Energy Minimisation, Recovery and Re-use within the Brewhouse

JOINT IBD MIDLANDS SECTION /BFBI ANNUAL ENGINEERING SYMPOSIUM: RENEWABLE ENERGY

15 February 2018

John Hancock – Briggs of Burton

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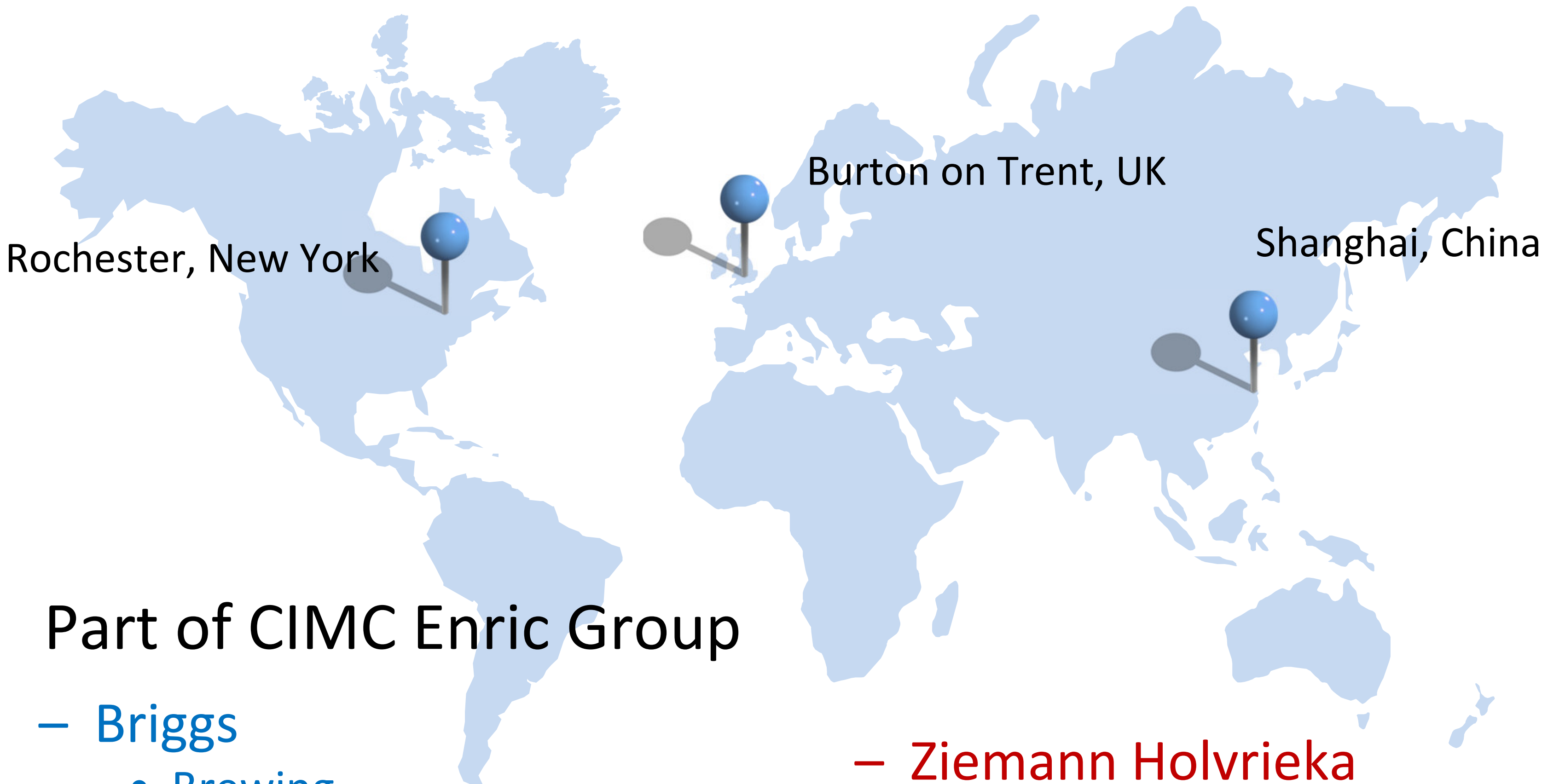

Part of CIMC Enric Group

- Briggs
  - Brewing
  - Distilled Spirits
  - Food
  - Pharmaceutical
  - Biofuel
- Ziemann Holvrieka
  - Brewing
  - Dairy and Juice
  - Chemicals

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Sectors

- Brewing
- Distilling
- Material Handling
- Food
- Health and Beauty
- Pharmaceutical
- Biofuel

Capabilities

- Project Management
- Process Engineering
- Automation and Control
- Electrical Engineering
- Manufacturing
- Concept / FEED Studies
- Value Engineering
- Detailed Design
- Project Implementation
- CDM + Health & Safety
- FSM - HAZOP
- EPC / EPCM / Hybrid

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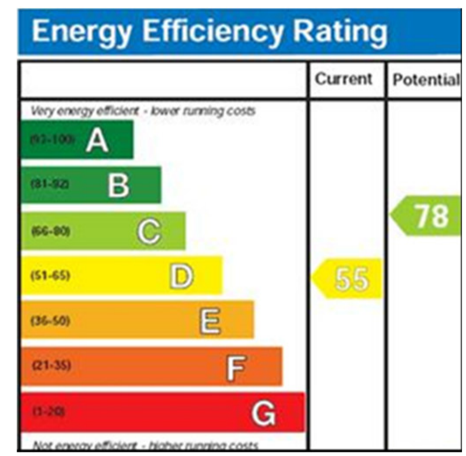
Energy Minimisation, Recovery and Re-use within the Brewhouse

- Energy Minimisation
  - Process change – use less energy
  - Reduce losses – waste less energy
- Energy Recovery and Re-use
  - Recycle energy directly
  - Recover energy for use elsewhere
  - Export energy
- Renewable / Alternative Energy



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Energy Minimisation, Recovery and Re-use within the Brewhouse

- Brewhouse Energy Use
- Mashing
- Wort Boiling and Energy Recovery
- Wort Cooling
- Energy Minimisation
  - Rapid TAT & Continuous
  - Pipe Sizing
  - Pumps –
    - Selection & Efficiency
    - VSD operation
  - Insulation
- Renewable Energy

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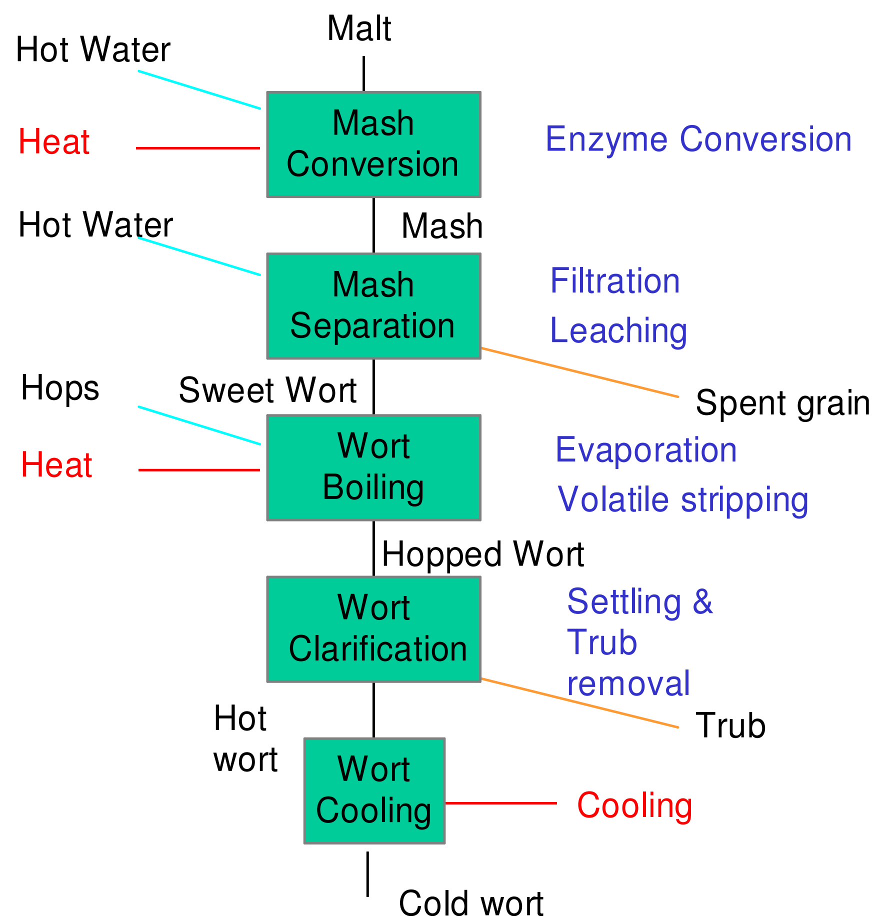
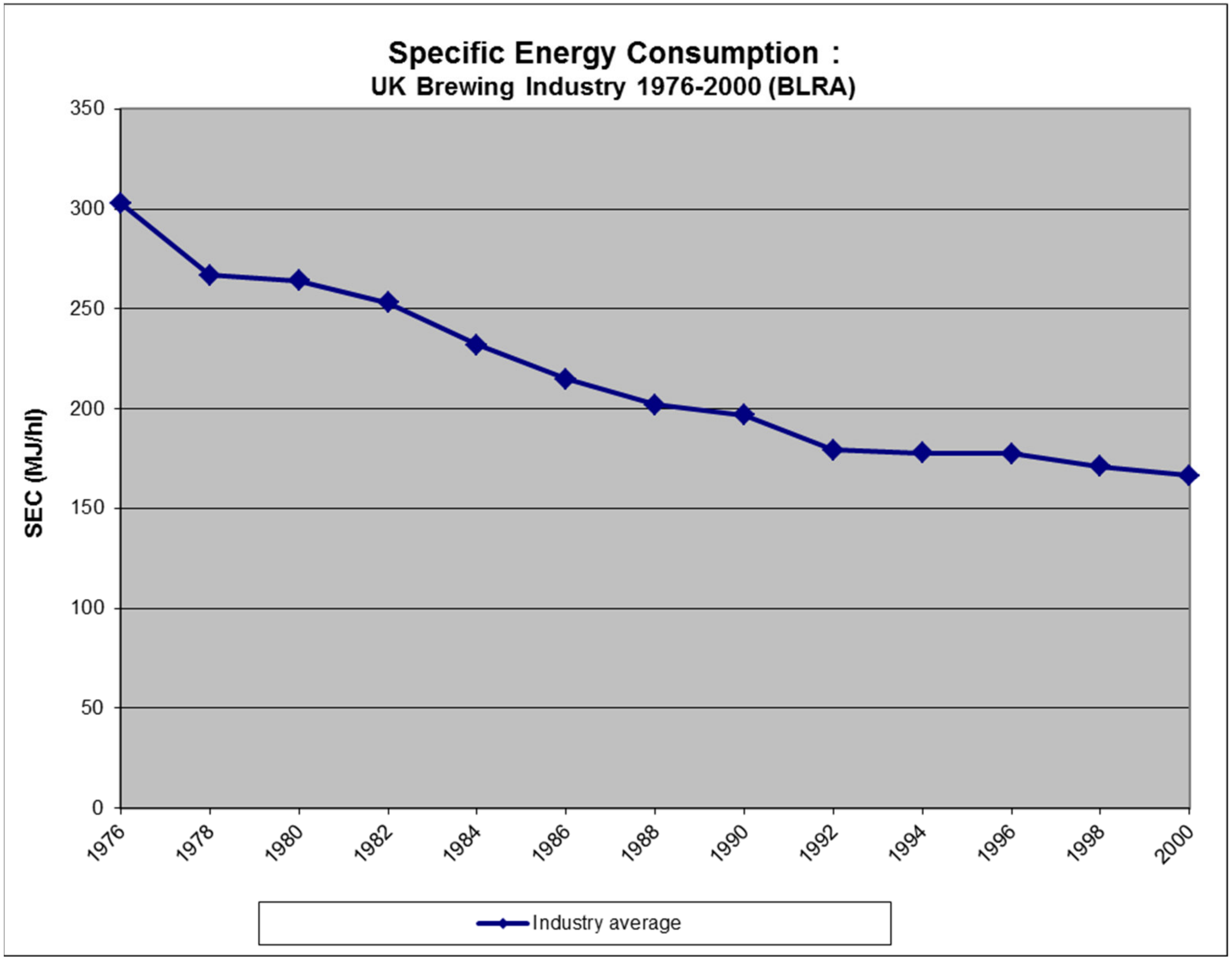
Brewhouse Process

- Process starts & ends cold
- Two major thermal energy input points
  - Mashing
  - Wort Heating & Boiling
- Mash separation
  - Extract efficiency
  - Pinch point
- Two major thermal energy recovery opportunities
  - Wort Boiling
  - Wort Cooling



Brewery Energy Usage
UK – 1976 to 2000



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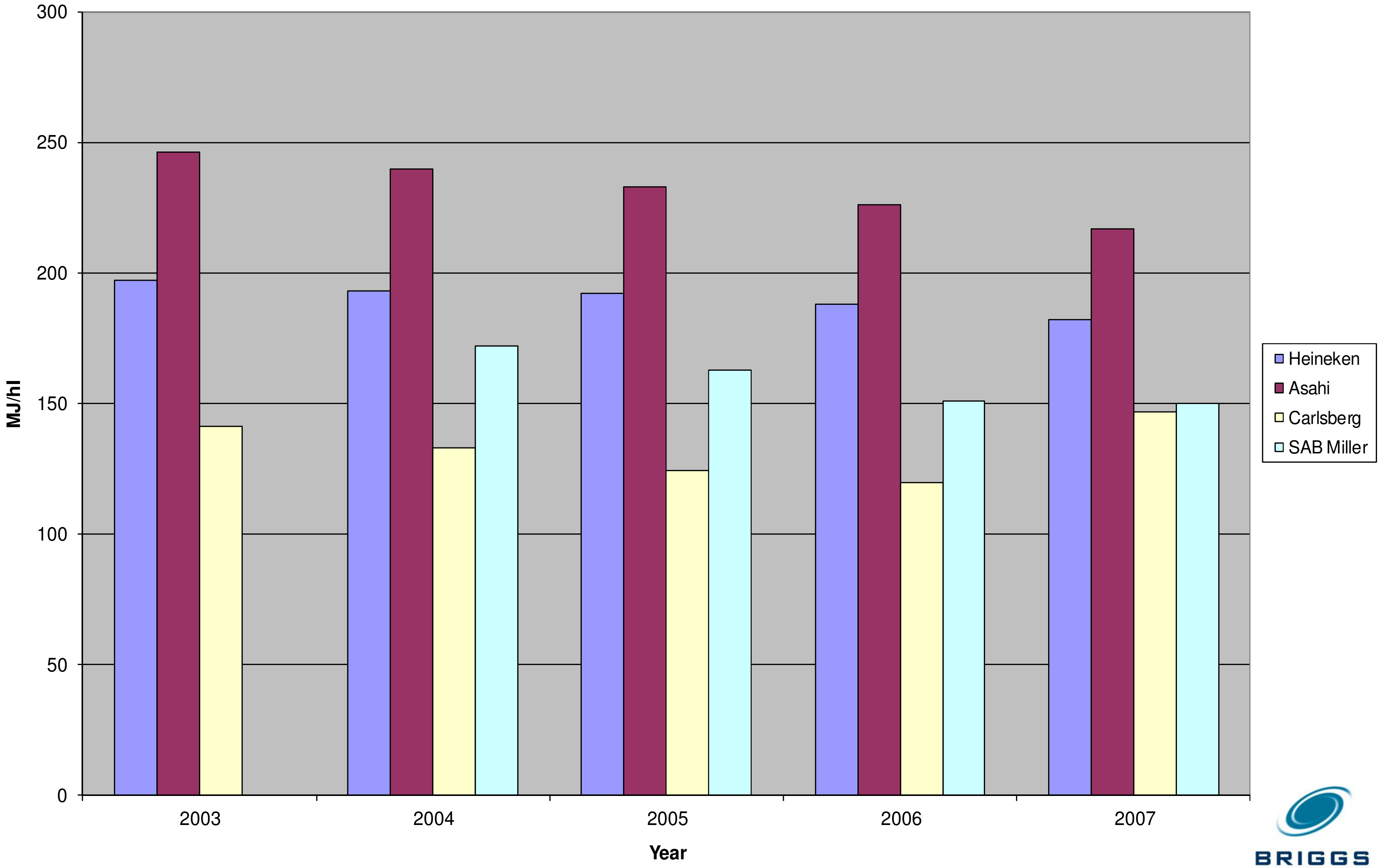
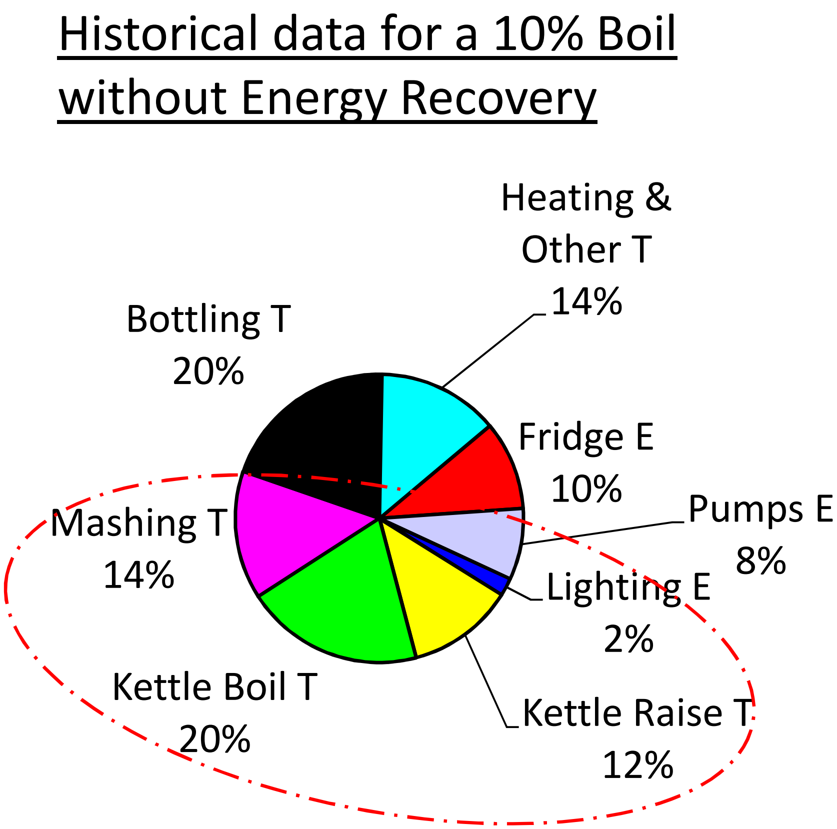
Specific Energy Consumption by Brewer 2007 to 2008

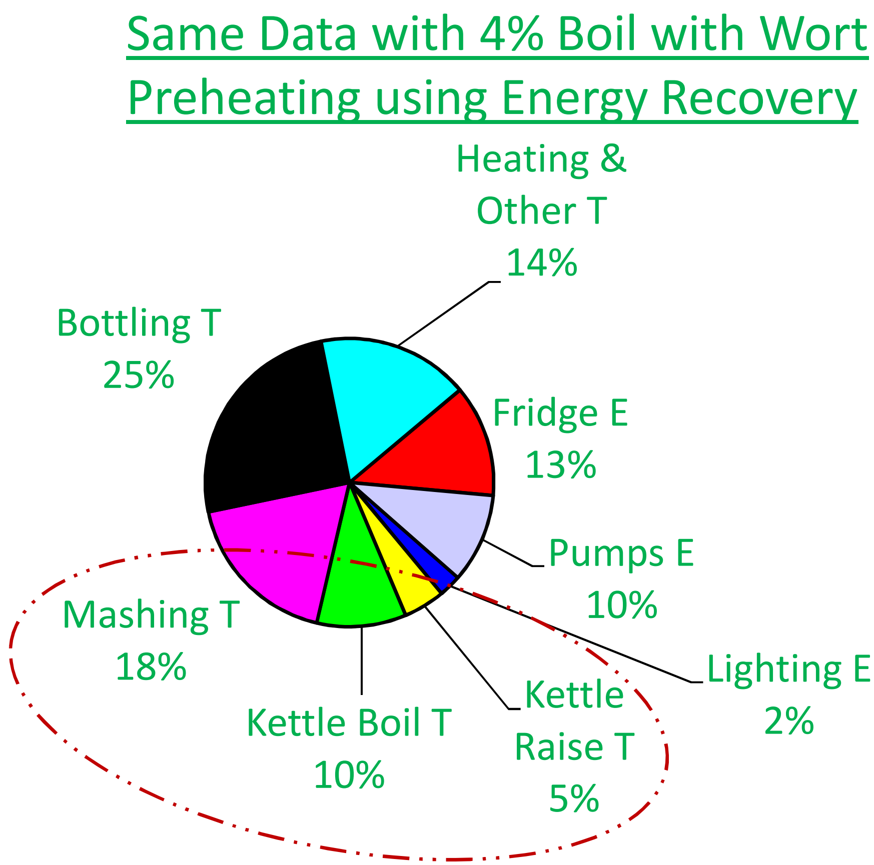


Brewery Energy Use

Brewhouse - Major Energy Users Mashing & Wort Boiling



Beer Production - 125 MJ/hl



Beer Production - < 100 MJ/hl

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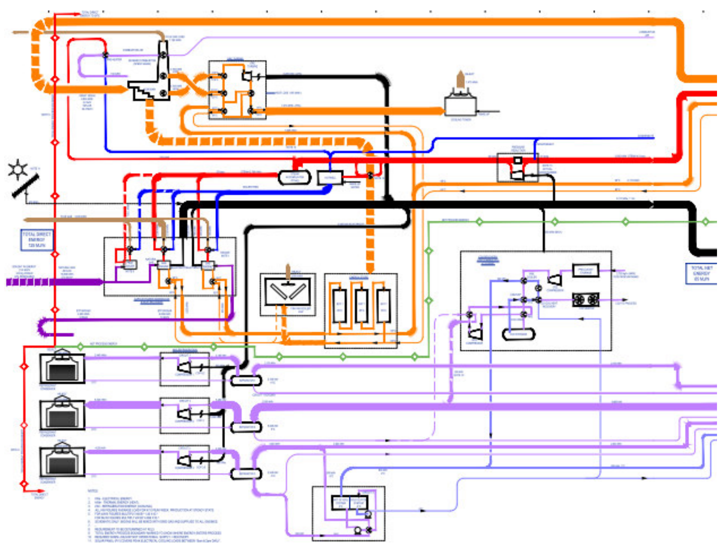
Brewery Energy Use - What is Possible

- Several large breweries, worldwide are operating at total Energy use between 75 and 100 MJ/hl
- Much less is achievable
- Recent New Brewery Design Concept
  - Thermal Energy used
    - Brewhouse 11 MJ/hl packaged beer
    - Brewery 25 MJ/hl packaged beer
      - Including Brewhouse
      - Excluding Packaging
    - Packaging 11 MJ/hl packaged beer



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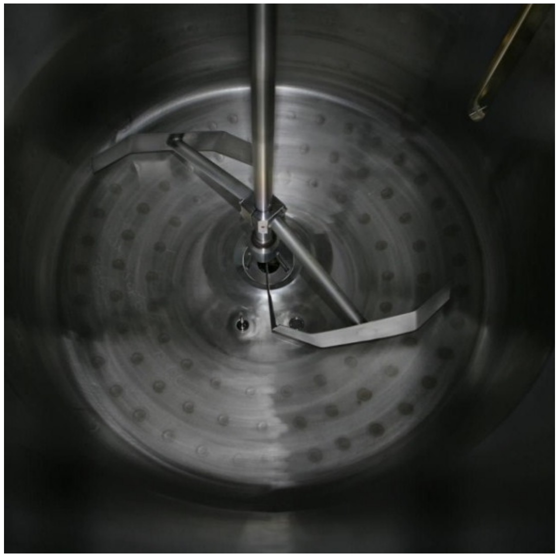
Mashing – Thermal Energy

- Mash-in using hot water generated at Wort Cooling
- Higher Mash-in temperature reduces thermal energy input at Mashing
- Traditional Infusion Mash tun
  - No mash heating load
  - Increased wort heating load
- Thicker Mash ratio reduces energy input

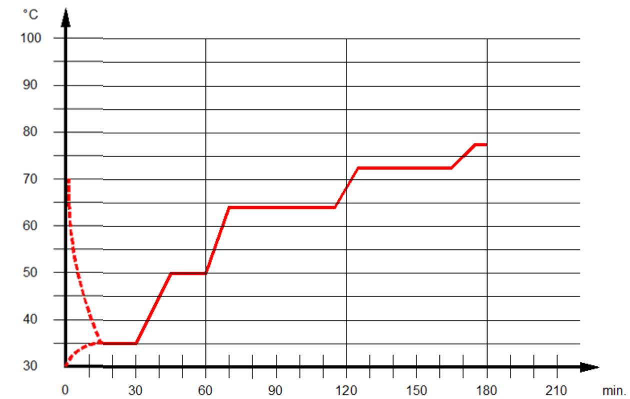


Mash Heating – Temperature raise

- Energy Input $q = M \times C_P \times (T_2 - T_1)$
    - M = Mass (kg)
    - C_P = specific heat (kJ/kg C) Energy to heat 1 kg by 1 °C (or °K)
    - T_1 & T_2 = Initial & Final Temperature (°C)
- Based on 1000 hl wort (1.06 SG) 100% Malt
    - 22 Te malt mashed at 3 L/kg, 86,700 kg total
    - Mashed in at conversion temperature
- Heat 86,700 kg from 65 to 76 °C
    - Specific Heat C_P kJ/kg K
        - Water = 4.2 kJ/kg K , Mash = 3.7 kJ/kg K
    - = 86,700 x 3.7 x (76 - 65) = 3,528,700 kJ = 3,529 MJ
      = 3.53 MJ/hl HG wort
      around 3 MJ/hl SG beer (30% HG)

Mash Heating – Temperature raise

- Based on 1000 hl wort (1.06 SG) 100% Malt
  - 22 Te malt mashed at 3.5 L/kg (thinner mash), 97,500 kg total
  - Mashed in at low temperature
- Heat 97,500 kg from 35 to 76 °C
  - Actually heated in steps as shown
  - Specific Heat C_P kJ/kg K
    - Water = 4.2 kJ/kg K , Mash = 3.75 kJ/kg K
  - = 97,500 x 3.75 x (76 - 35) = 14,990,600 kJ = 14,990 MJ
    = 15 MJ/hl HG wort
    around 12 MJ/hl SG beer (30% HG)



Wort Heating – Temperature raise

- Energy Input $q = M \times C_P \times (T_2 - T_1)$
  - M = Mass (kg)
  - C_P = specific heat (kJ/kg C) Energy to heat 1 kg by 1 °C (or °K)
  - T_1 & T_2 = Initial & Final Temperature (°C)
- Heat 1000 hl wort (1.06 SG) from 75 to 100 °C
  - Density = 1.06 x 97.4 kg/hl = 103.2 kg/hl
  - Mass M = 1000 hl x 103.2 kg/L = 103,200 kg
  - Specific Heat C_P kJ/kg K
    - Water = 4.2 kJ/kg K , Wort = 4.0 kJ/kg K
  - = 103,200 x 4.0 x (100 – 75) = 10,320,000 kJ = 10,320 MJ
    = 10.3 MJ/hl HG wort
    around 8 MJ/hl SG beer (30% HG)

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Wort Boiling – Evaporation phase change

- Liquid to Vapour – Energy Intensive
- Specific heat of Evaporation – h_{fg}
  - Energy to evaporate 1 kg
  - Water - h_{fg} = 2257 kJ/kg at atm pressure

- Boil Energy input
  - e.g. 5% volume off 1000 hl wort

= M_E x h_{fg} M_E = Mass Water Evaporated

- M_E = 1000 hl x (5/100) x 100 kg/L = 5,000 kg

= 5,000 kg x 2257 kJ/kg = 11,285,000 kJ

=11,285 MJ

= 11.3 MJ/hl HG wort

around 9 MJ/hl SG beer (30% HG)

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Wort Boiling – Energy Minimisation, Recovery or Recycle

- Wort Boiling - Major Energy User
- Minimise Evaporation
  - Maintain Wort Quality
  - 1 % reduction in evaporation
    - saves approximately 2 to 4% of Brewhouse energy consumption (1 to 2% of total brewery energy consumption)
    - Reduces peak steam / HTHW loads
    - Reduces emissions
- Energy - Recycle or Recovery
  - Energy Store – *Recover energy for use elsewhere*
    - Wort Pre-heating
  - MVR – *Recycle over 90% of energy during boil*
  - TVR – *Recycle up to 50% of energy during boil*

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Wort Boiling – Energy Recovery – Alternative Solutions

There are several potential methods of recovering heat from the wort boiling process, or recycling energy within the wort boiling system (which will also eliminate odour emission).

a) Conversion of energy into another form for export outside the brewhouse, either by a simple condenser system exporting hot water (or by absorption refrigeration).

b) Conversion of energy into another form for use in the brewhouse, using hot water from a vapour condenser/energy store system for wort preheating prior to wort kettle.

c) Recycling energy directly within the wort boiling process using either, mechanical vapour recompression (MVR) or thermal vapour recompression (TVR).

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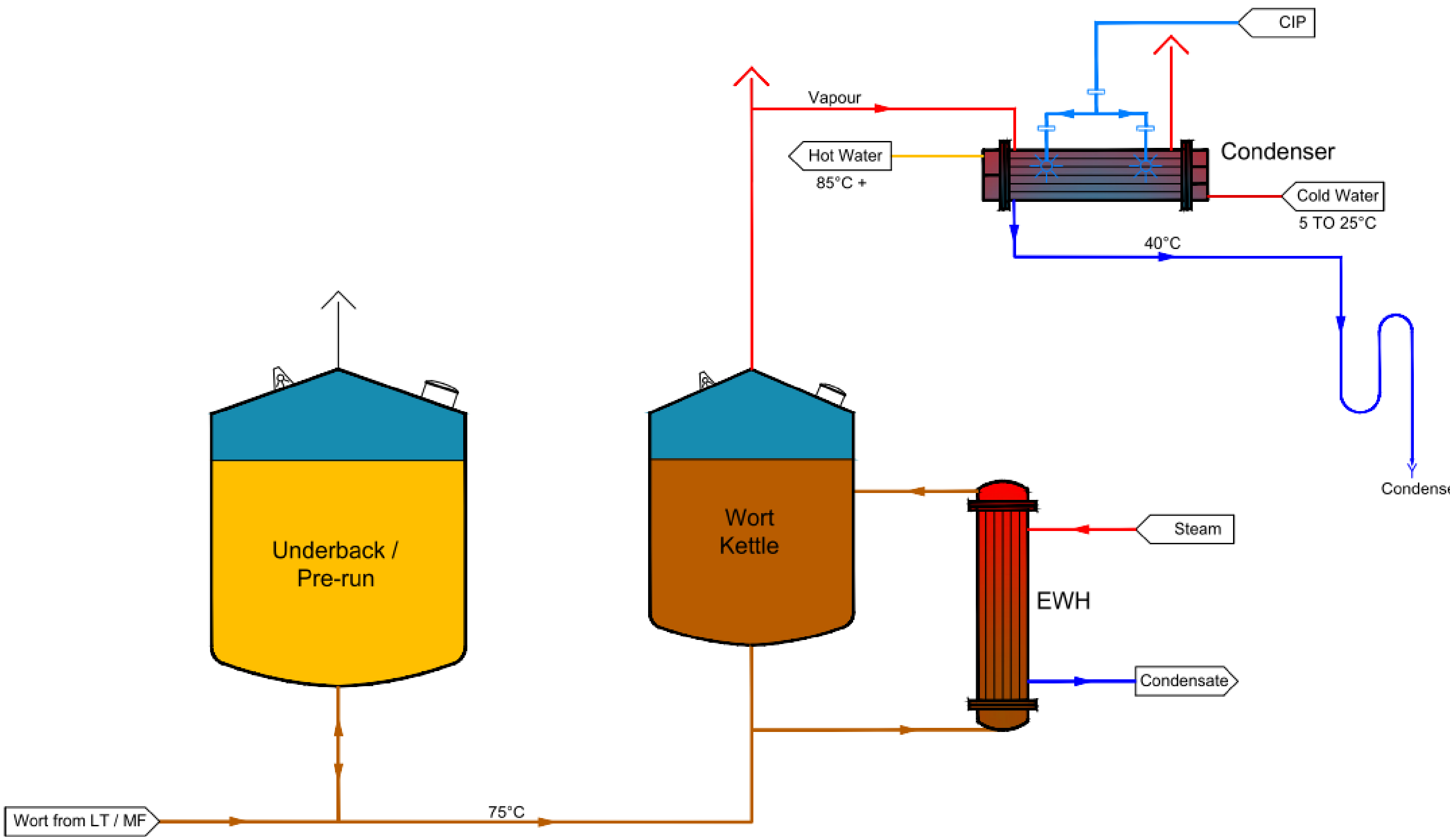
Vapour Condenser – Hot Water



Energy Recovery System - Hot Water Generation
Production of Hot Water for use elsewhere

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Vapour Condenser – Hot Water

- The simplest, lowest capital cost system
- Heating cold water up to 85^{o}C for use elsewhere.
- In most cases, the water balance already produces surplus of hot water, and / or little use for hot water created, so often not relevant.
- A spray condenser may be used as a very simple low cost means of odour removal, with a secondary heat exchanger being used for energy recovery.
- Direct water/ vapour heat exchanger more effective as a condenser.

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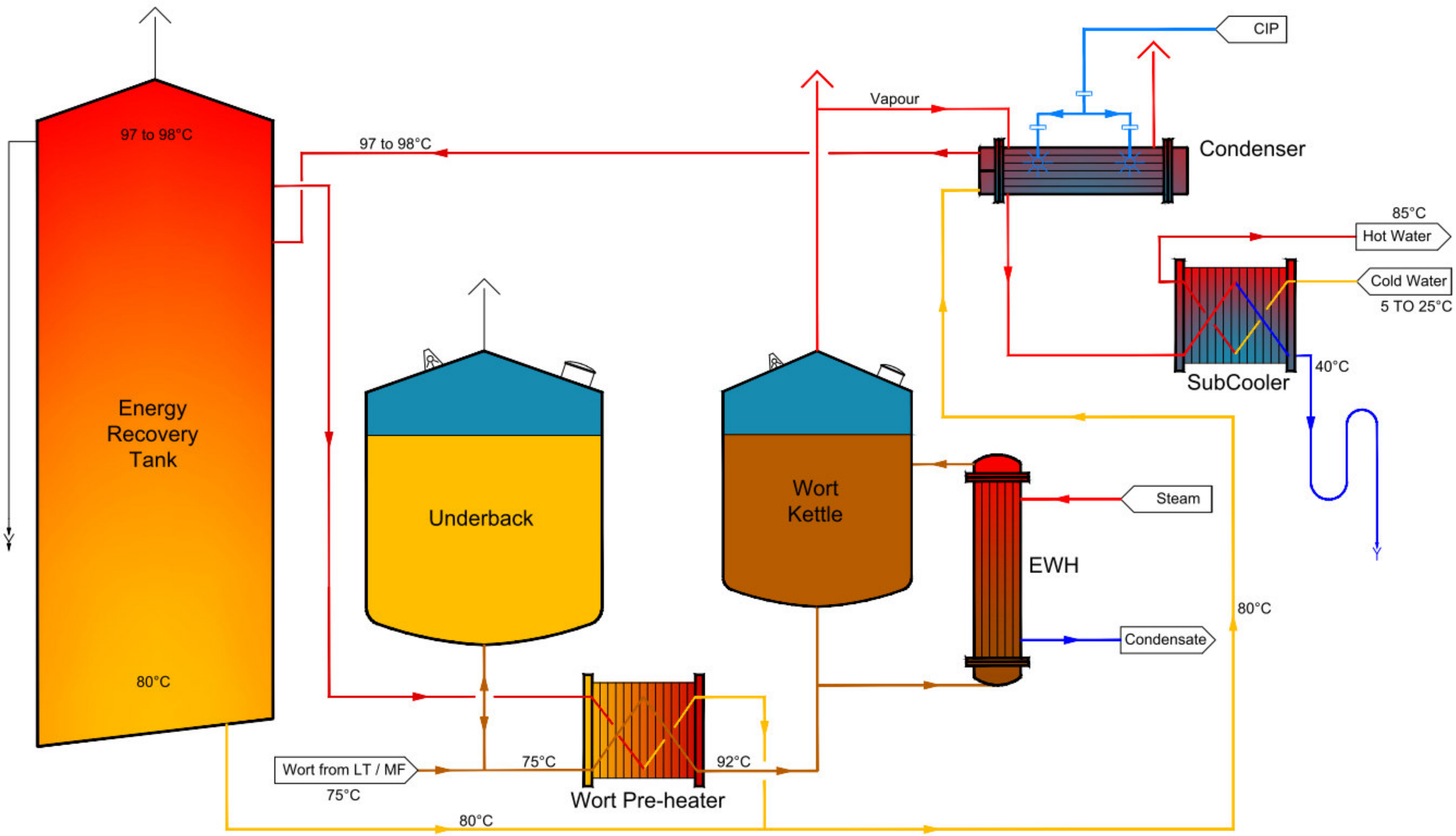
Energy Store – Wort Pre-heating



Energy Recovery System - Wort Pre-heating

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Energy Recovery - Wort Pre-Heating

- Heating Energy = M x C_P x (T_2 – T_1)
- No Energy Recovery
  - Heat 1000 hl wort – 75 to 100 °C

    = 100,000 x 4.0 x (100 – 75) = 10,000,000 kJ

    = 10,000 MJ or 10 MJ/hl HG wort

    around 8 MJ/hl SG beer (30% HG)
- With Wort Pre-heating to 92 °C
  - Heat 1000 hl wort – 92 to 100 °C

    = 100,000 x 4.0 x (100 – 92) = 3,200,000 kJ = 3,200 MJ
- Energy Saving = 10,000 MJ - 3,200 MJ = 6,800 MJ

  = 6.8 MJ/hl HG hot wort or 68% reduction

  around 5.2 MJ/hl SG beer (30% HG) reduction

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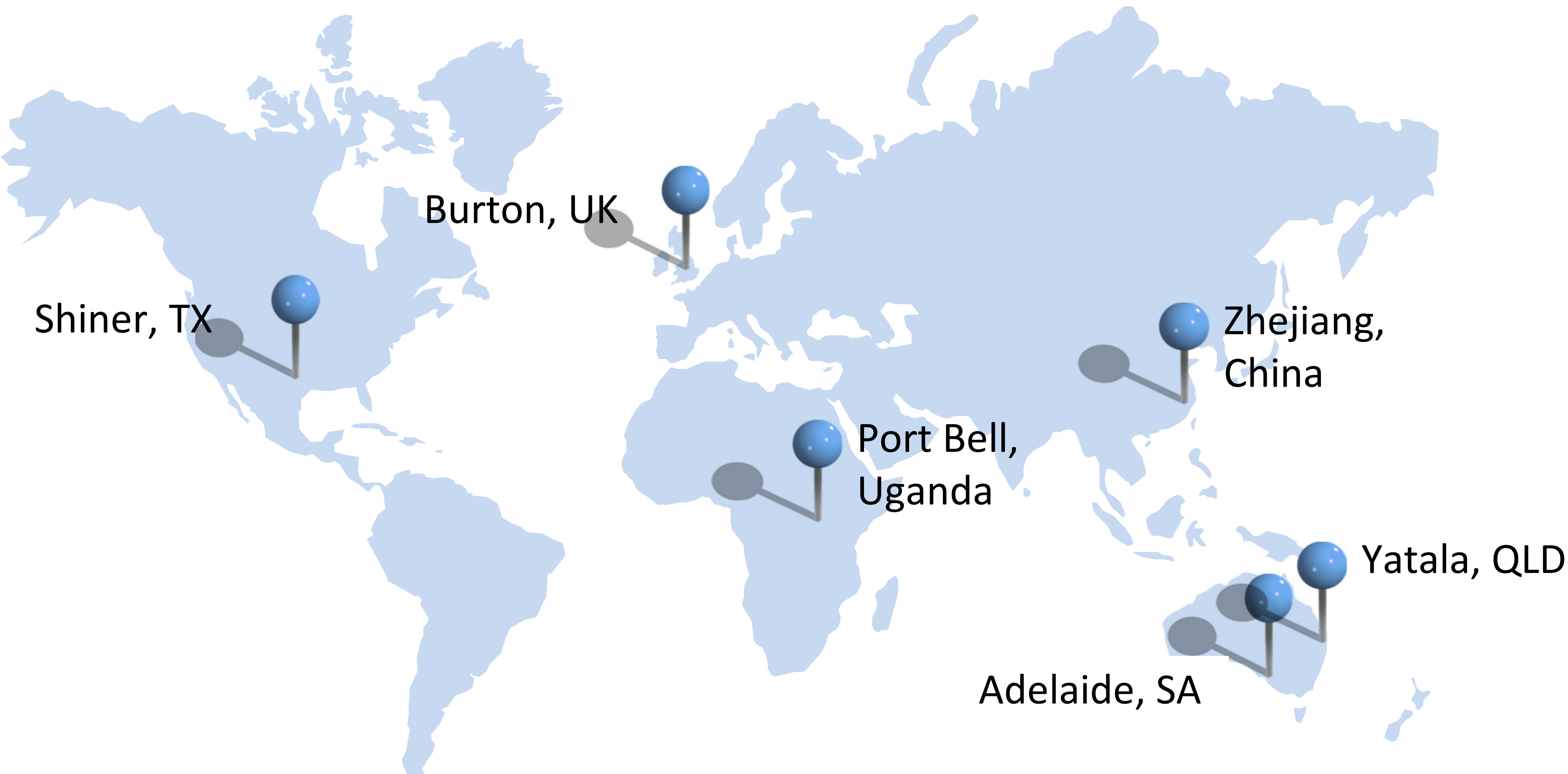
Energy Recovery – Case Studies



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Energy Recovery – Case Studies

Year	Cold Wort Vol	Brew Streams	Mash Separation
	hl	No	
1998	1,000	2	LT
2000	770	1	MF
2004	850	2	LT
2009	1,040	1	MF
2012	380	1	MF
2016	205	2	LT

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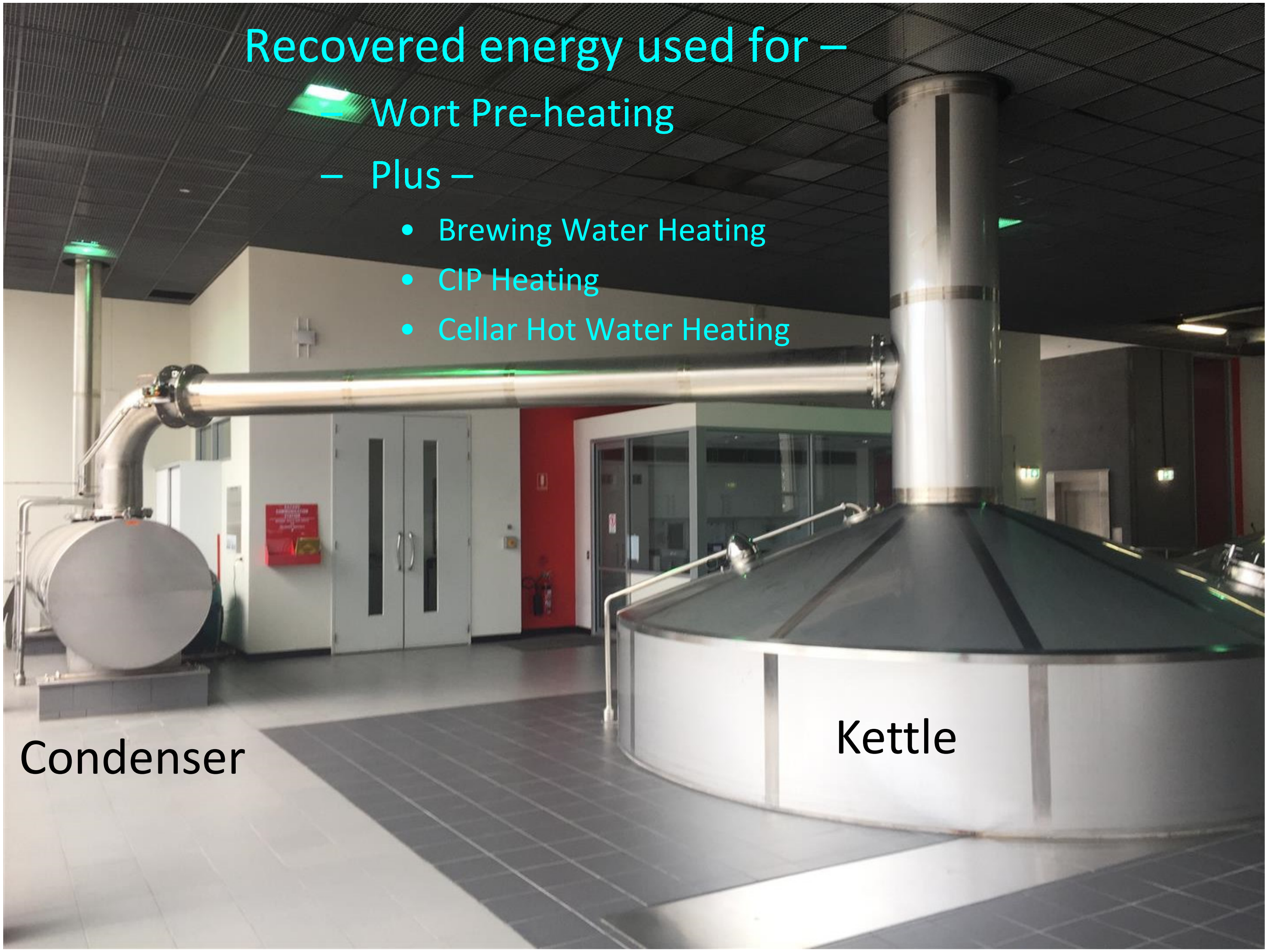
Zhejiang, China

Recovered energy used for –

- Wort Pre-heating (2 streams)

Coopers - Adelaide, SA



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Coopers - Adelaide, SA

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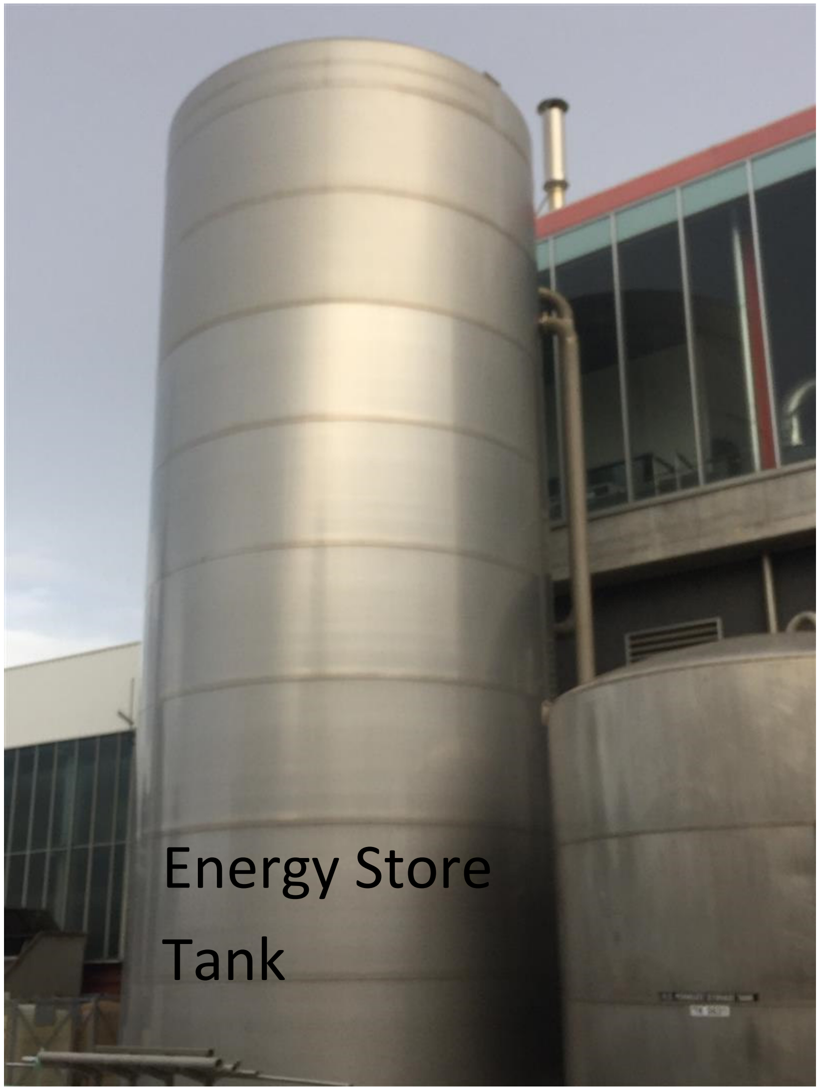
Coopers - Adelaide, SA



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Yatala - Queensland

Recovered energy used for –

- Wort Pre-heating (2 streams)
- Plus –
  - Soft (CIP) Water heating

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Yatala - Queensland

Molson Coors - Burton, UK

Energy Store

Tank

Recovered energy used for –

- Wort Pre-heating
- Plus –
  - De-Alk Water heating

Condenser

Wort

Pre-heater

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UBL - Port Bell, Uganda

Condenser

Recovered energy used for –

- Wort Pre-heating

Operation at 1200 m ASL

Spoetzl - Shiner, Texas

Recovered energy used for –

- Wort Pre-heating (2 streams)
- Plus –
  - HVAC Heating

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Spoetzl - Shiner, Texas

Energy Store Tank

Condenser

Energy Recovery – Case Studies - Capacity

WK Evap (Max)	Condenser Capacity		Preheater Capacity		EST Working Vol
%/h	KW	MJ	KW	MJ	hl
10%	8,150	29,340	2,990	8,880	3,500
8%	4,430	18,580	2,900	6,020	2,200
6%	3,620	13,030	4,380	6,620	2,600
10%	6,930	23,050	4,930	8,580	2,000
6%	1,390	6,250	1,790	3,160	1,020
9%	1,400	5,900	1,430	1,930	704

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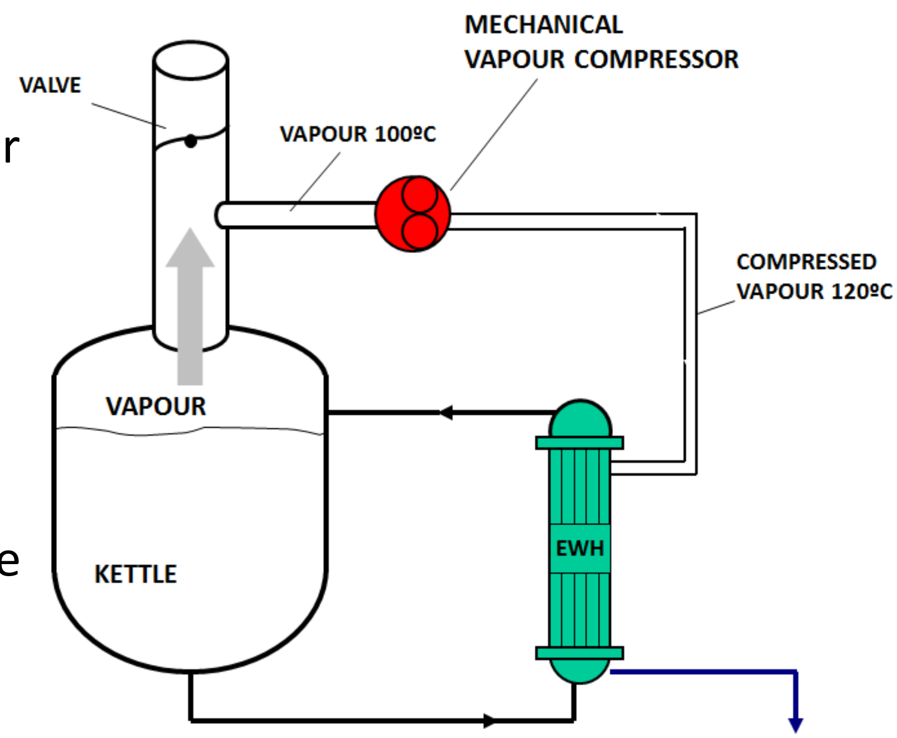
MVR – Mechanical Vapour Compression

- Direct Recycling of Boil Energy
  - Minimal Thermal Boil Energy Requirement
- Replaced with smaller Electrical Power Input
  - Electricity Requirement 0.1 - 0.7 kWh/hl
- High Capital Investment
  - Long Payback Period (>3 years)
- Large rotating machine – Maintenance
- Difficult to Maintain Air Free Wort Boiling
- Contaminated condensed vapour limits reuse



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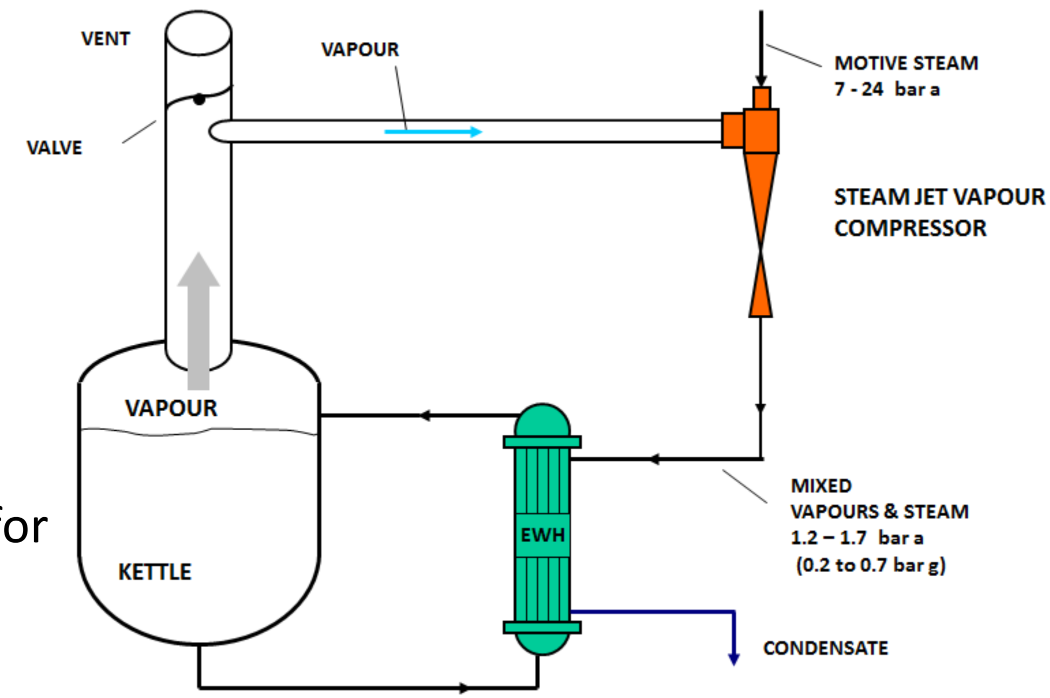
TVR – Thermal Vapour Compression

- Lower Capital cost than MVR
- Recycles 50% or less of boil thermal energy
  - Reduced Energy saving
  - Can be combined with Energy Store to increase recovery
    - Dual system – increased complexity & cost
- Requires high pressure steam for recompression
  - typically 10 bar g or higher
- Contaminated condensed vapour limits reuse



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Wort Boiling – Reduce Evaporation or Not?

- Is boiling really necessary at all?
  - Temperature & time
  - Gas bubbles?
- Simmer & Strip
  - ABInBev patented
  - Minimal Evaporation
  - Minimal gas usage

Objective	Process Factors
Volatile Removal Gas stripping?	Evaporation & Turbulence
Isomerisation	Temperature & Time Boil not needed
Flocculation Gas stripping?	Vigorous Boil (Wort/vapour interface - bubbles), Low Shear
Sterilisation & Enzyme Inactivation	Temperature & Time Boil not needed
Gravity / Volume Boil Not Required	Evaporation – Brew to right gravity

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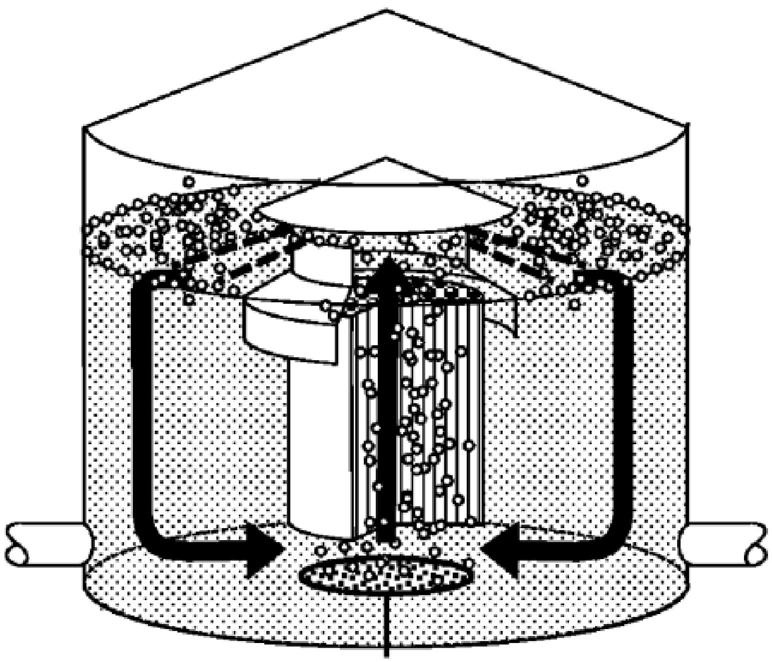
Simmer & Strip – ABInBev Patent

(54) Title: METHOD FOR TREATING A WORT IN A BOILING KETTLE



(10) International Publication Number

WO 2015/067737 A1

(57) Abstract: The present invention concerns a process for treating a wort in a kettle, said method comprising the steps of: (a) providing: • a kettle (1) provided with an inlet (1 u) suitable for feeding a wort into the kettle and with an outlet (1 d) suitable for flowing the wort out of the kettle, • heating means (2) suitable for bringing the wort contained in the kettle close to or at boiling temperature, as well as for controlling said temperature, • a gas sparging system suitable for sparging an inert gas into said wort, (b) feeding wort from a lautering step into said boiling kettle through the inlet, said wort being at a temperature below its boiling temperature; (c) while sparging an inert gas through the wort, heating said wort to, and maintaining it at a treatment temperature, T_a, which is below the boiling temperature, T_b, of the wort for a duration, t_{treat}, comprised between 15 and 90 min, and no longer than required to evaporate at most 4 wt.% of water initially present in the wort; (d) transferring the treated wort to a trub separation step through the outlet.

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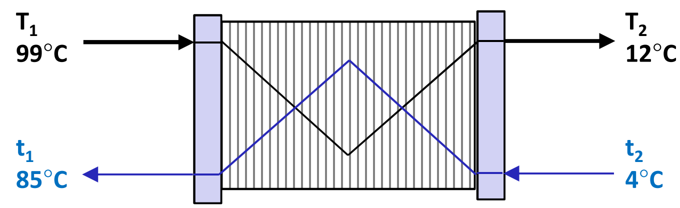
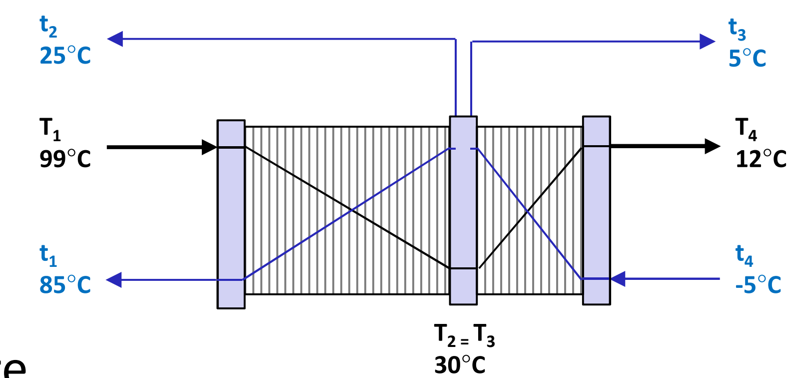
Wort Cooling – Conventional Systems

- Single Stage
  - Wort / Water
  - Simple – easy to control
    - Can't control Hot Water temperature
  - Chilled Water
    - Direct Ammonia chilling of water
  - Buffered refrig load

- 2 Stage
  - Wort / Water + Wort / Coolant
  - Control Wort & Hot Water temperature
  - High peak refrig load



SINGLE STAGE
CHILLED WATER



2 STAGE
AMBIENT WATER & GLYCOL

Wort Cooling – Energy Optimisation

- Heating of Hot Brewing Water at Wort Cooling
    - Biggest single energy saver in the Brewhouse
    - Established and proven
- Seasonal water temperature variation & recipe variation
    - Variation / excess hot water volume, and / or temperature
- Single Stage Cooling with Blending of chilled and ambient water
    - System balanced / optimised
    - Closer approach temp - Refrigeration energy minimised
- Multi Stage Wort Cooling
    - 1 - Hot section with Energy Store – Heat energy source -> Wort Pre-heating
    - 2 – Wort / Ambient Brewing water -> Hot Brewing water
    - 3 – Wort / Chilled water or glycol - Cold Energy buffer
        - – Buffering smooths peak loads
        - – Alternatively direct primary refrigerant on final stage

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Short TAT / Rapid Batch Brewhouse

- More brews/day x Smaller Brewlength
- Lower peak / smoother utility loads
- Smaller physical size – shorter runs
- Reduced energy loss

Brews/Day	Brewlength hl	Volume / Day hl/day
14	200	2800
12	233	2800
10	280	2800
8	350	2800
6	466	2800

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Continuous Brewhouse

- Comparison -
  - Batch –
    - 200 hl x 14 BPD   350 hl x 8 BPD
  - Continuous – 100 hl/h
- Small plant size –
  - 50% vs 14 BPD   30% vs 8 BPD
- Reduced losses & energy consumption
- Smooth utility load – minimal peaks
  - Less starts & stops

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Pipe Sizing

- Under sizing of process pipework can be attractive due to lower installed capital cost , but has long term energy implications

Dia mm	50	75	100	125	150
Capital Cost £ (Material & Installation)	£ 2,796	£ 3,854	£ 5,485	£ 7,533	£ 9,252
Relative Capital Cost	51%	70%	100%	137%	169%
Relative Velocity	400%	178%	100%	64%	44%
Relative Pressure Drop & Power Use	1600%	316%	100%	41%	20%

- Pressure drop is proportional to pipe velocity^2
    - ½ Diameter -> 2 x Velocity -> 4 x Pressure Drop
- Pump duty is a function of pipework pressure drop (+ Static head)
    - Power proportional to flow x pressure
    - 4 x Pressure Drop = 4 x Power use (+ Static head power element)
- Undersized pipework will mean long term high pump power use

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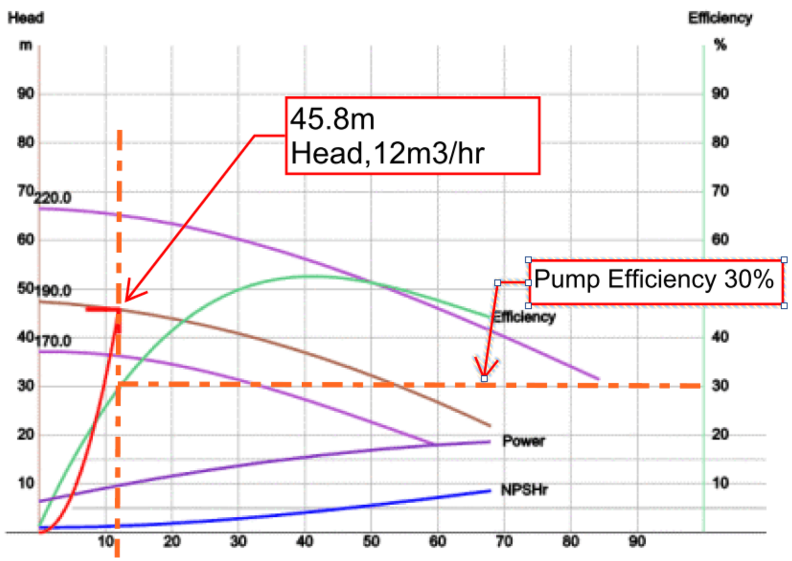
Pump Selection

- Pumps consume 10% of world electrical energy
- Power is typically 85% of a pumps total cost of ownership
- Pump Efficiency = $\dfrac{\text{Power Imparted on Fluid}}{\text{Power Supplied to Drive}}$
- Pump Efficiency –
    - High efficiency at duty point = Low power use
    - Low efficiency at duty point = High power use (& higher shear)
- Case Study: Pump Duty = $12 m^3/hr$ at 39m head
    - Pump A: Low capital cost
    - Pump B: Higher efficiency

Pump - Capital Cost vs Efficiency

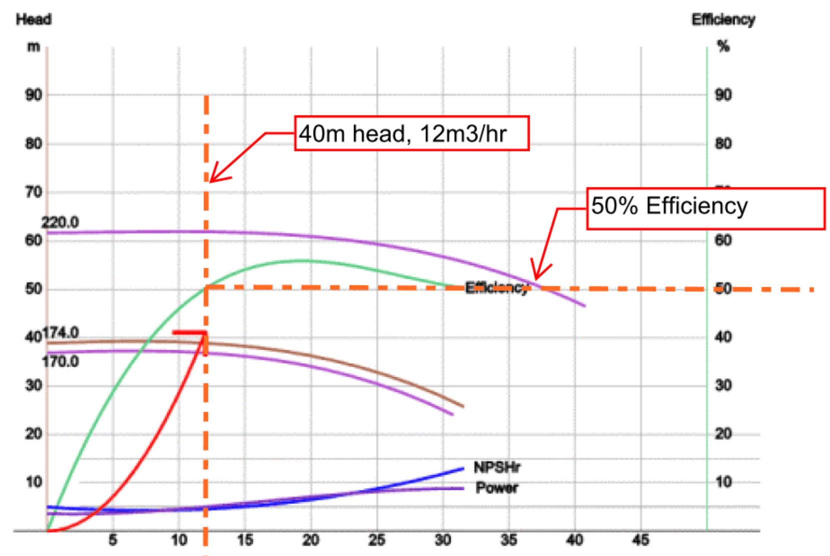


Low Capital Cost & Efficiency

This pump could achieve 50% + efficiency, but not at duty point. Low efficiency at duty, high power usage & running costs.

Higher Capital Cost & Efficiency

This pump has duty point closer to maximum efficiency.
Higher efficiency & lower operating costs.
In reality efficiency could be higher, typically 60 to 70%.



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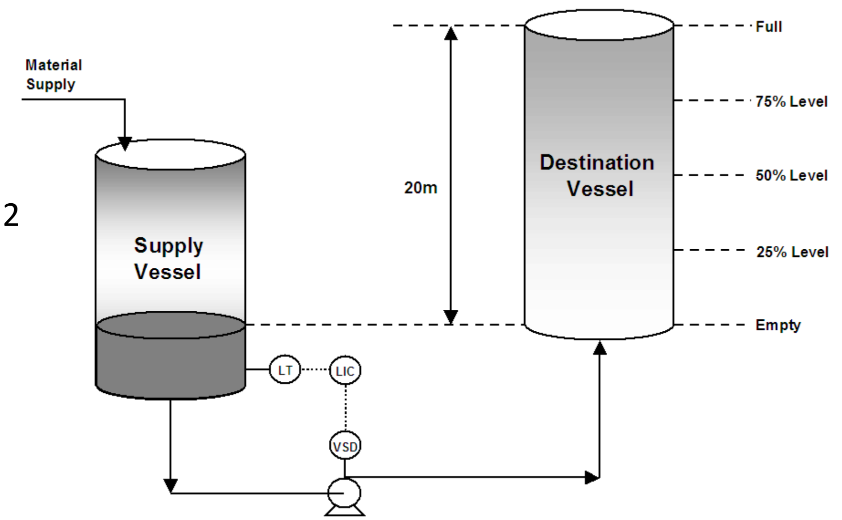
VSD Pump Operation

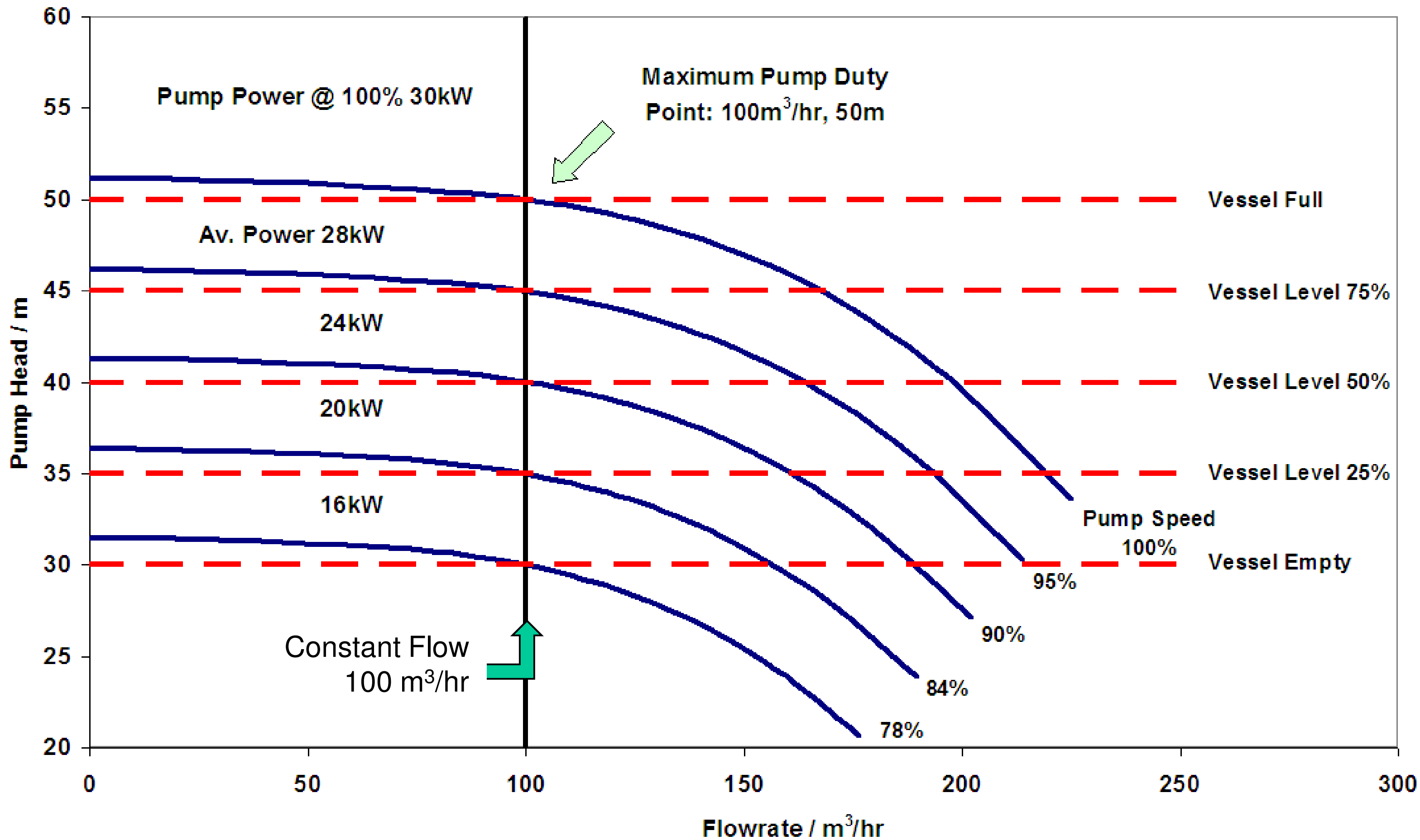
- In reality pumps often have a range of duties.
- Example – filling a tank at constant flow and variable level
- Pump Affinity Laws
  - Flow proportional to (speed)
  - Head (pressure)proportional to $(\text{speed})^2$
  - Power is proportional to $(\text{speed})^3$



- Pump Speed 50%

  Power Consumption 12.5%
- Using pump affinity laws we can estimate the pump speed & power used to maintain flow as the level in the tank increases

VSD Pump Curve



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VSD Pumps – Power Use

Tank Level	Pump Speed	Power Consumption
Empty	78%	14 kW
25%	84%	18 kW
50%	90%	22 kW
75%	95%	26 kW
Full	100%	30 kW

- Daily Energy Consumption
  - Fixed Speed 720 kWh
  - VSD <u>526 kWh</u>
- Energy Consumption Reduction <u>26%</u>

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Insulation

- Thermal insulation is proven, simple and often overlooked
  - Low cost
  - Low maintenance
  - Long term energy savings

INSULATION DEPTH	RELATIVE HEAT LOSS
Un-insulated	2373%
25	192%
38	130%
50	100%
75	68%
100	51%

- Small un-insulated areas have huge energy losses
  - Un-insulated approx. 24 x loss/m^2 vs 50 mm insulation
- Increased insulation thickness &/or better insulation gives significant long term energy saving
- Distribution lines continually lose (or gain) heat
- Uninsulated Vessel tops?

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Renewable / Alternative Energy

- Spent Grain Combustion
- Dry De-Husking (DDH) – ABInBev
  - Patented system
  - Husk separated – Boiler fuel source
  - Reduced Brewhouse water use
- AD Biogas
  - Waste water treatment
  - Thermal energy produced
- Solar PV Panels
  - On site electric power generation
- Process / Utility Integration

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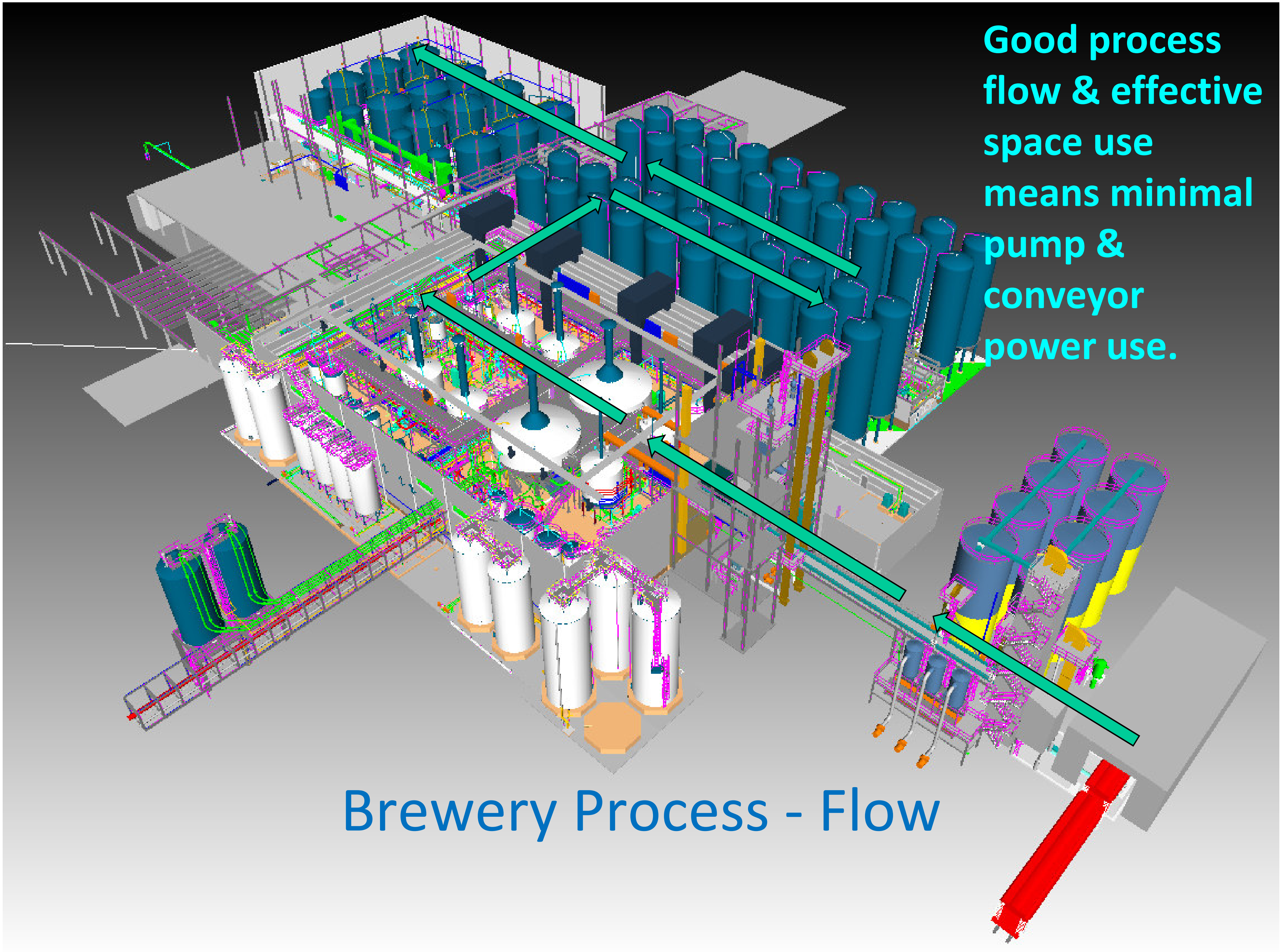

Brewery Process - Flow

Thank you for your attention.
Any questions?

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