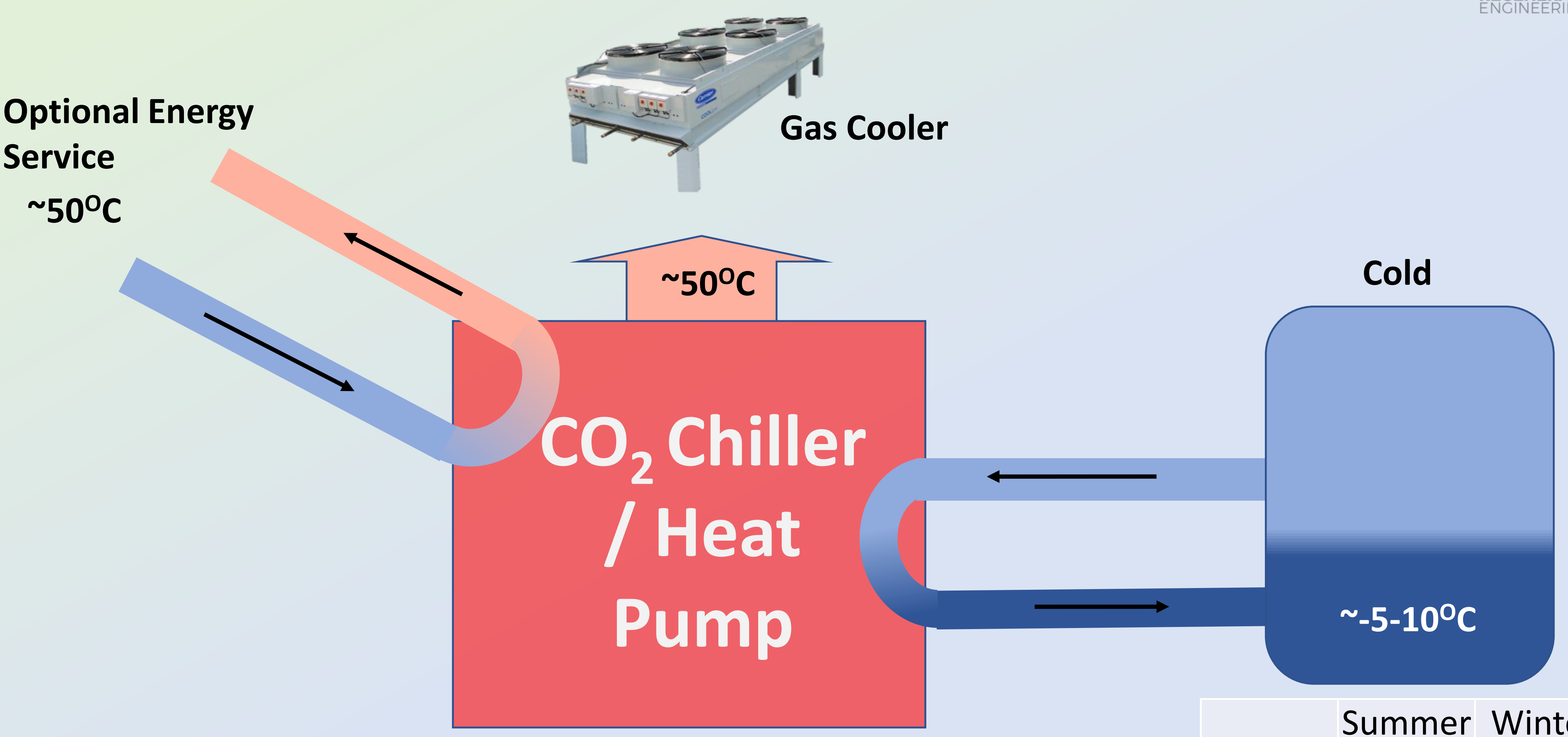
Trans-critical mode



Manufactured by Enex, Italy
Variable speed ~20kW-45kW

	Summer	Winter
COPc - Cooling	2.1	2.2

Sub-critical mode



Manufactured by Enex, Italy
Variable speed ~20kW-45kW

	Summer	Winter
COPc - Cooling	3.3	4

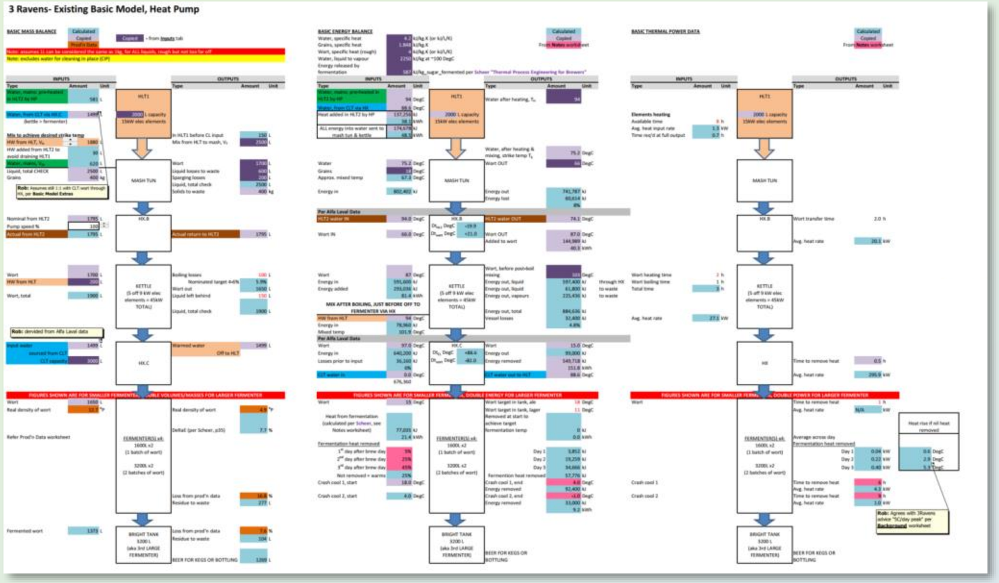
3 Ravens situation

- Stable and competent management and brewing team
- Growth aspirations
- Environmental conscience and strategic ‘feel’ that they need to do something special
- 1st step a success –Reduce cost and emissions intensity by installing Solar PV.
- Curiously, on paper this makes the subsequent upgrade prospect worse – but in practice it has freed up cash

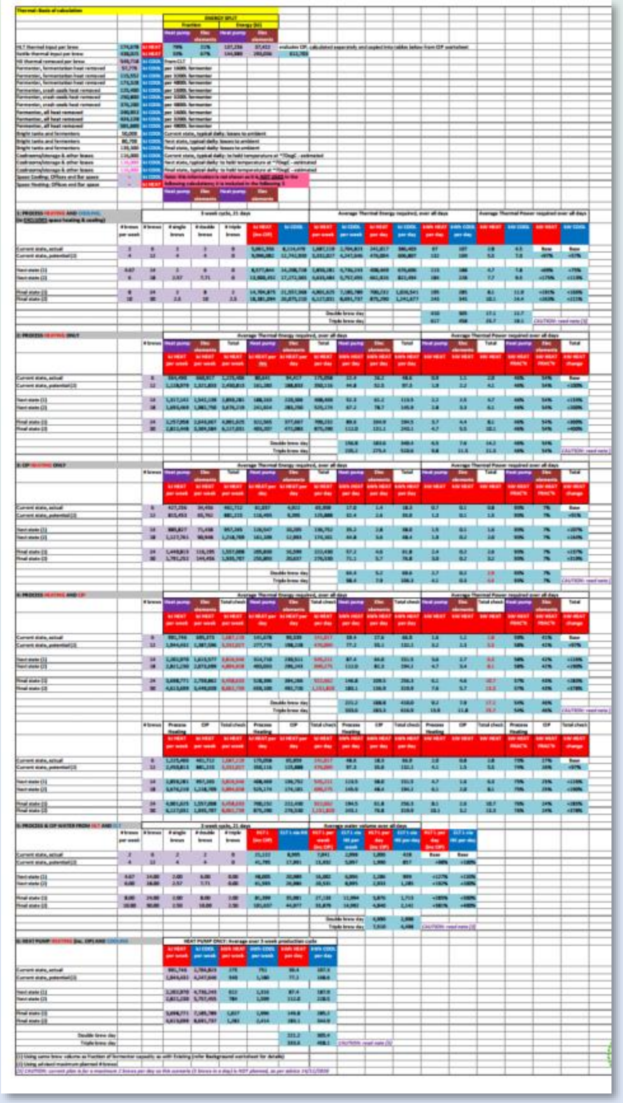
3 Ravens situation

- A2EP pre-feasibility study accepted early 2020. COVID was a challenge.
- Successful finance applications for extended upgrade including renewable heating opportunity
  - There is much goodwill towards artisanal industries!
- Subsequent “Full Feasibility” process proved to be invaluable due to full hydraulic re-design required for the brewery.

Regenerate's Engineering's Brewery Energy Model



Mass and Energy Balance plus Power data



Energy service energy totals over time

3 Ravens

AT HLT1: PER WORT BATCH

CURRENT: NO HEAT PUMP

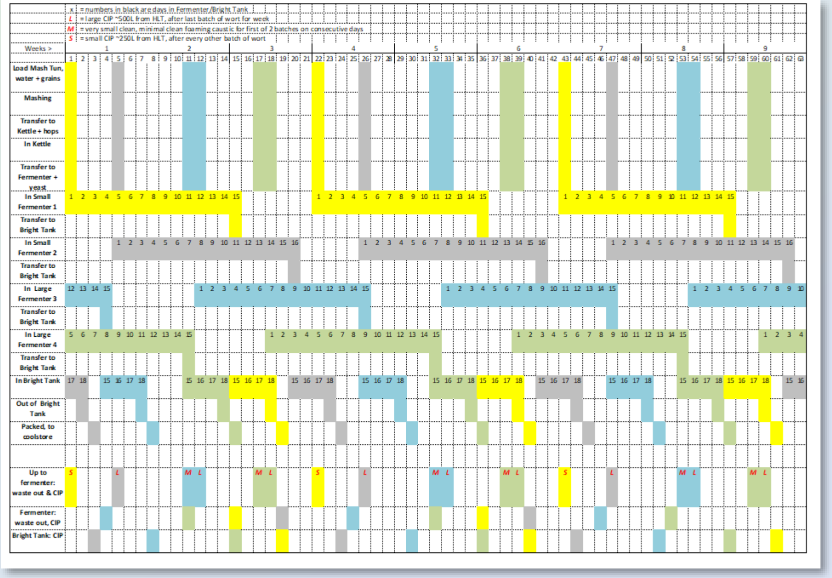
		Water Volume in HLT1 (L)			Temp of water in HLT1 (DegC)			Heat added by HLT1 elements		
		At Start	Change (+ = IN, - = OUT)	At End	At Start	Temp of water added	At End	kJ	kWh	Time to heat (h)
1	OUT: To Mash Tun	2000	-1850	150	95.0	-	95.0	-	-	-
2	IN & MIX: Mains top up to have enough to send to kettle post-boil [1]	150	+150	300	95.0	18.0	56.5	-	-	-
3	HEAT: mixed water to target temp	300	+0	300	56.5	-	95.0	48,510	13.5	0.90
4	OUT: To Kettle (post-boil)	300	-200	100	95.0	-	95.0	-	-	-
5	IN: from CL via HX.C	100	+1650	1750	95.0	88.6	89.0	-	-	-
6	IN & MIX: Mains top up for next batch	1750	+250	2000	89.0	18.0	80.1	-	-	-
7	HEAT: mixed water to target temp	2000	+0	2000	80.1	-	95.0	125,202	34.8	2.32
		Total inputs:	+2050			Total energy added to HLT1:		173,712	48.3	3.2
		Total outputs:	-2050							

FUTURE: WITH HEAT PUMP OPERATING TO HEAT SUFFICIENT WATER IN HLT2 TO 95 DegC FOR PROCESS REQ'TS, OTHERWISE WORKS AT 80 DegC

		Water Volume in HLT1 (L)			Temp of water in HLT1 (DegC)			Heat added by HLT1 elements			Heat added by HP to HLT2		
		At Start	Change (+ = IN, - = OUT)	At End	At Start	Temp of water added	At End	kJ	kWh	Time to heat (h)	kJ	kWh	
1	OUT: To Mash Tun	2000	-1880	120	94.0	-	94.0	-	-	-	-	-	
	IN: from HLT2 during mash tun drawoff				-	94.0	94.0				0	0.0	
2	IN & MIX: Mains top up from HLT2 to have enough to send to kettle post-boil [1]	120	+150	270	94.0	94.0	94.0	-	-	-	47,880	13.3	
3	HEAT: mixed water to target temp	270	+0	270	94.0	-	94.0	0	0.0	0.00	-	-	
4	OUT: To Kettle (post-boil)	270	-200	70	94.0	-	94.0	-	-	-	-	-	
5	IN: from CL via HX.C	70	+1650	1720	94.0	88.6	88.8	-	-	-	-	-	
6	IN & MIX: Mains top up for next batch (from HLT2)	1720	+280	2000	88.8	94.0	89.5	-	-	-	89,376	24.8	
7	HEAT: mixed water to target temp	2000	+0	2000	89.5	-	94.0	37,422	10.4	0.69	-	-	
		Total inputs:	+2080			Total energy added to HLT1:		37,422	10.4	0.7	137,256	38.1	174,678
		Total outputs:	-2080										

[1] This is an estimate, but is probably not too far off. Could be as high as 400 L, which would mean 0 L topup at Step 6. Changing it shouldn't have any impact on overall calculations

HLT batch calculations



Timeline, days from production data analysis

AS DESIGNED: ALFA LAVAL

Date: 6/11/2020	Alfa Laval data			Alfa Laval data	
Hot Side, from HLT2, back to HLT2			Cold Side, wort from Mash Tun to Kettle		
Mass flow rate	850	kg/h	Mass flow rate	850	kg/h
Density	968.9	kg/m^3	Density	1023	kg/m^3
Specific heat capacity	4.19	kJ/kg.K	Specific heat capacity	3.97	kJ/kg.K
Inlet temperature	94.0	DegC	Inlet temperature	66.0	DegC
Outlet temperature	74.1	DegC	Outlet temperature	87.0	DegC
Volume flow rate	877	L/h	Volume flow rate	831	L/h
HLT2 water required	1795	L	Wort transferred	1700	L
			Transfer time	2.05	h
Heat transfer rate	-19.7	kW	Heat transfer rate	19.7	kW

HX.B

HLT2 water IN	94.0 DegC	Dt_{HLT2} DegC	-19.9	HLT2 water OUT	74.1	DegC
	1795 L			Removed from HLT2 water	145,008	kJ
	1739 kg					
Wort IN	66.0 DegC	Dt_{wort} DegC	+21.0	Wort OUT	87.0	DegC
	1700 L			Added to wort	144,989	kJ
	1739 kg				40.3	kWh

DeltaT inlet streams	28.0	DegC
DeltaT HLT2 water	-19.9	DegC
DeltaT wort	+21.0	DegC
DeltaT HLT2 water	-0.71	Fraction of DeltaT inlet streams
DeltaT HLT2 water	0.75	Fraction of DeltaT inlet streams

Heat Exchanger B Calcs

Version No.: 8

Inputs moved to new Tab named "Inputs"

"Existing Basic Model" Tab

- Added new heat exchanger (HX.B per Minus40 schematic) to add heat to wort during transfer from MASH TUN to KETTLE, using HL sourced from and returned to new HLT2
- Renamed existing heat exchanger (from HX to HX.C, per Minus40 schematic) to remove heat to wort during transfer from KETTLE to FERMENTATION TANK

Corrected minor errors in calculation of fluid volumes

Tab formerly called "Basic Model Extras" thought to be now redundant but kept just in case

New tab added named "HLT1" to allow process steps through this component to be more clearly shown. Results copied (linked) into Mass balance Models

New tab added named "HX,B" to allow estimation of heat exchange at non-design conditions (lower diagram); design conditions are shown in upper diagram. Linked to mass-balance models

Inputs includes "spin control" to allow variable HP-heated water from HLT2; range from 80 DegC to 95 DegC (HX.B design value) in steps of 5 DegC

HX.B modelling based on data from Terralba

Version No.: 10

HX.B modelling now based on data from Alfa Laval "Nov 6 revised design"

Version No.: 11

HX.C modelling based on data from Alfa Laval 1 Dec "Final re-configuration", new tab added, "HX.C"

"Background" tab updated to add new table, **REVISED "Final State" as per Stage 4 drawing dated 24/11/2020**, additional notes added in ***bold italic purple***

"Production" tab, "Final State" updated to revisions shown on "Background" tab as per previous note

"Thermal HP": caution note added re triple brew days, these are not planned as per advice received 14/12/2020

"Production" tab: ***Caution note [3]*** added re triple brew days, not planned under current thinking but retained for possible future reference

"Thermal HP" tab: added table at bottom HEAT PUMP HEATING (inc. CIP) AND COOLING to pull together weekly average HP required heating and cooling delivery

"Thermal HP" tab: added rows for Offices & Bar Space Heating and Cooling, Typical daily, average across 12 months

Caution: "Thermal" tab has not been updated with abovementioned enhancements as it is considered redundant now

Version No.: 12

New tab added: "Hourly Calc - R2" as received 19/1/2021 (Revision 2 dated 18/1/2021), for space heating and cooling loads

"Thermal HP" tab updated to include information from this new tab, byt note that information not used here, see below for where it has been incorporated

Note that "Thermal" tab has not been updated

Three (3) new "Thermal HP" tabs added "Thermal HP Summer", "Thermal HP Shoulder" and "Thermal HP Winter"

On all Thermal HP tabs, fraction of space cooling and heating from HP set at 100%

Updated assumption for loss to ambient to calculated heat losses, replacing estimated values.

On all 3 new Thermal HP tabs, final table expanded to add associated space heating and cooling information

Version No.: 13

Three (3) "Thermal HP" tabs added "Thermal HP Summer", "Thermal HP Shoulder" and "Thermal HP Winter": added numbers to each of the 6 tables

Corrected a double-counting error on the 3 new tabs from v12, namely "Thermal HP Summer", "Thermal HP Shoulder" and "Thermal HP Winter". Space heating & cooling was incorrectly included in Table 6 in the PROCESS ONLY component

Corrected circular reference error on "Hourly Calc - R2" tab

Version control and change-log

Project Partner Input (Minus40)

MINUS40

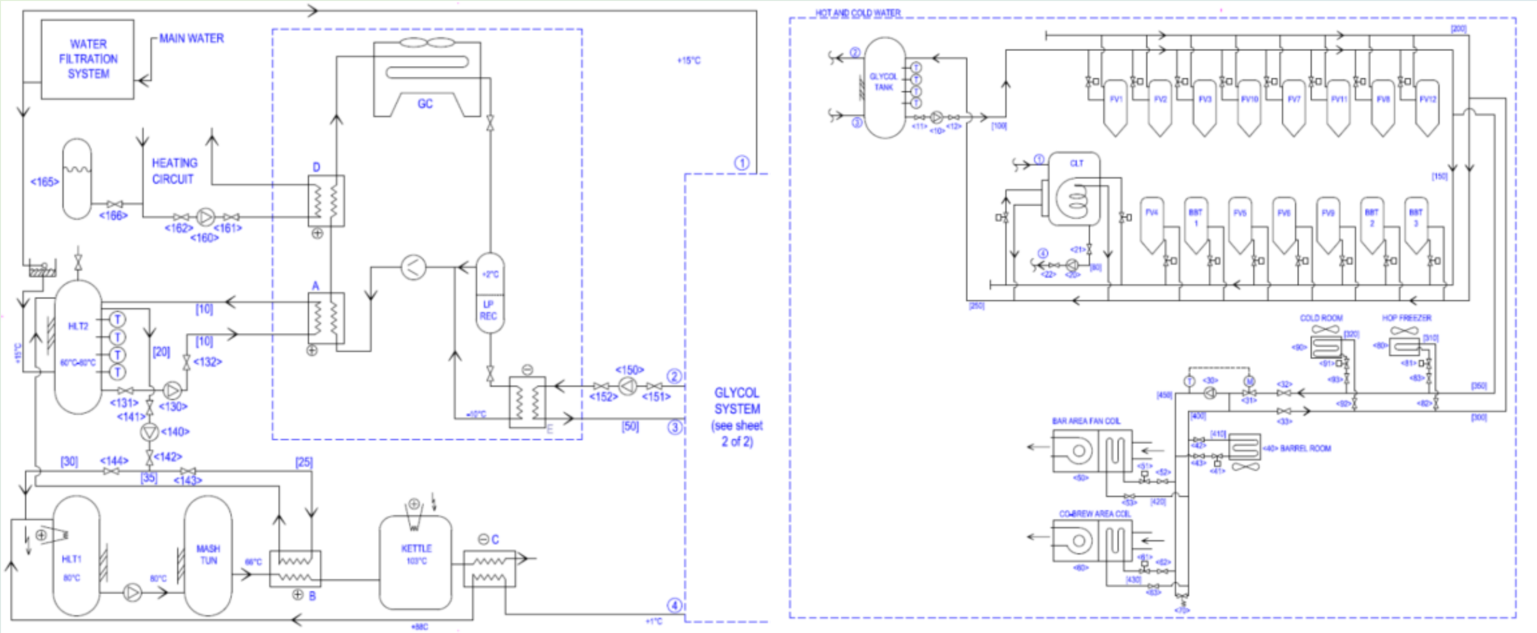


TABLE 14: 3 RAVENS CO2 HEAT RECOVERY CHILLER INSTALLATION, THERMAL NETWORK P1 ©MINUS40

TABLE 15: 3 RAVENS CO2 HEAT RECOVERY CHILLER INSTALLATION, THERMAL NETWORK P2 ©MINUS40

Process input data			Temperatures (degC)		Comment
Required capacities	kWh/week		Delivery	Inlet to HEX	
					Losses assumed included in capacities
Cold liquor and Glycol	1375		15	4	Generated using glycol coil in CLT
Space Cooling	490	worst week	0	-4	
Total cooling	1865				
Process heating	518		15	80	
Space heating	550	worst week	30	50	
CIP	413		15	80	
Total 80degC	1481				
Wort heating	113		65	80	Need HT operation for this
Total 95degC	113				

Heat Pump input data	Transcritical		Subcritical	
	Summer	Winter	Summer	Winter
COPc - Cooling	2.1	2.2	3.3	4
Capacity - Cooling	45	45	46	46
Capacity - 80 degC	50	50	5	5
Capacity - 95degC	45	45	0	0
Operating input				
	Summer	Winter		
% TC operation	20%	35%	80.0%	65.0%
% HT operation during TC	18%	10%		
Months/season	6	6		
Running hours/week	85	85		

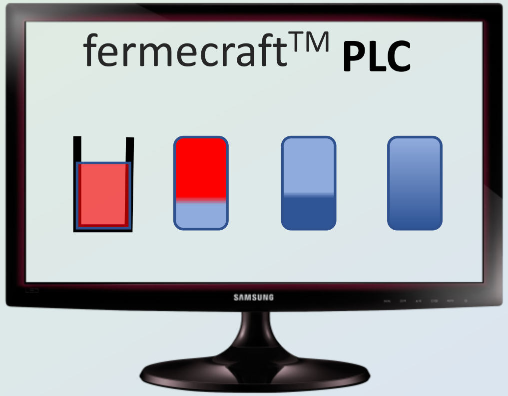
Summer operation (zero space heating)					
	Transcritical	Subcritical	Total	Deficit/surplus	
Cooling generated	765	3,128	3,893	2,028	52%
80degC generated	697	340	1,037	106	10%
95degC generated	138	-	138	25	18%
Energy used	364	948	**1,312**		
Winter operation					
	Transcritical	Subcritical	Total	Deficit/surplus	
Cooling generated	1,339	2,542	3,880	2,015	52%
80degC generated	1,339	276	1,615	134	8%
95degC generated	134	-	134	21	16%
Energy used	609	635	**1,244**		
Annual energy use			**66,458**	kWh	

Hydraulic design: Process and Instrumentation Diagram of upgrade

Minus40 Energy Model

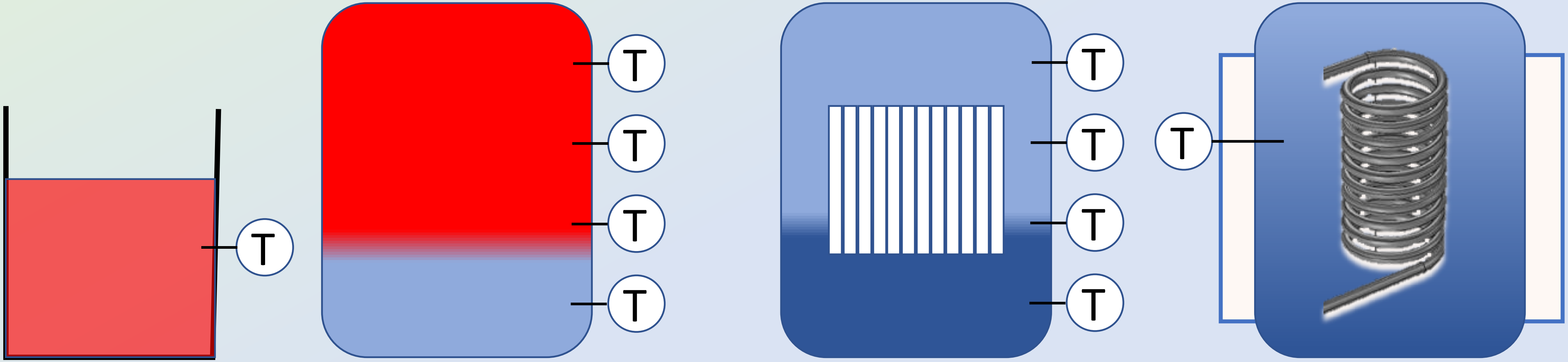
Storage as a system

- Scenario modelling, system ‘flexing’
- Variation between brew recipes
- Stratification levels in tanks, temps in mixing tanks = storage – to be used as variables
- MUCH more COLD storage needed
- 29kWh Phase Change Material in Glycol tank
- Coil + jacket for fast Hx and ice bank storage in Cold Liquor tank



‘Production’ Inputs to PLC
Beer Recipes
'Complete by' schedule

‘Energy’ Inputs to PLC
PV production
Weather forecasting
Energy Charges
Site demand



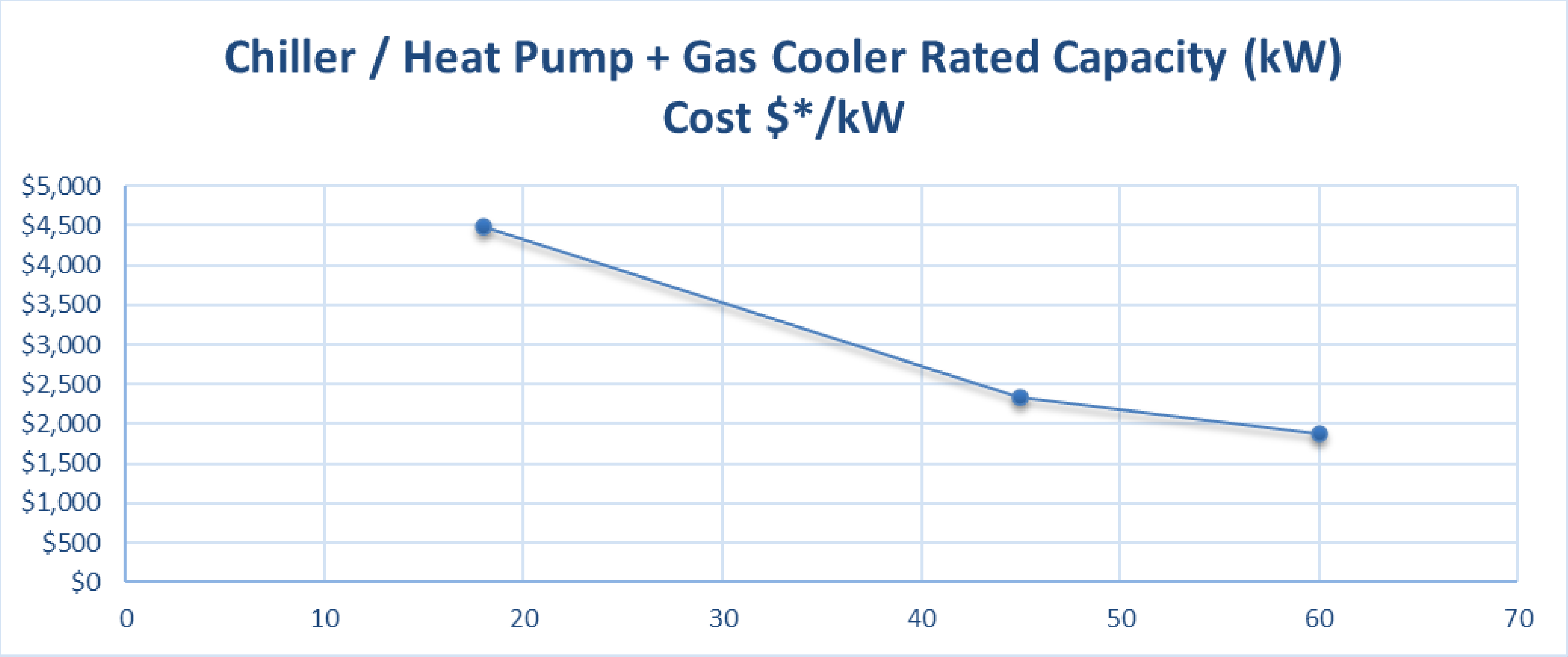
Hot Liquor batch tank

Hot Liquor Hydronic tank

Glycol tank

Cold Liquor tank

Scale-ability of single cycle, single compressor CO_2 system from Enex



*For comparison, cost is shipped to site, excluding installation and commissioning.

- 18kW original model: Brewing, cold storage
- 45kW expanded model: Brewing, cold storage and HVAC

kW	Cost / kW
18	$4,483
45	$2,333
60	$1,867

Energy Save and viability of the project

Project Variant	Energy Save	Simple Pay-back as modelled (years)	Simple pay-back after direct subsidies (years)
18kW Enex Chiller/Heat Pump system + necessary peripherals. Value added with cool room and hop freezer energy services.	54%	9	4.5
45kW Enex Chiller/Heat Pump system + necessary peripherals. Value added with cool room, hop freezer and site + bar space heating energy services. Includes small building fabric upgrade.	76%	6.5	3.2

Finance, Subsidies and other support mechanisms

- Viability is improved when a thorough engineering job is done w.r.t. support mechanisms.
- Applying for grants: State, federal, various streams
- Green Finance + Instant asset write-off.
- Measurement and verification methodology – White Certificates ~10 year abatement
  - NSW: Project Impact Assessment with Measurement and Verification (PIAM&V) (ESC ~\$30/TCO_2)
  - Vic: Project Based Assessments. (VEECs are >\$45 / TCO_2)
  - Note where massive expansions are planned M&V Methodologies may not be viable due to 'effective range' for Vic and NSW schemes which can work against energy productivity.
- M&V methodology ERF Scheme (ACCU's are ~\$18.50 / TCO_2)

…. In conclusion

There are at least 720 craft breweries in Australia

Refrigerants:

- the price elasticity favours larger upgrades, but is still viable for small breweries where value-added and subsidised.
- Depending on the application, another Natural Refrigerant, Ammonia can be used.

This renewable heat system was developed for breweries, but can be adapted to many other industries / areas which heat and cool and this can include collaborations or new product lines.

- Chill filtering / bottling spirits
- Dairy / various
- Bakeries / various
- Wine-making

Thank you for listening!

Questions?

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