Increasing Plate Heat Exchanger Thermal Duty: An Industrial Case Study

Method for Improving Heat Recovery Loops

Tim Walmsley, Michael Walmsley, Martin Atkins, James Neale
Industrial Energy Efficiency Division
Waikato Energy Research Centre, University of Waikato

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Talk Outline

- Introduction
- Integrating semi-continuous processes
- Heat Recovery Loop & Thermal Storage
- HRL Design Methodology
- HRL Storage Temperature selection
- HRL HX Area Targeting
- Conclusions

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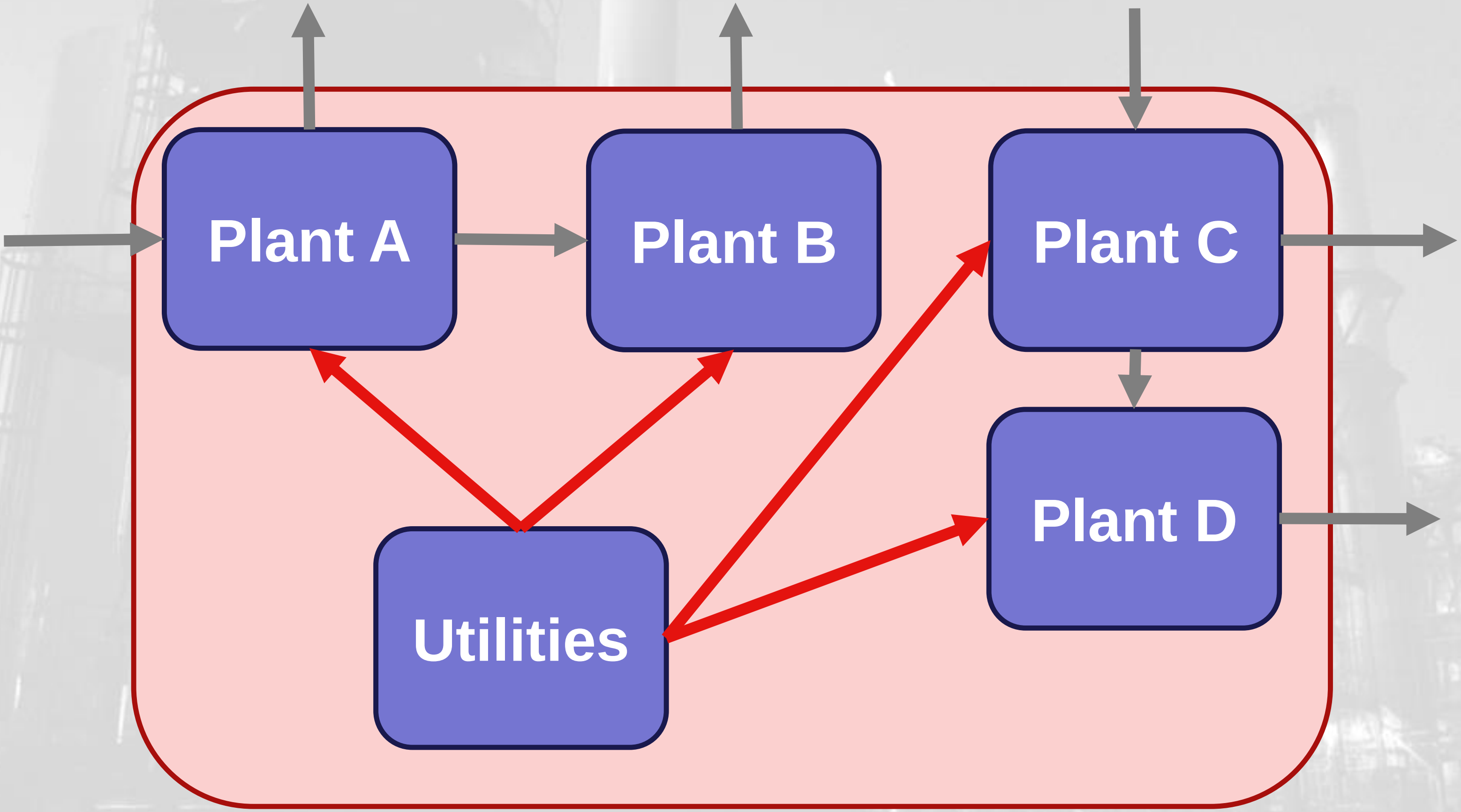
Introduction

- Large semi-continuous multi-plant sites are difficult to integrate



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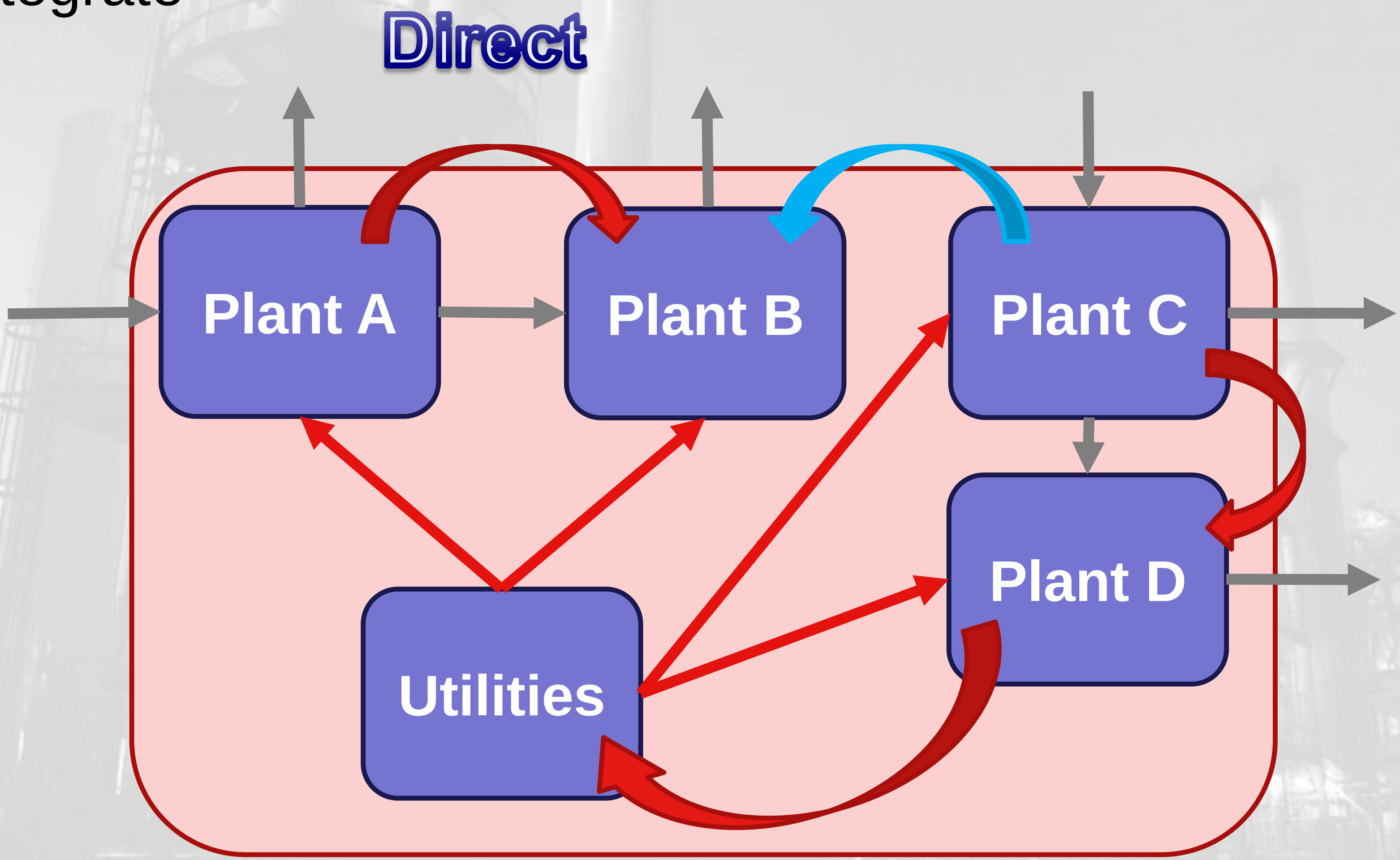

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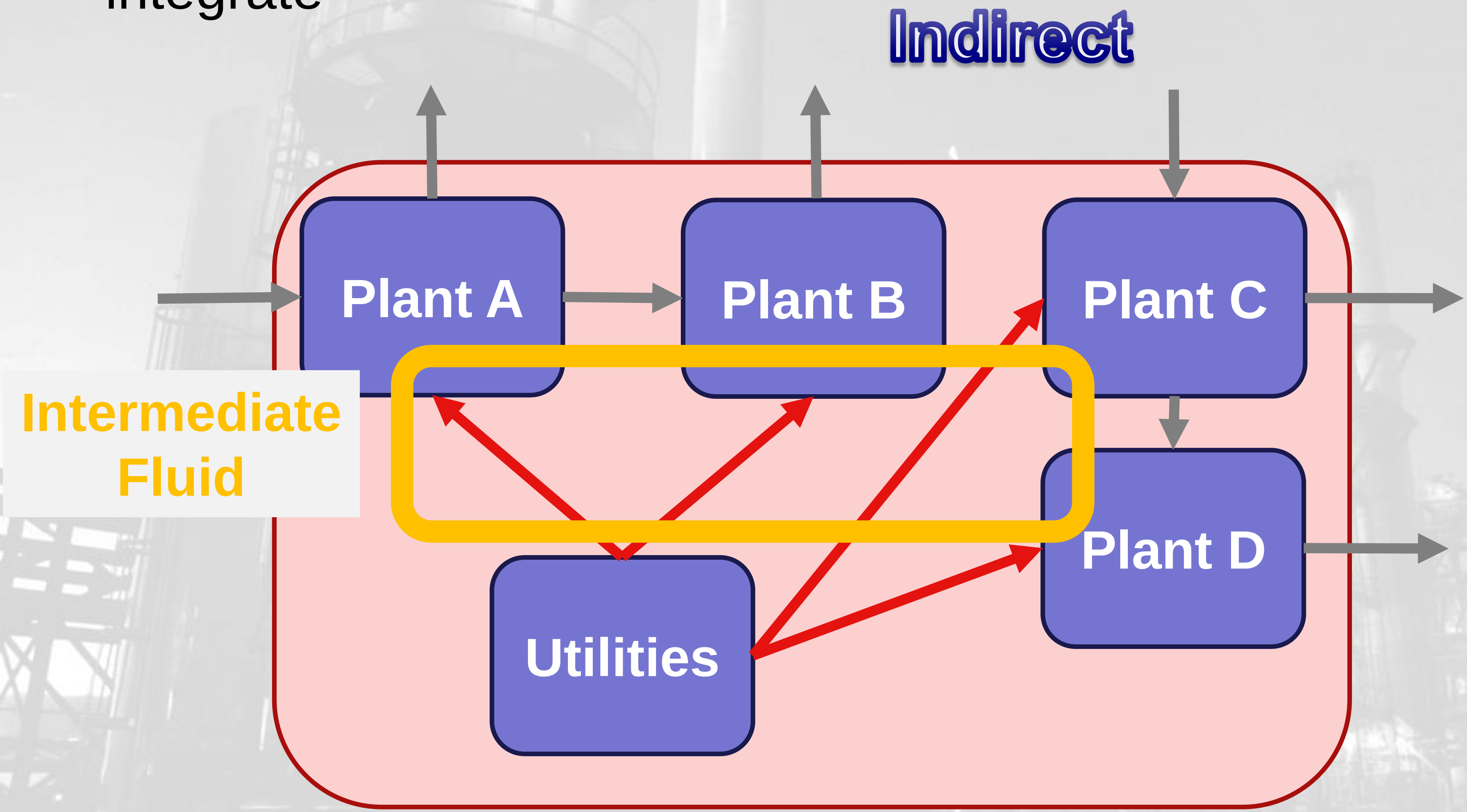
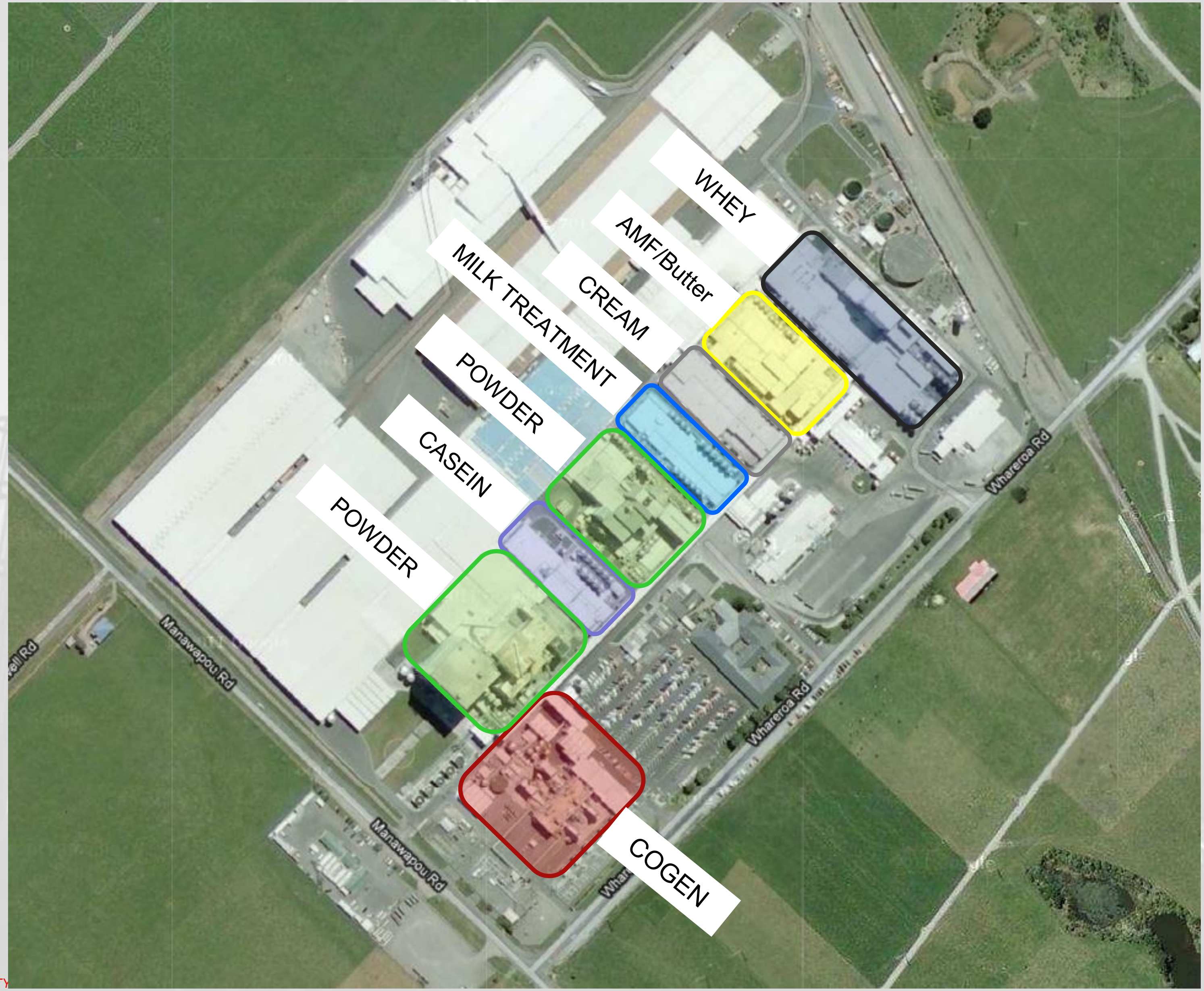


Large Multi- Plant Dairy Processing Site

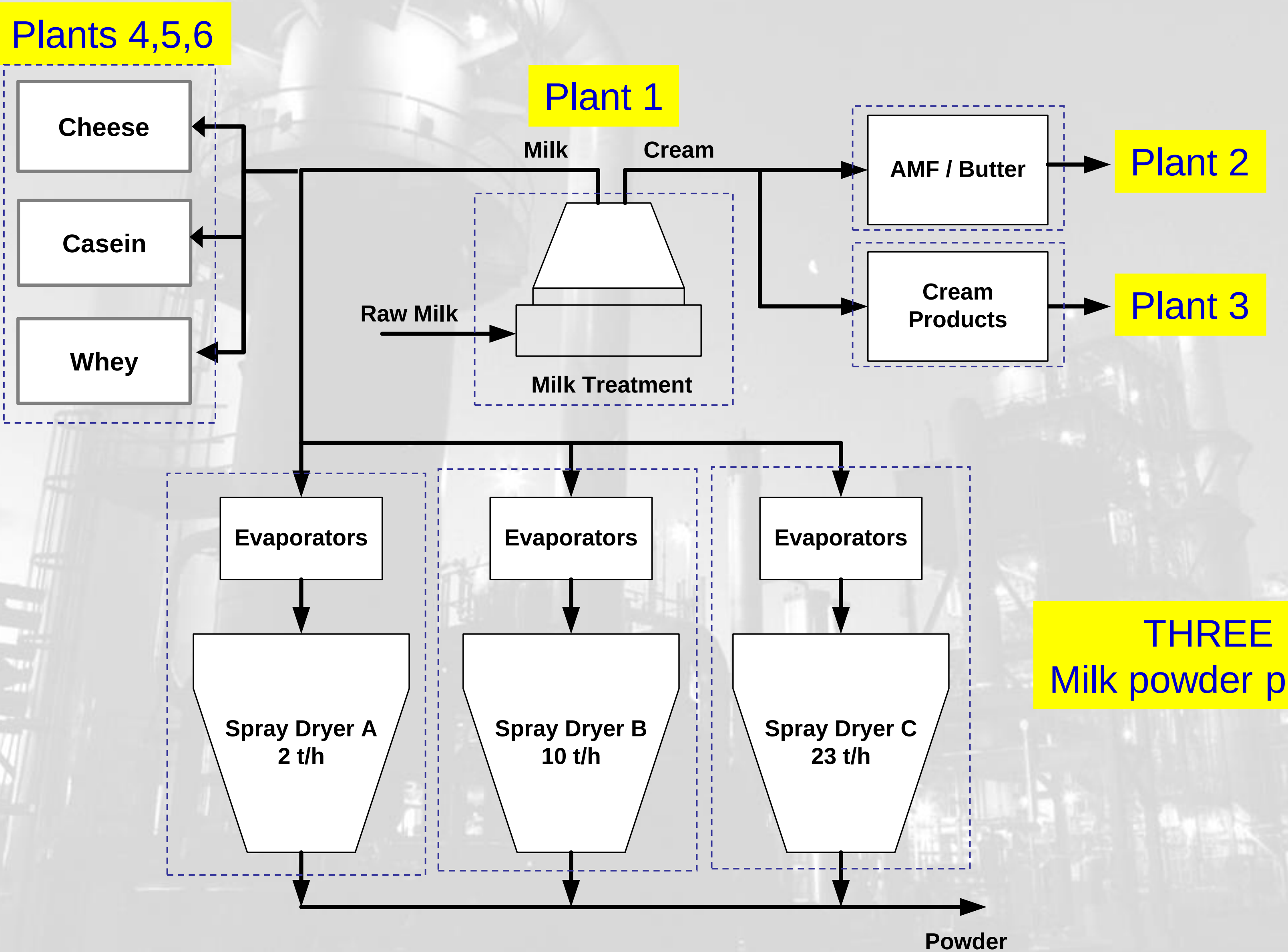
Site Layout

Manawapou Rd
Manawapou Rd
Whareroa Rd
Whareroa Rd
Whareroa Rd

Site Layout – Multiple Plants



Large Dairy Factory – multiple plants



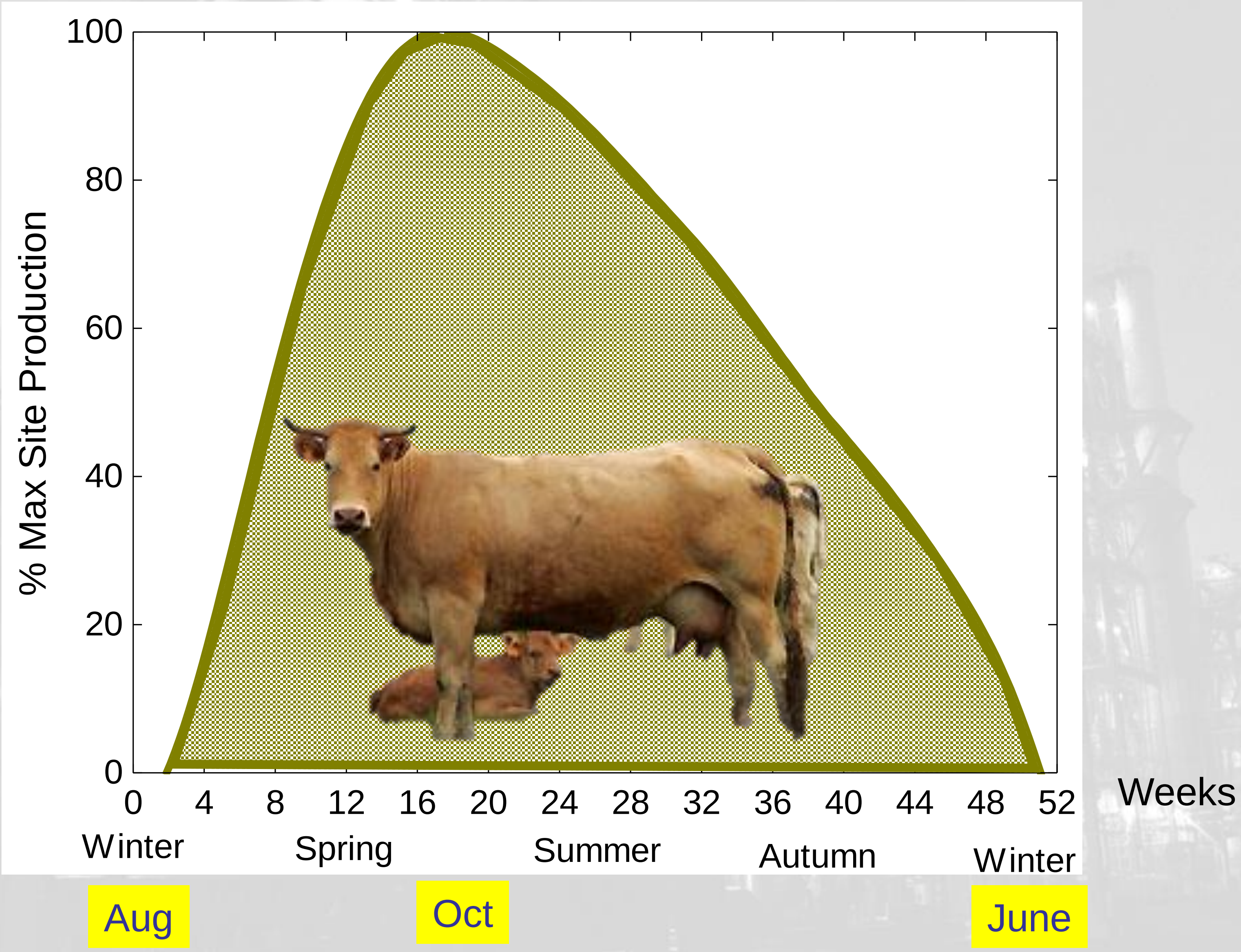
THREE
Milk powder plants

Large Dairy Factory – multiple plants

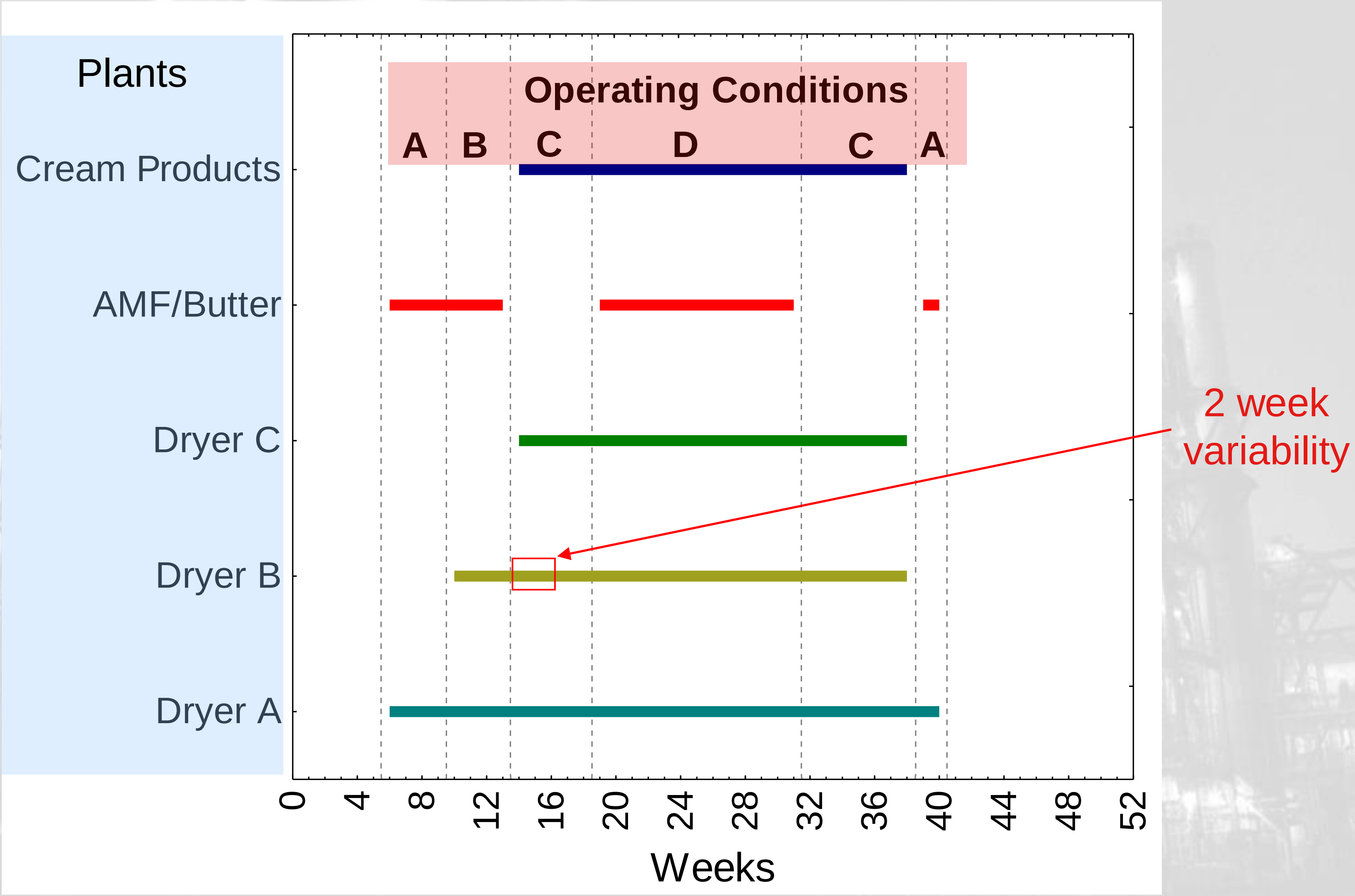
- 8 million litres (peak) per day
- 8 Plants
  - Anhydrous Milk Fat (AMF) / butter plant
  - Cheese, Casein, Whey
  - THREE milk powder plants
- Semi continuous plants
  - Regular cleaning required
  - Product changes (start-up, shut down)
  - Variable milk supply over season
- Inter-plant integration opportunity

How semi-continuous are the plants?

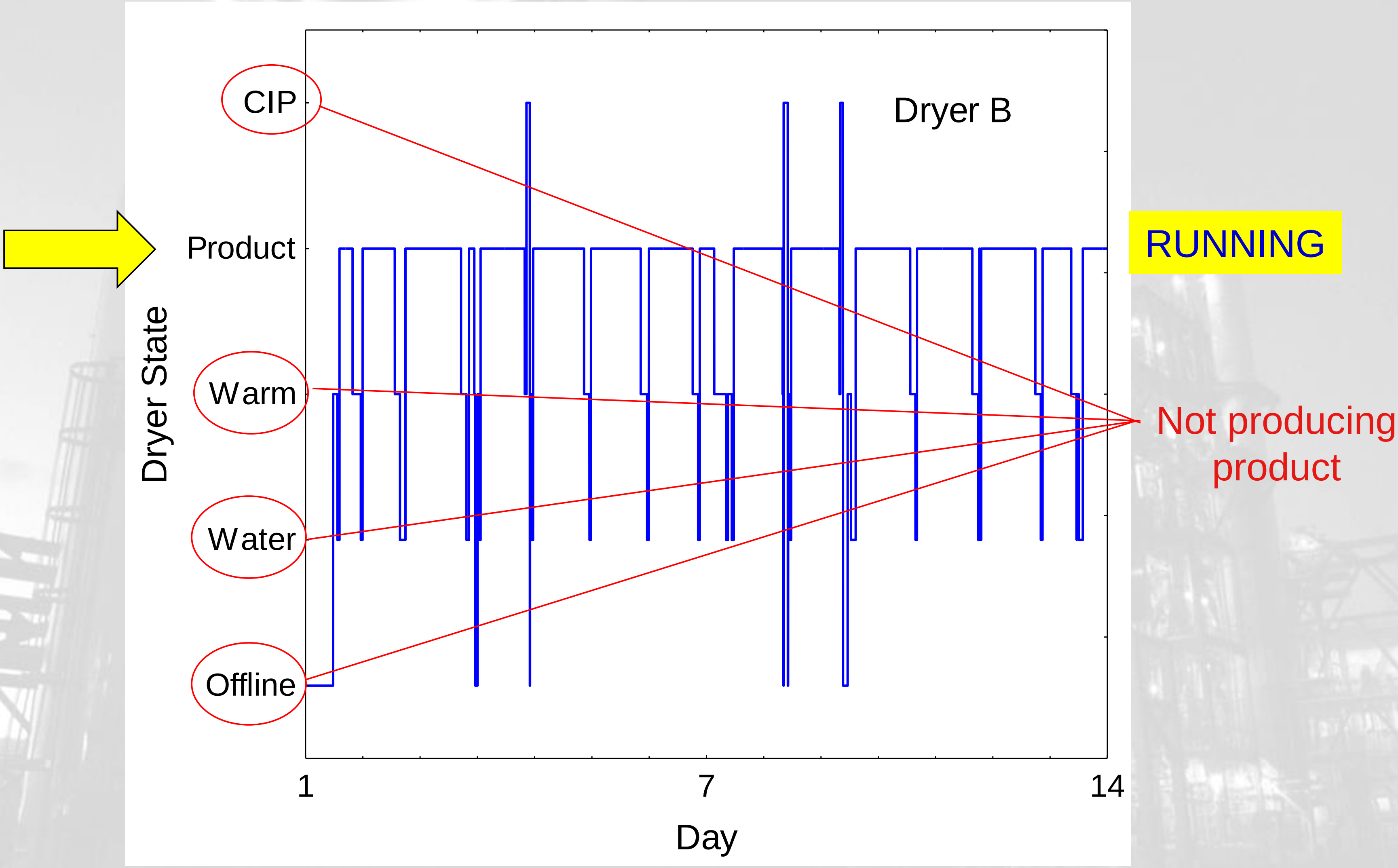
Milk to Factory for Processing



Annual Operating Schedule

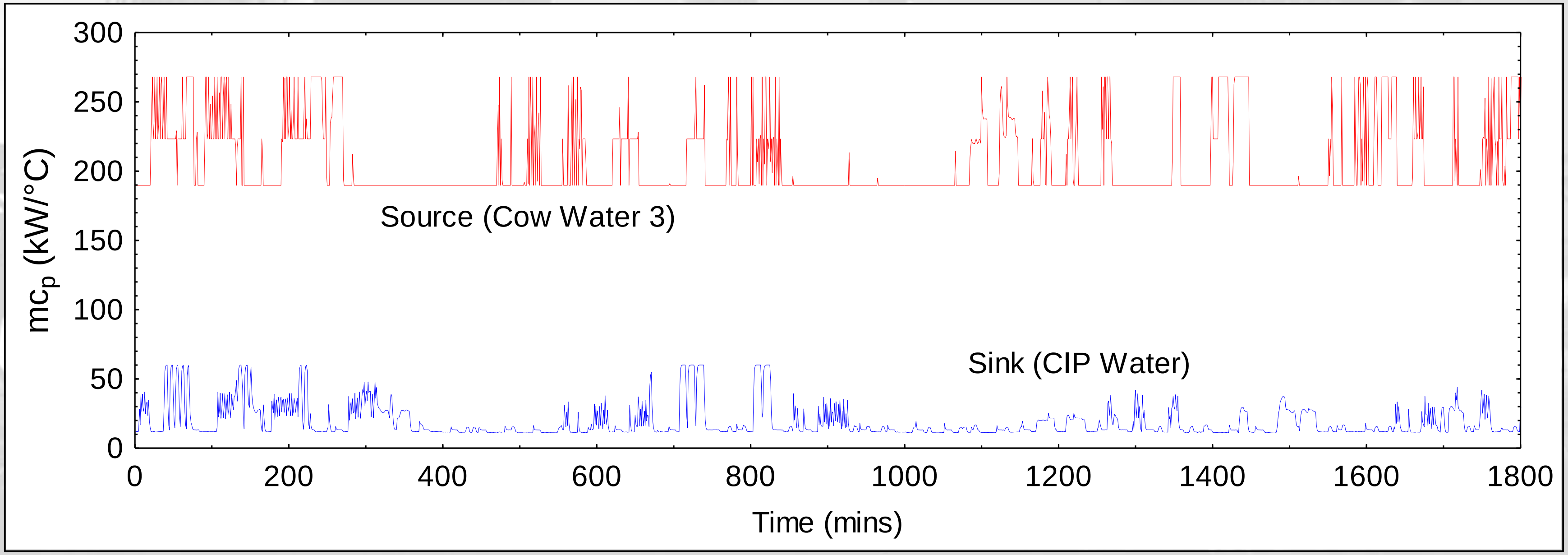


2 Week Operation of Dryer B



Unsteady plant operation

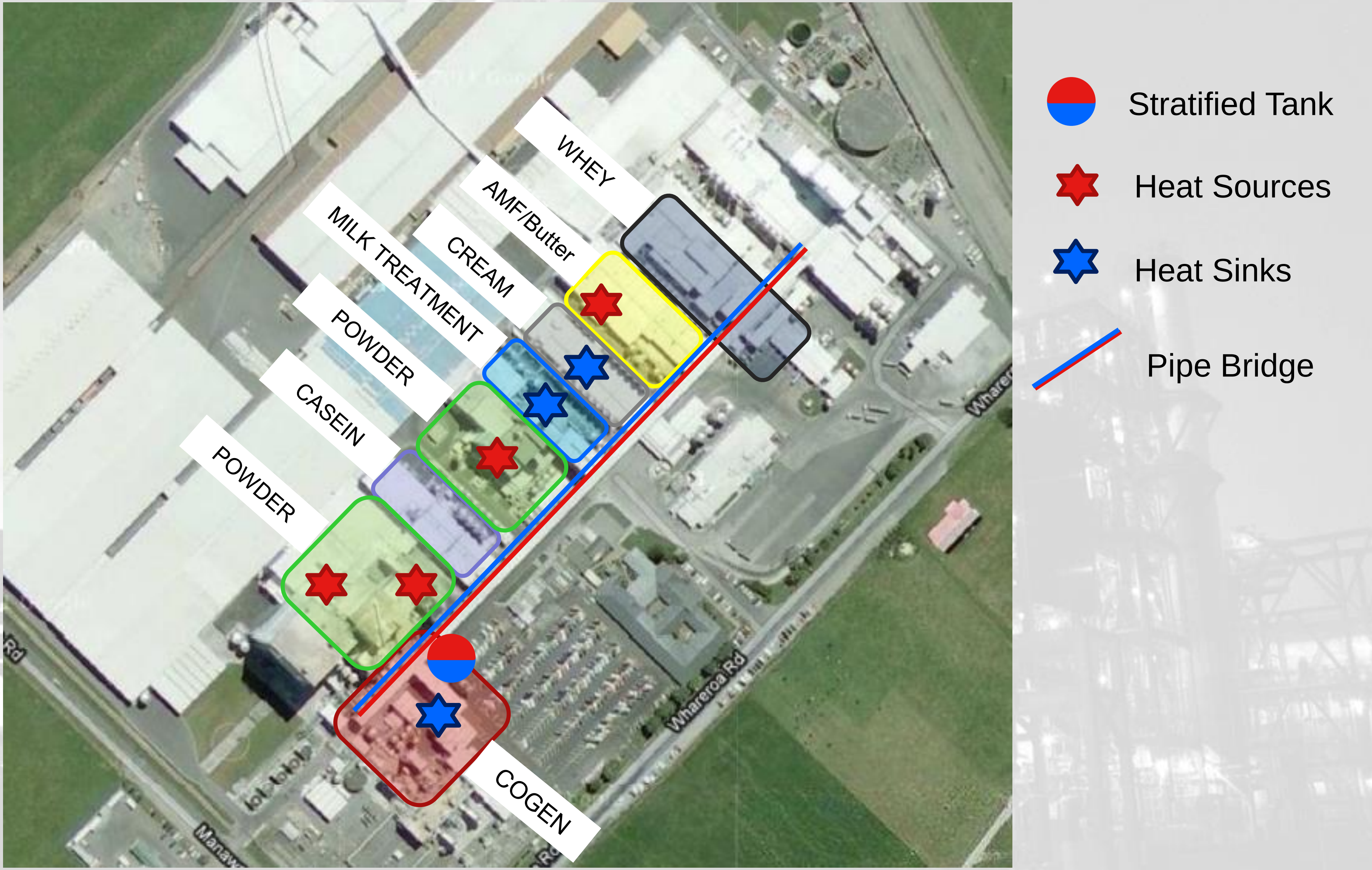
- Streams can be unsteady in both Temp and Flow
- Unsteady due to many factors
  - Production Rate Changes & Variations
  - Regular Cleaning
  - Multiple Plants



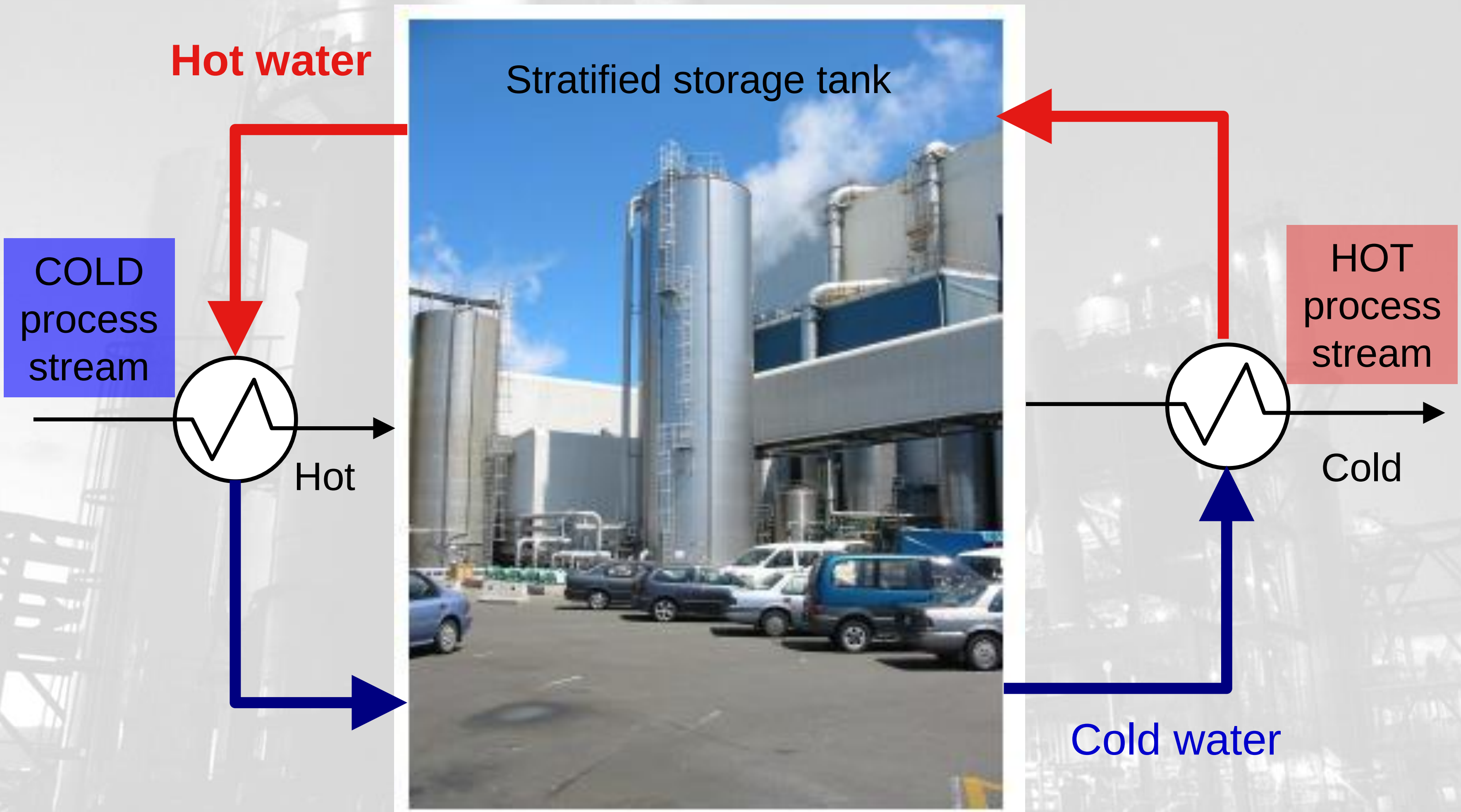
Total Site Integration

- Interplant integration (Previous work: Bagajewicz and Rodera, 2000, 2002; Krummenacher and Favrat, 2001)
  - Direct
  - Indirect
- High Pinch Temperature Applications
  - Use steam belt system for indirect heat exchange between sources and sinks.
  - Surplus can be used for power generation.
  - Deficit met with utility.
- Low Pinch Temperature Applications
  - Food & Beverage
  - Pulp & Paper
  - Heat Recovery Loop

Heat Recovery Loop

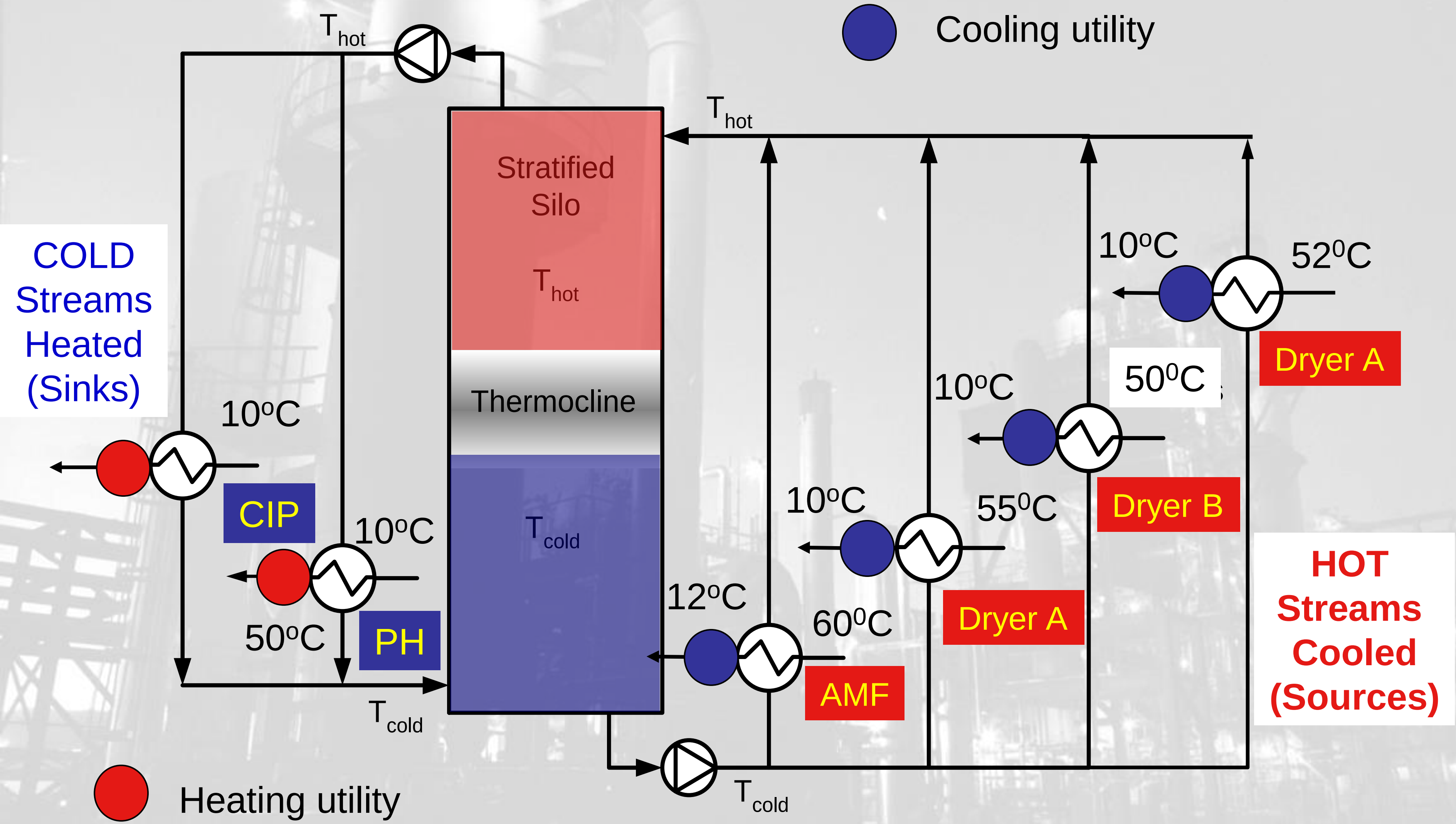


Indirect Heat Transfer + Thermal Storage



Heat Recovery Loop

Dairy Case Study - Heat Recovery Loop



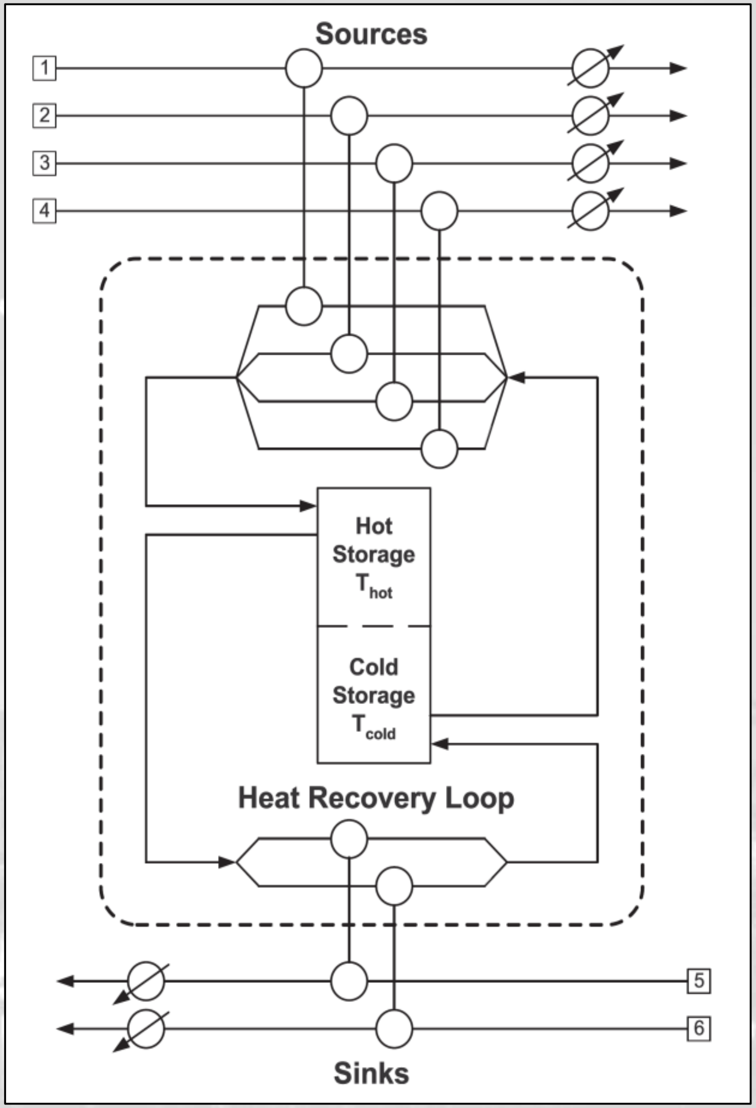
Hot & cold water loop temperatures?

Stratified Tank

Pipe Bridge & Heat Exchangers

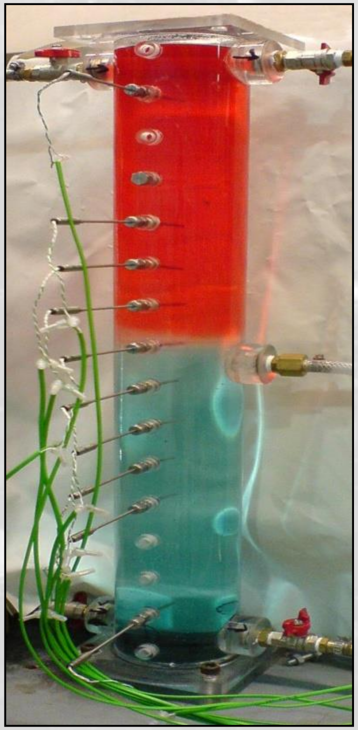
Heat Recovery Loop

- Low Temperature Applications
  - <100 - 150 °C
- Indirect Heat Transfer
- Non-Continuous or Variable Rate
- Heat Sources / Heat Sinks
- Thermal Storage
  - Single Stratified Tank
  - Multiple Tanks
- Distribution System
- Control System

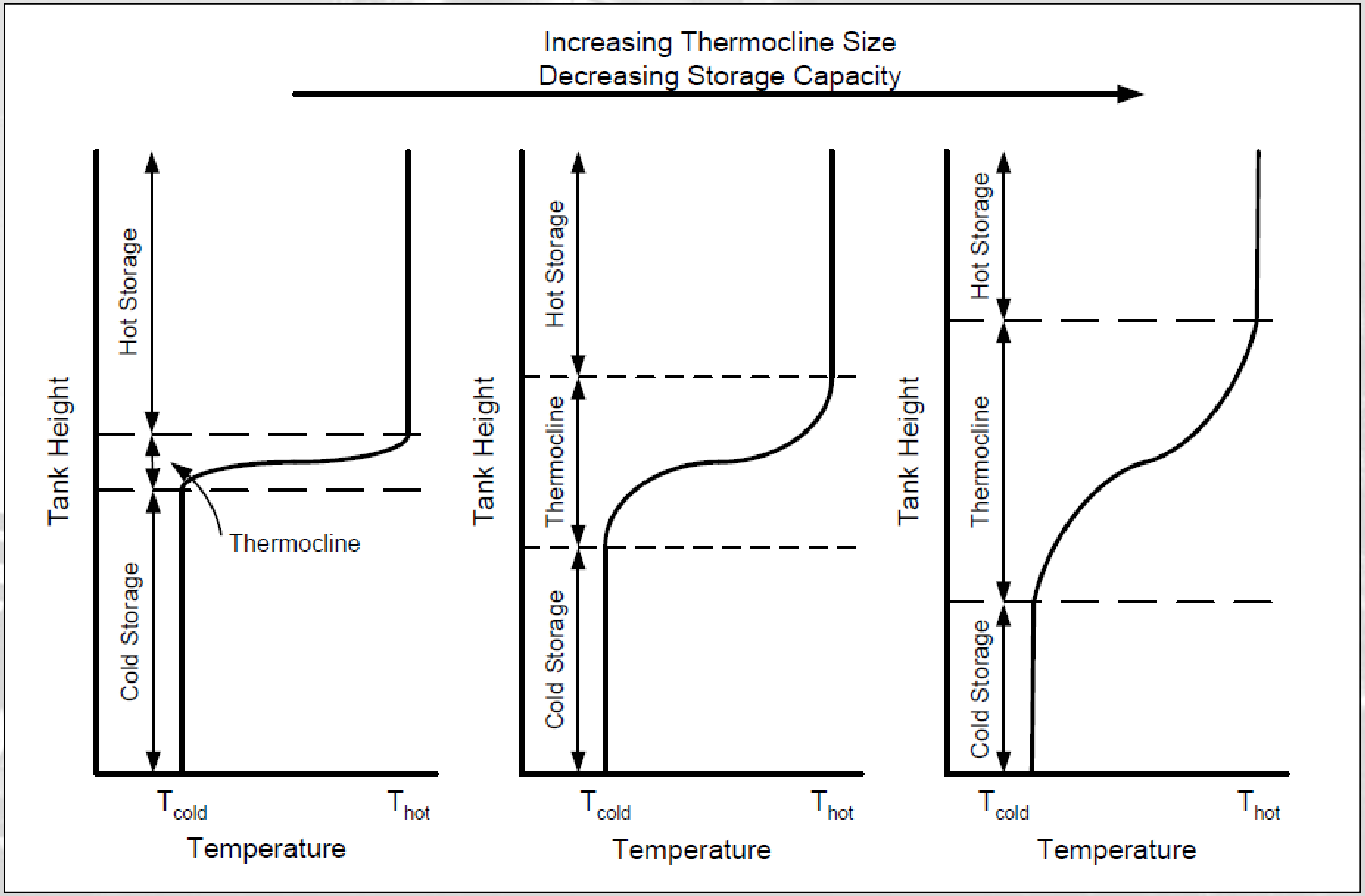


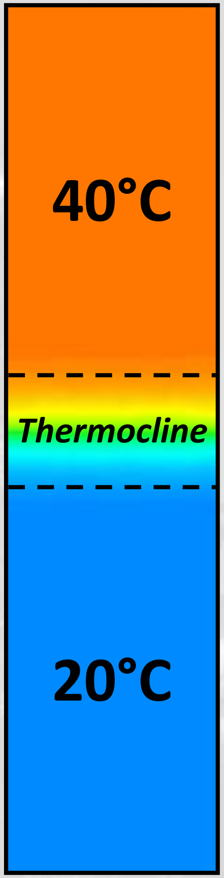
Thermal Storage – Stratified Tank

- Used for storage of thermal energy
  - e.g. Hot Water, Chilled Water
- Usually operated in a *charge – hold – discharge* cycle
- Exploits a density difference of the fluid to create stratification
- Can be very large ~15,000 m^3
- Thermocline reduces effective storage



Thermal Storage – Stratified Tank





Two Tanks vs. Single Stratified Tank

- Why not have 2 tanks?

Single Stratified Tank

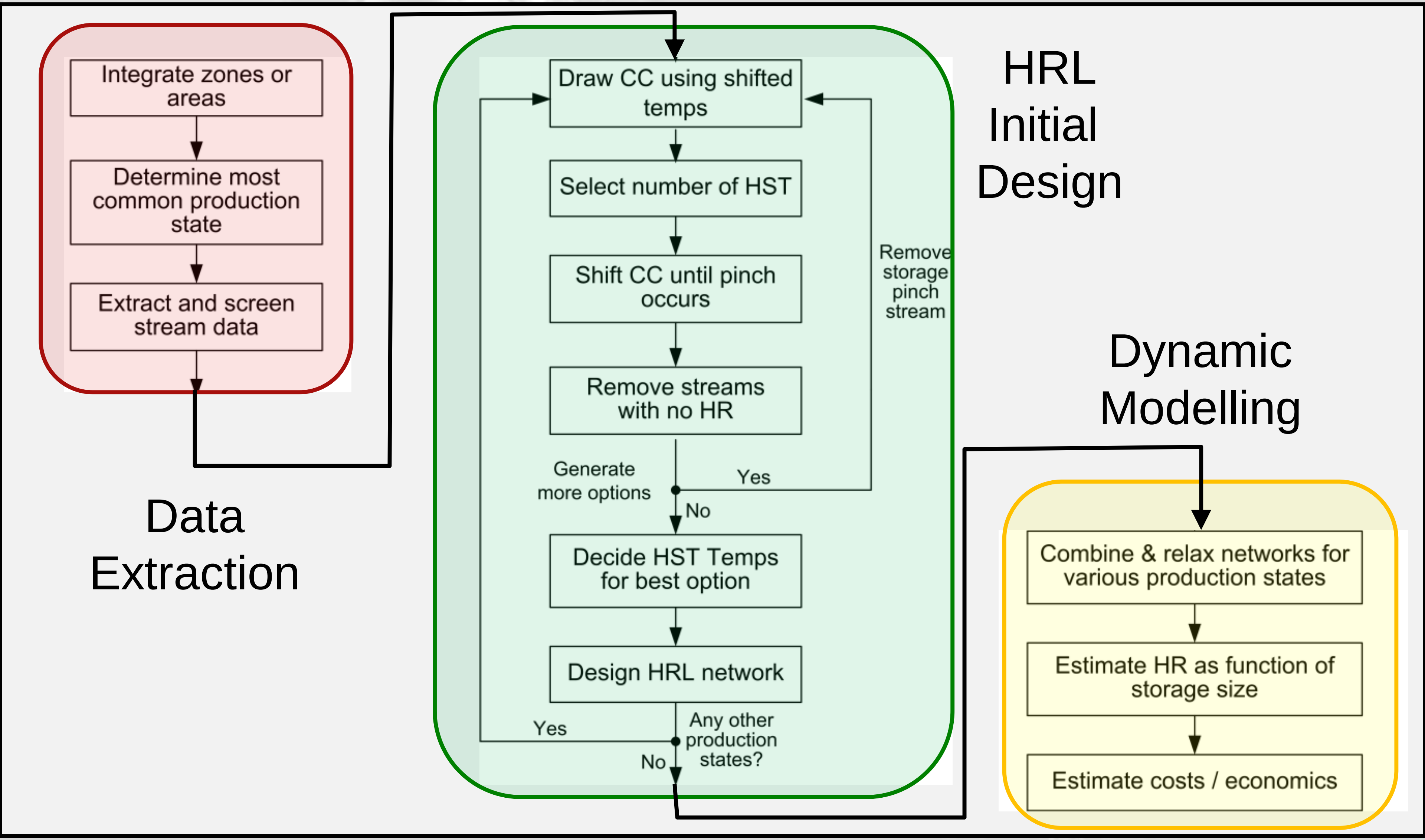
Two Individual Tanks

Fixed Volume System
Eliminate Thermocline Problem
BUT need 2x amount of tank volume

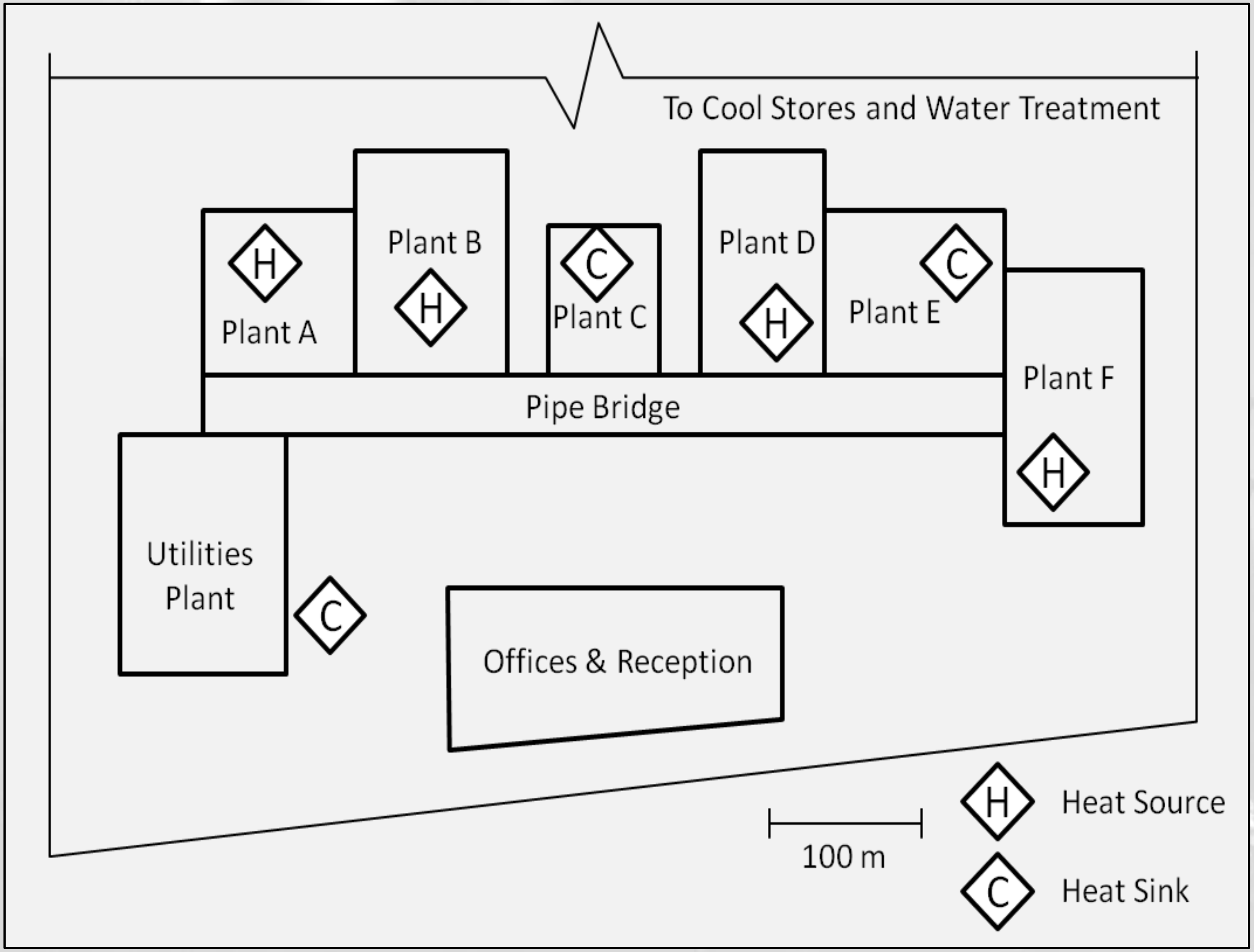
Designing a Heat Recovery Loop

- Selection of T_{hot} and T_{cold}
- Selection of Sources & Sinks
- Availability and Variability of Streams
  - Availability – When is the stream “on”?
  - Variability – What is the variability in T_s, mc_p?
- Sizing of Thermal Storage
  - Optimal Heat Recovery
  - Optimise Life Cycle Cost
- System Control
  - HX Trimming
  - Load Balancing

HRL Design Methodology

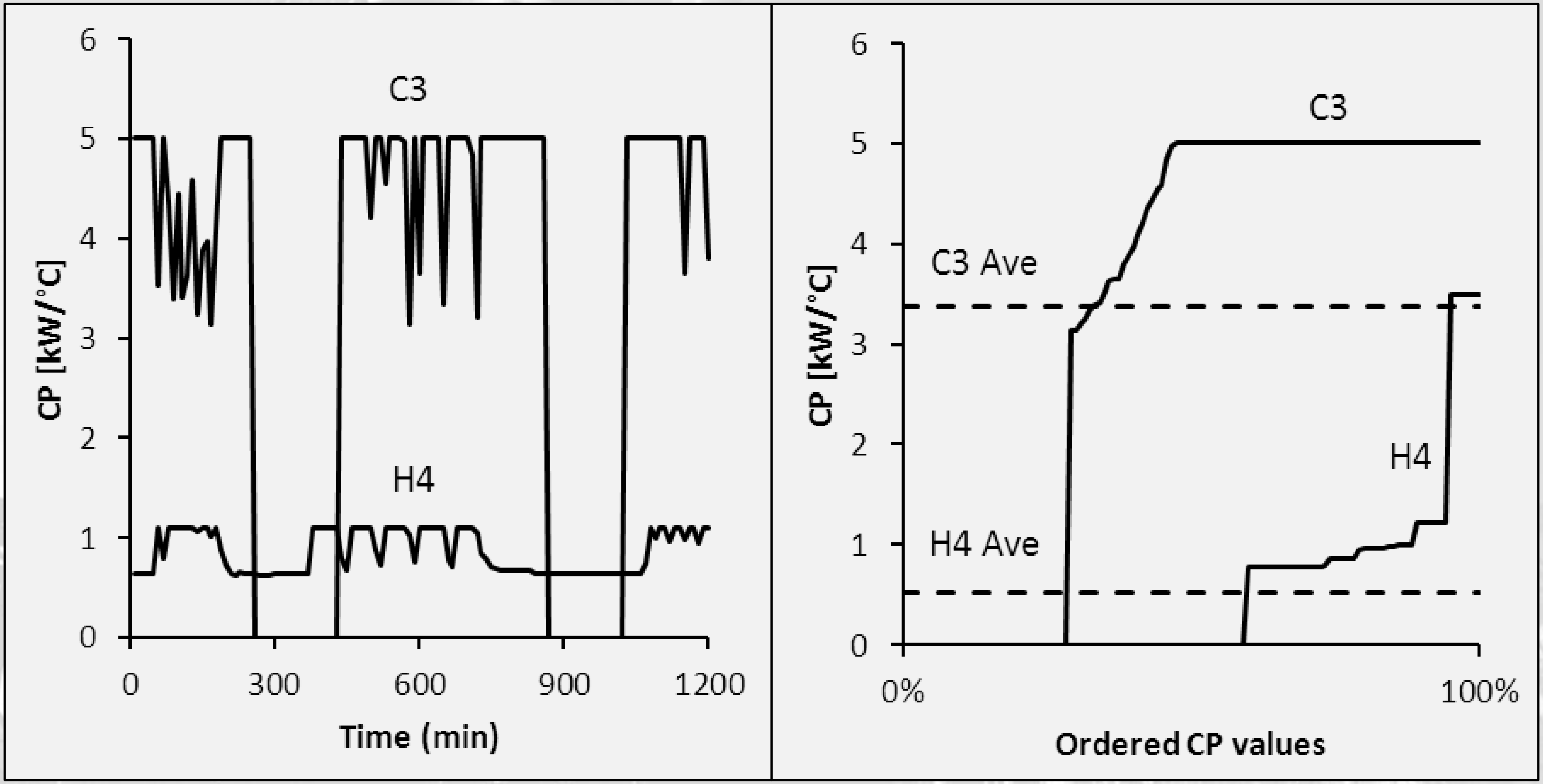


Integrate each plant (zone) & identify heat sources & heat sinks



Extract stream data

Average versus Peak Design Heat Flows

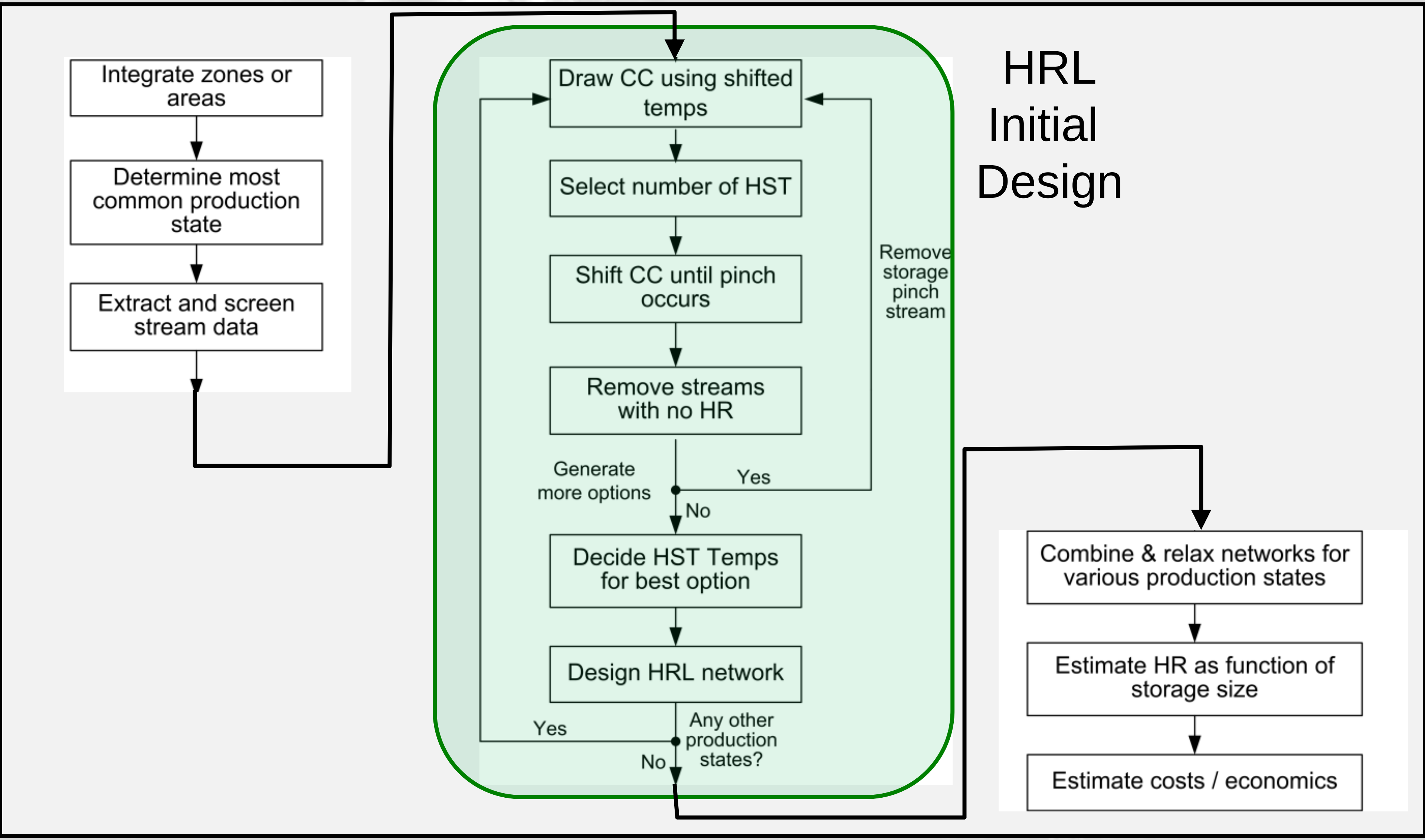


Extract Stream & Screen Data

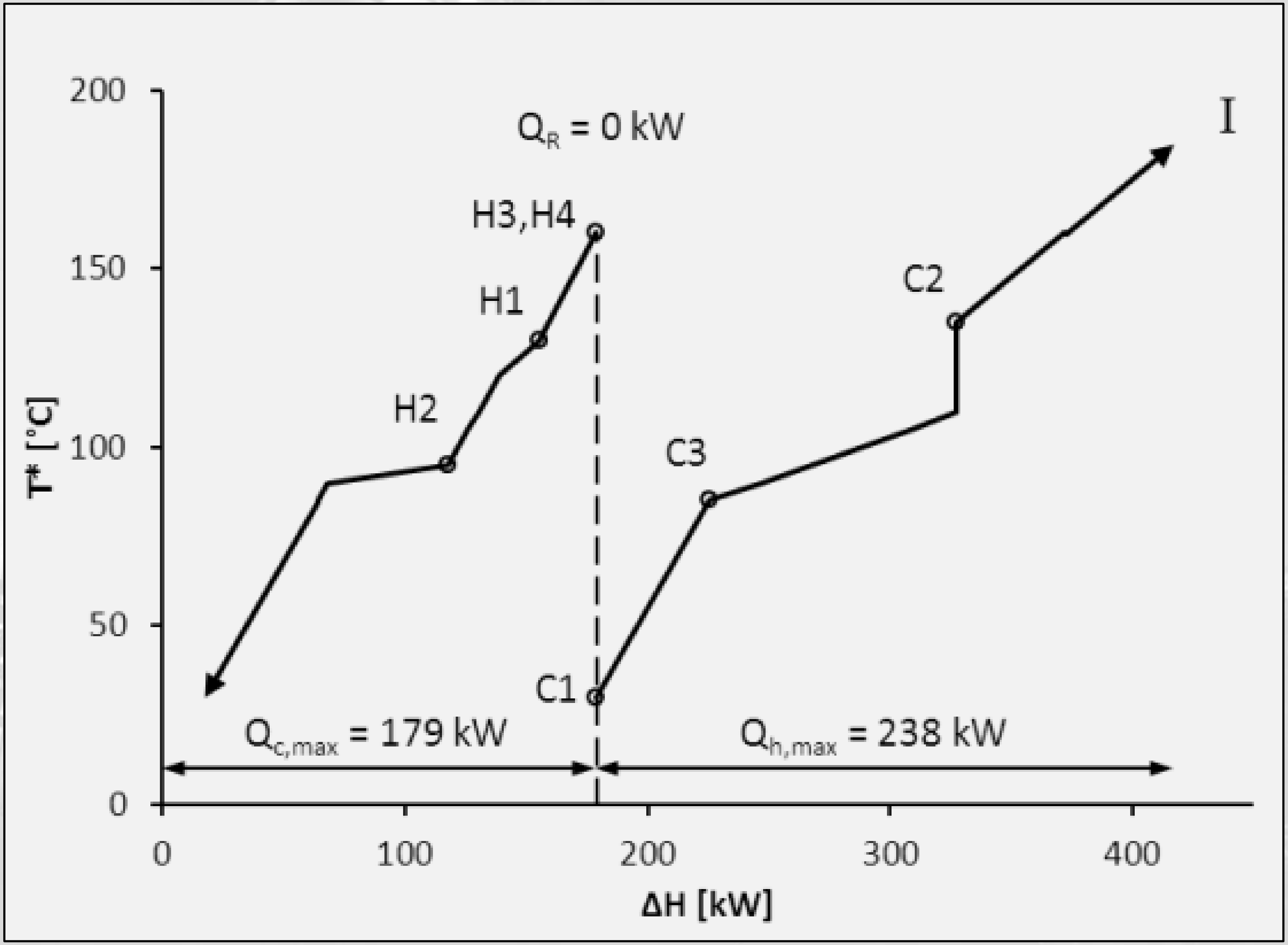
Stream	T_S [°C]	T_T [°C]	Time Average CP [kW/°C]	Design CP [kW/°C]	Time Average ΔH [kW]	Production State
C1	25	100	0.850	1.0	63.75	A,
C2	130	180	1.800	3.0	90.00	A, B
C3	80	105	3.375	5.0	84.38	A
H1	135	15	0.853	1.1	102.36	A
H2	100	95	9.000	20.0	45.00	A, B
H3	165	125	0.263	3.5	10.52	A, B
H4	165	125	0.525	3.5	21.00	A, B

A = 60% time, B = 40% time

HRL Design Methodology



Inter-plant process Composite Curves



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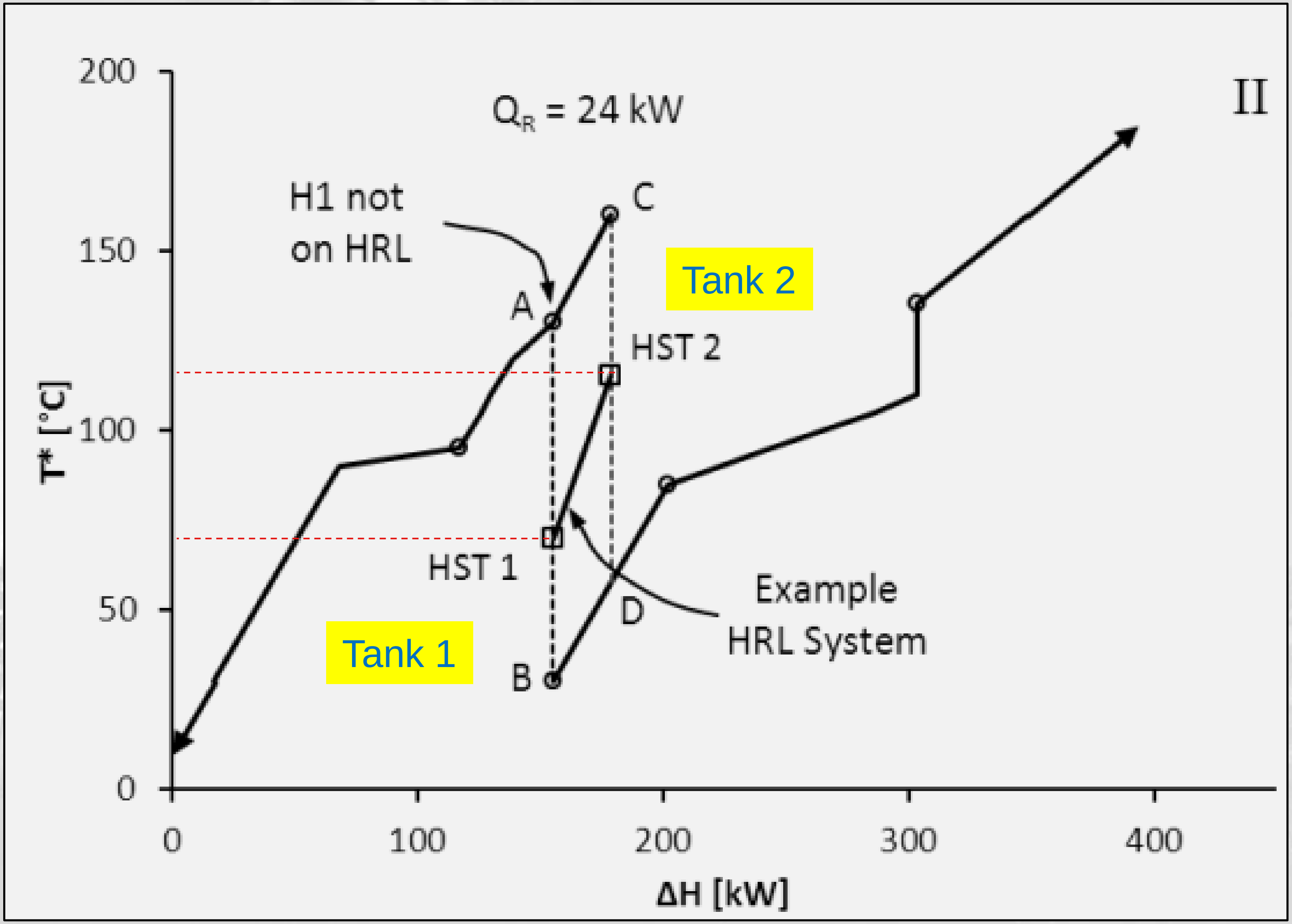
Two Tank Case – Selecting Storage Temp



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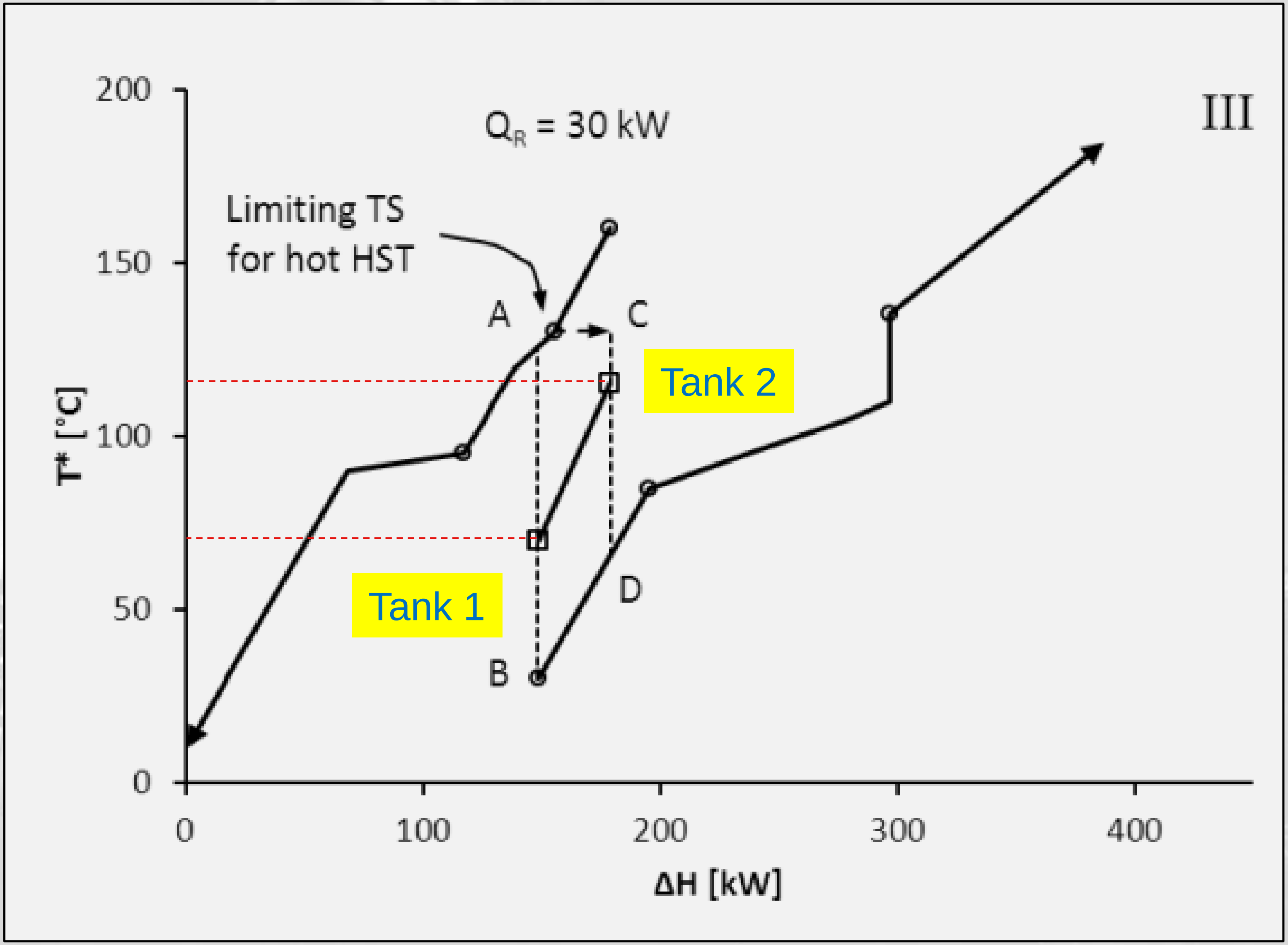

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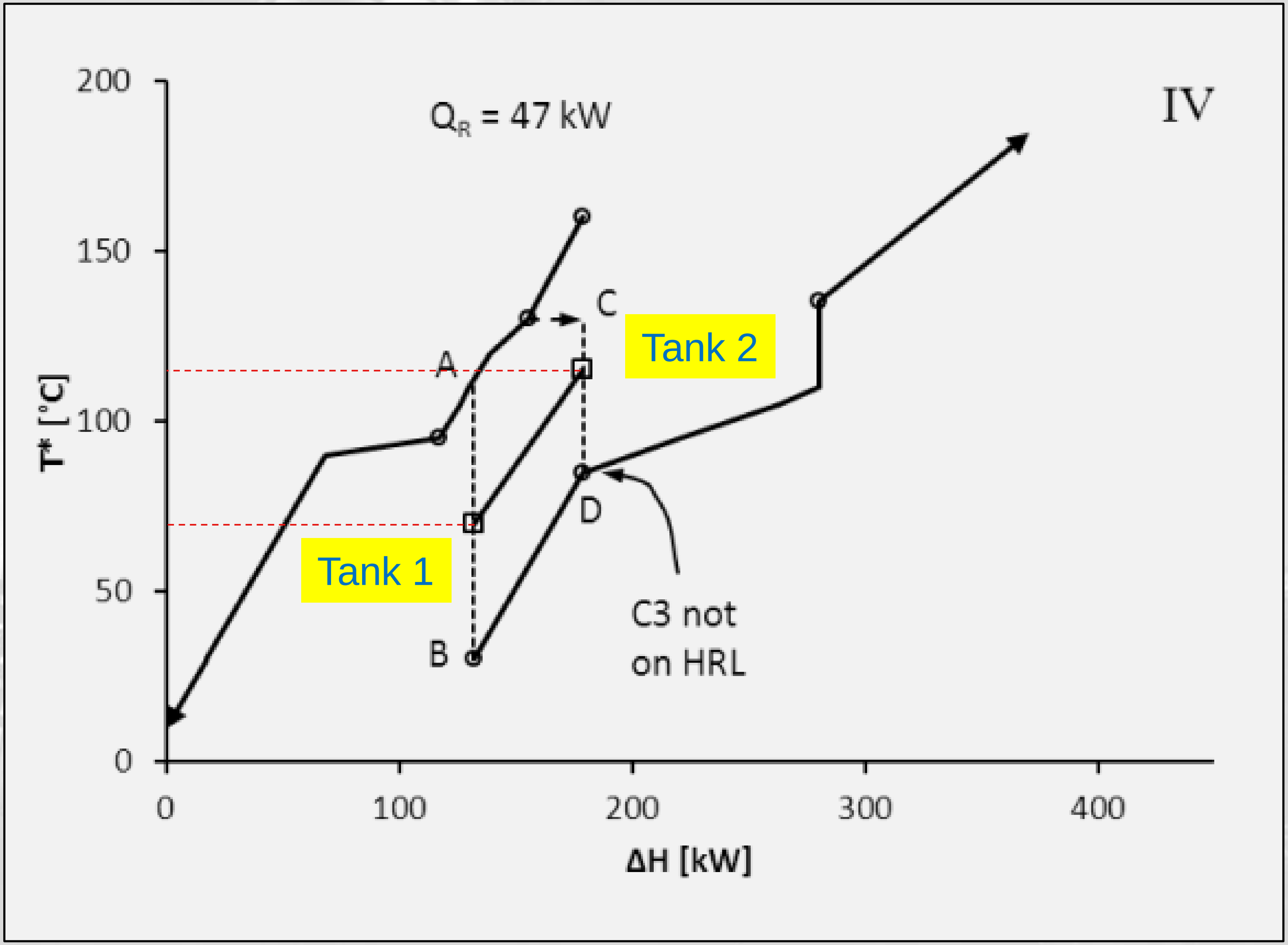

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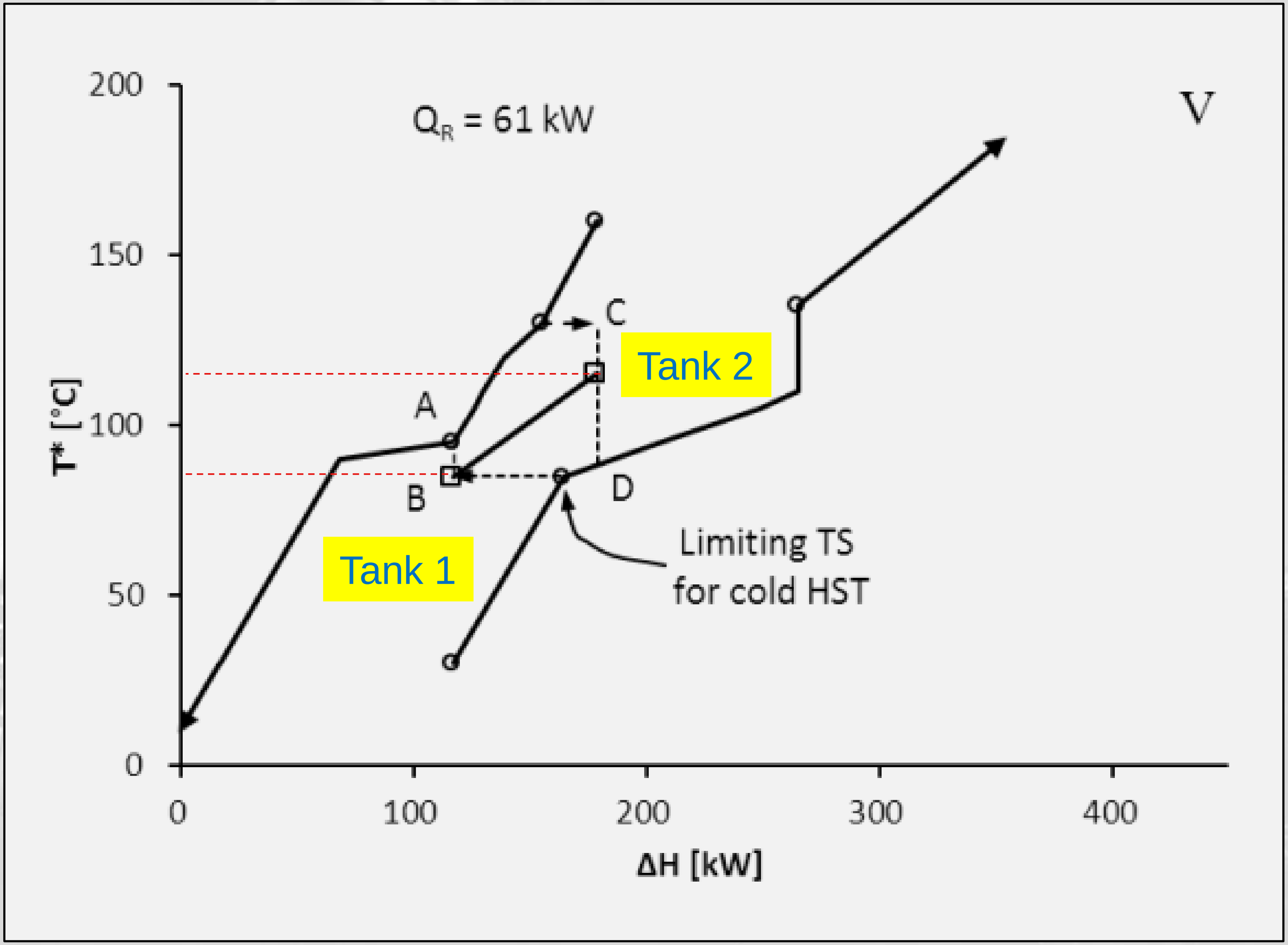
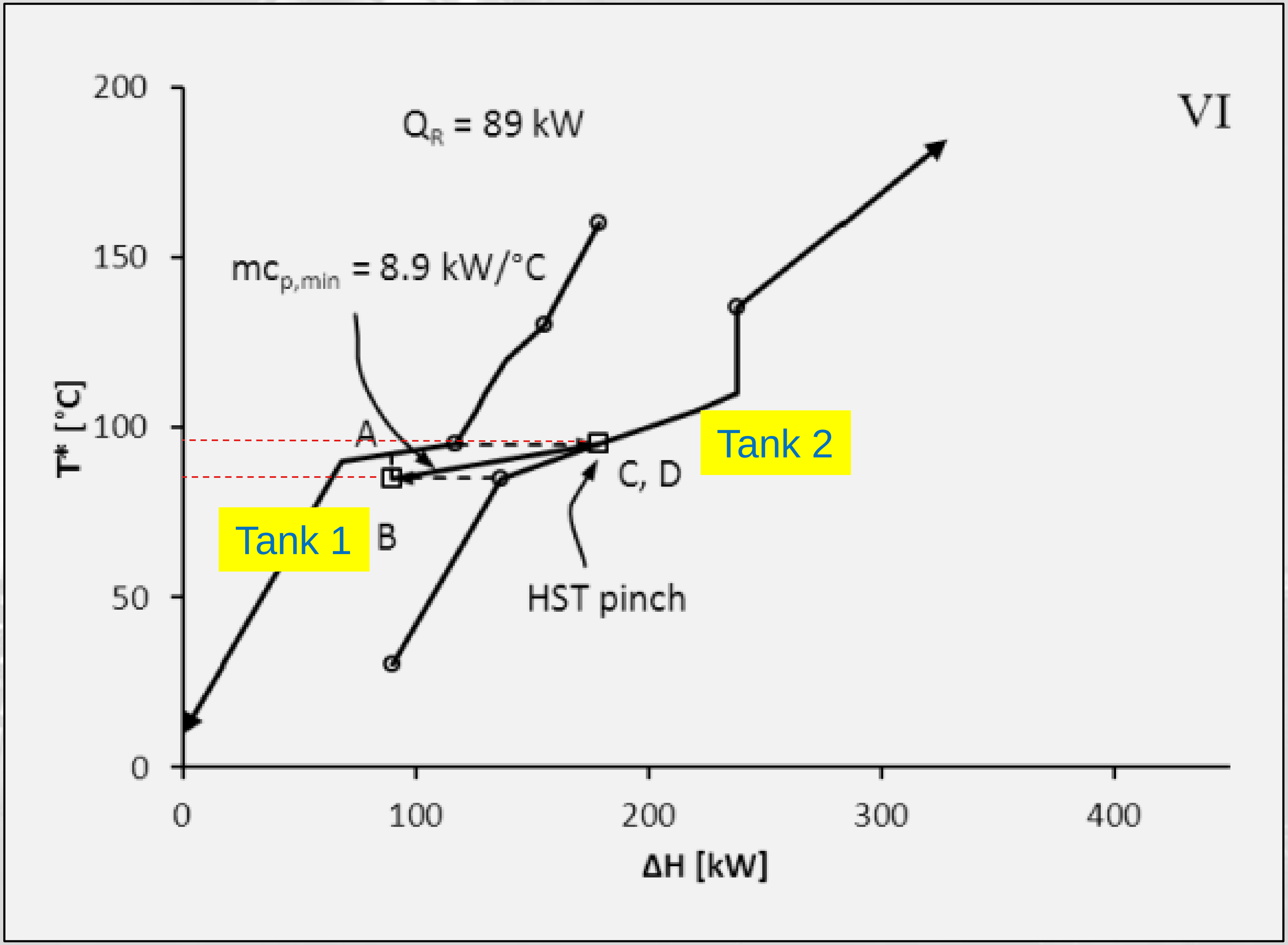
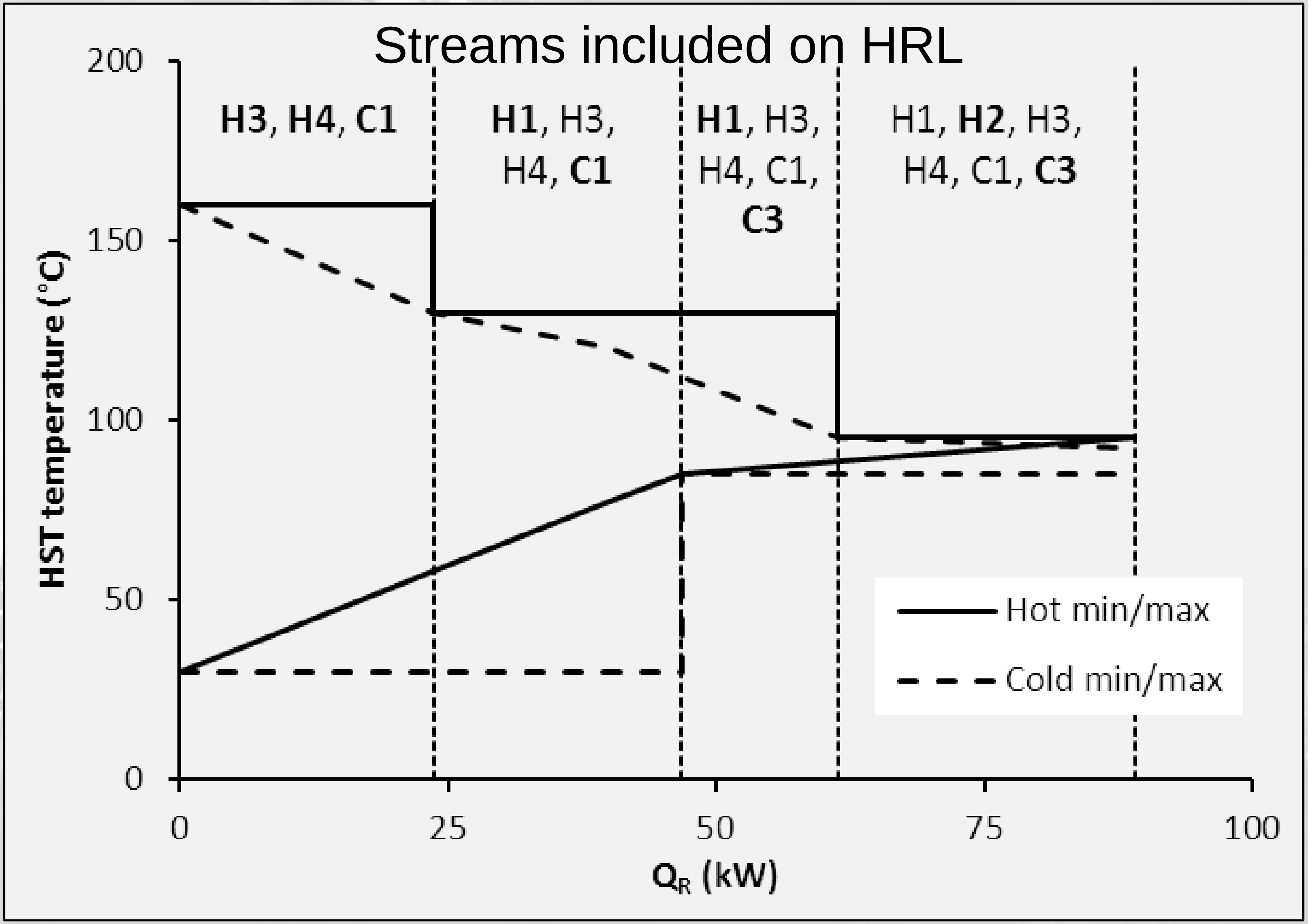


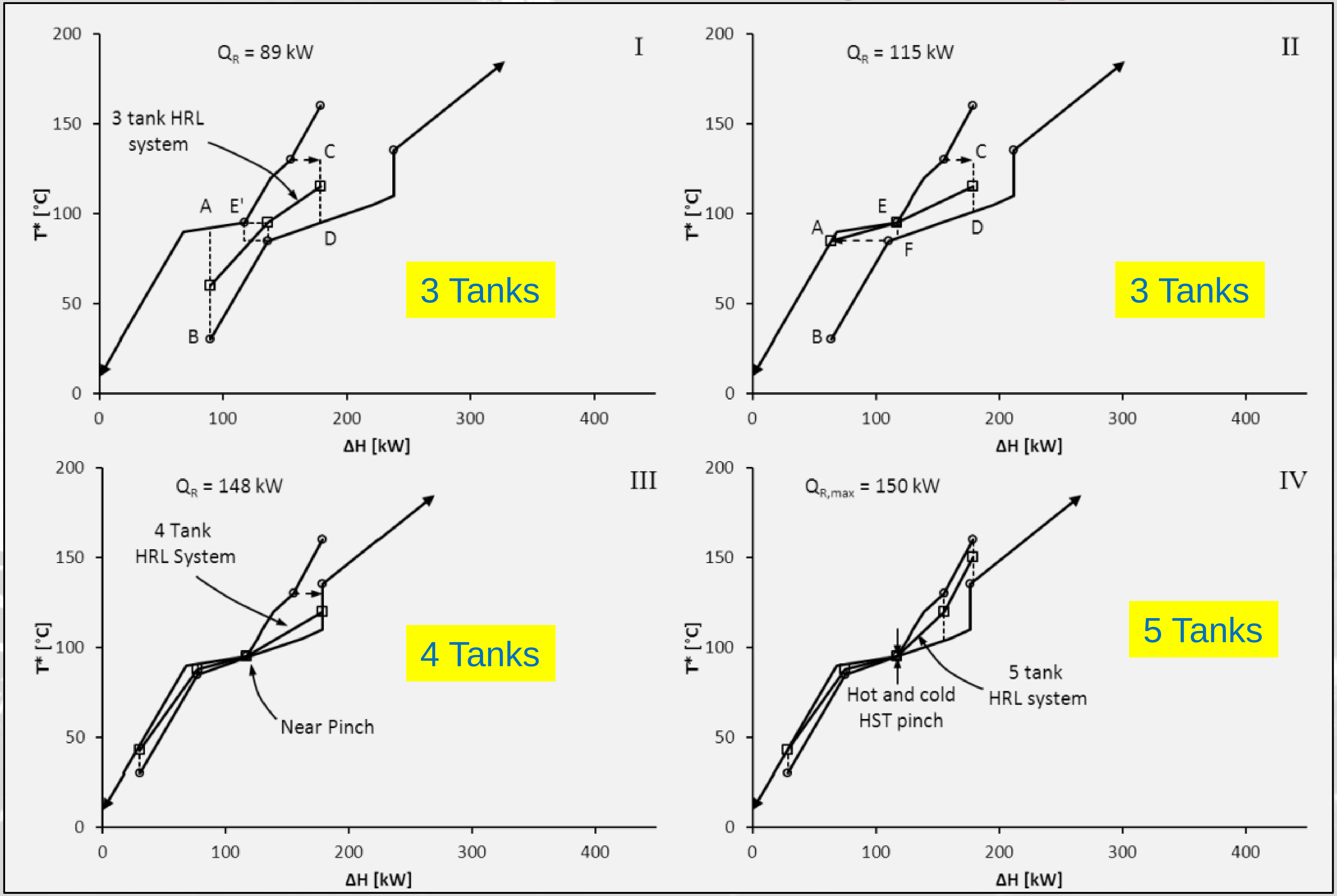
Two Tank Case – Selecting Storage Temp



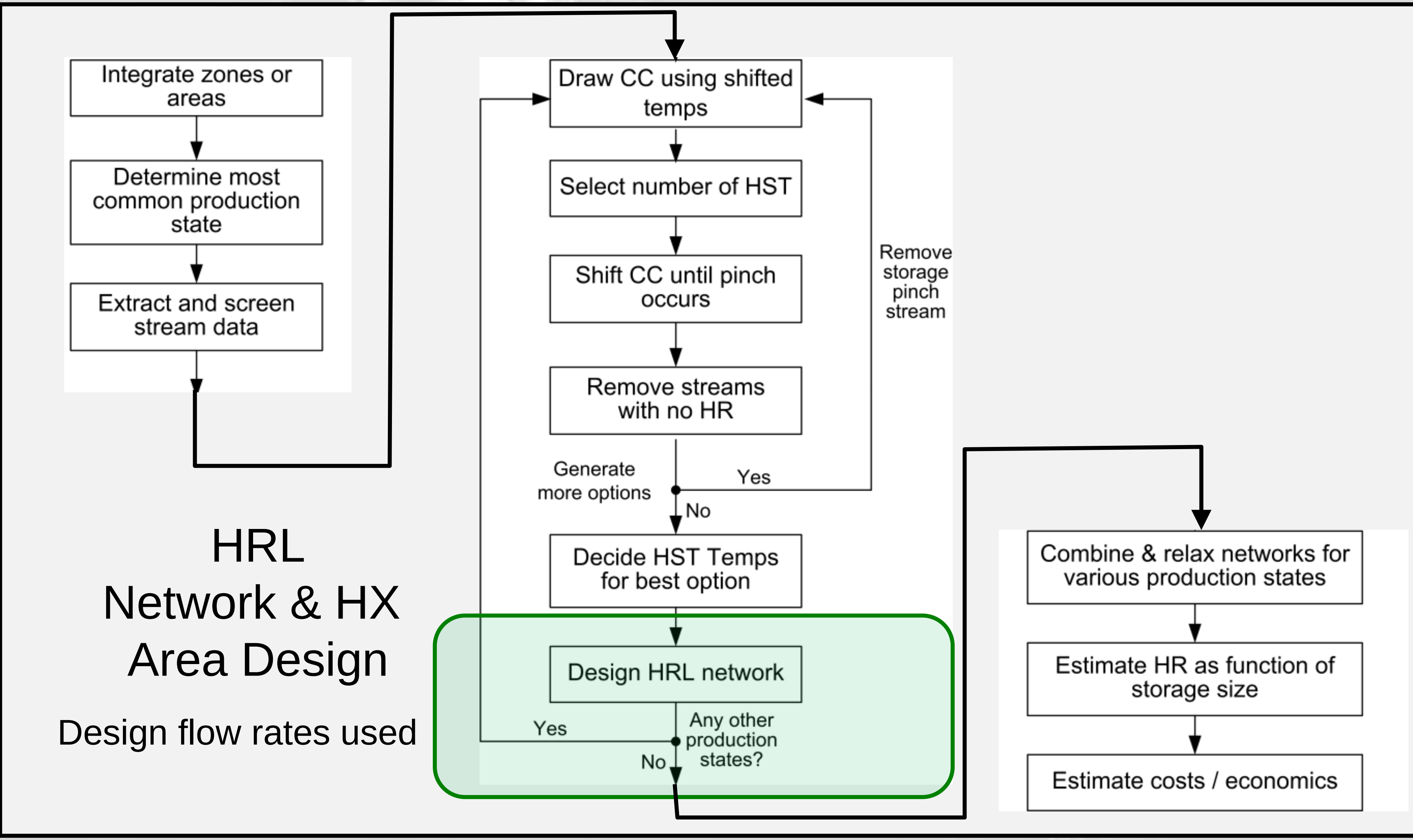
Selection of Streams & Storage Temp.



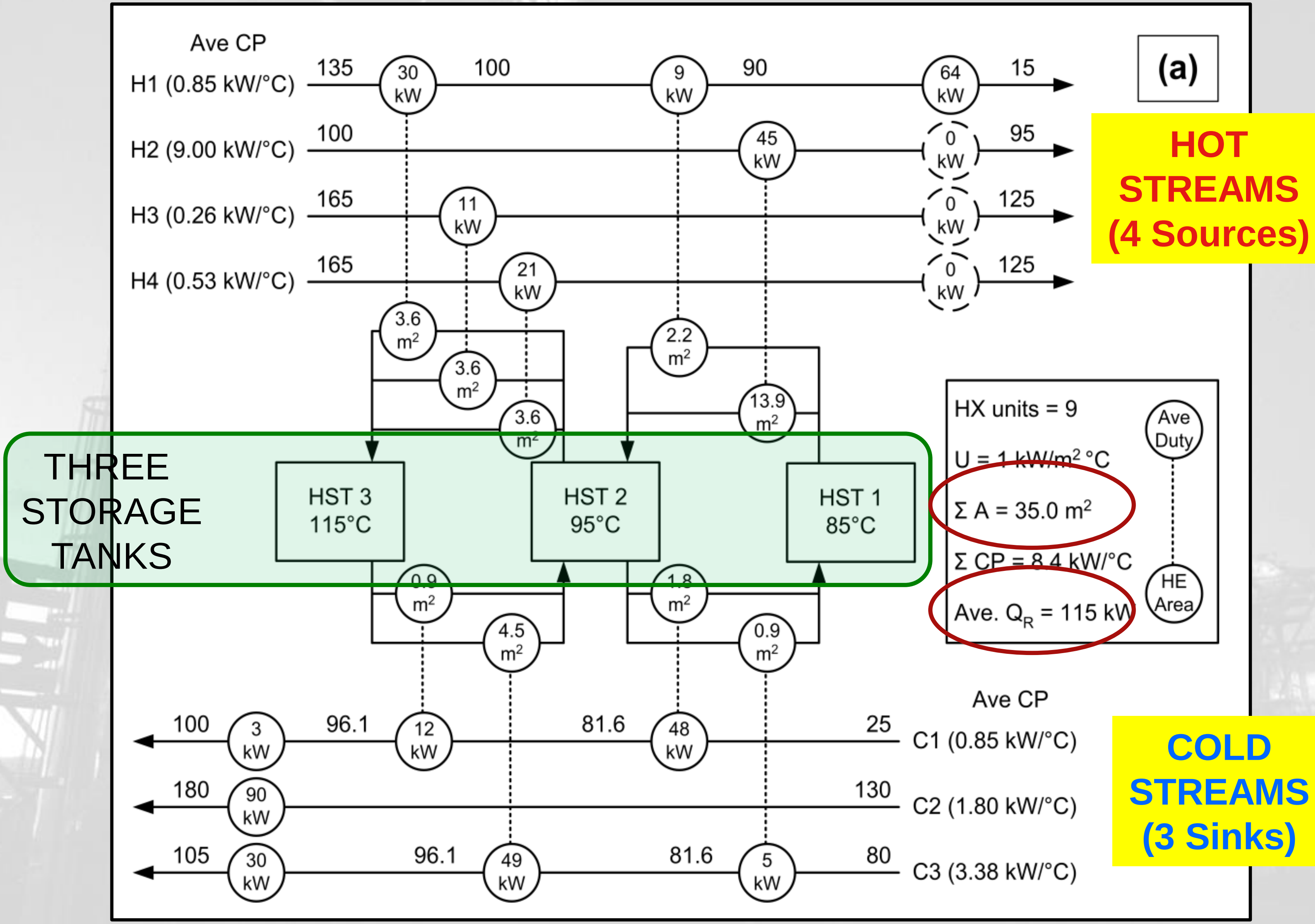
Multi Tank Cases – Selecting Storage Temp



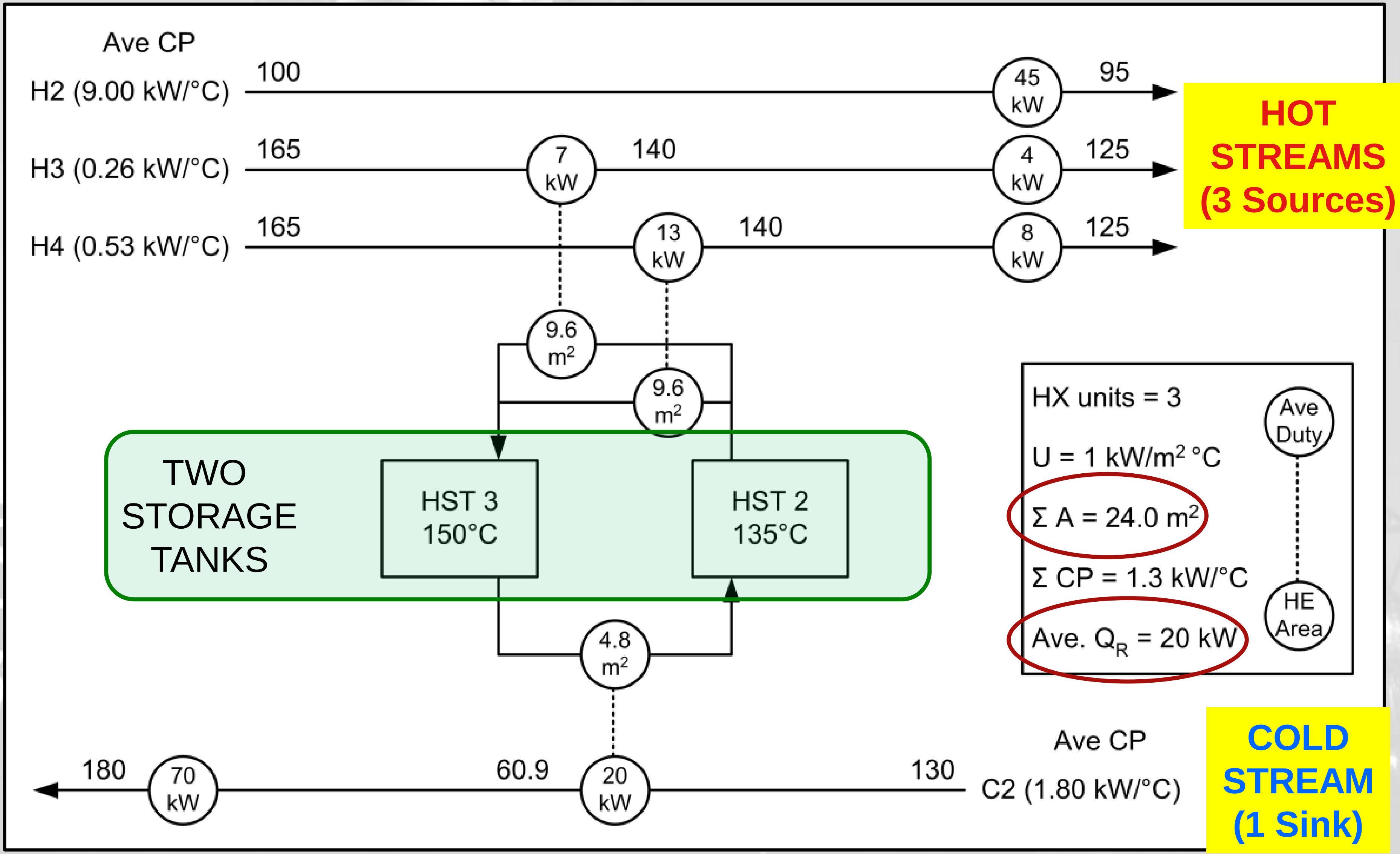
HRL Design Methodology



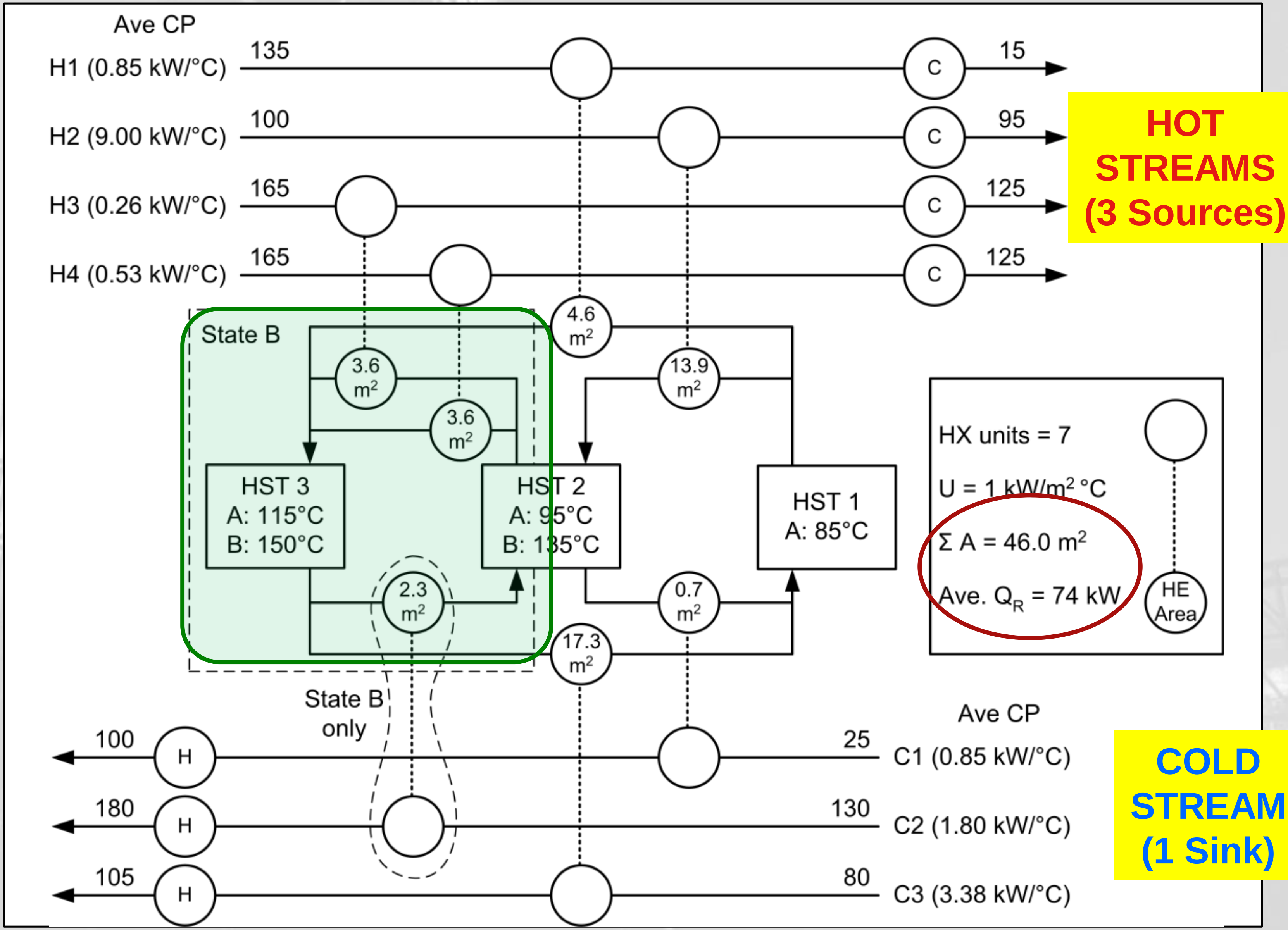
HRL Heat Exchange Network – State A



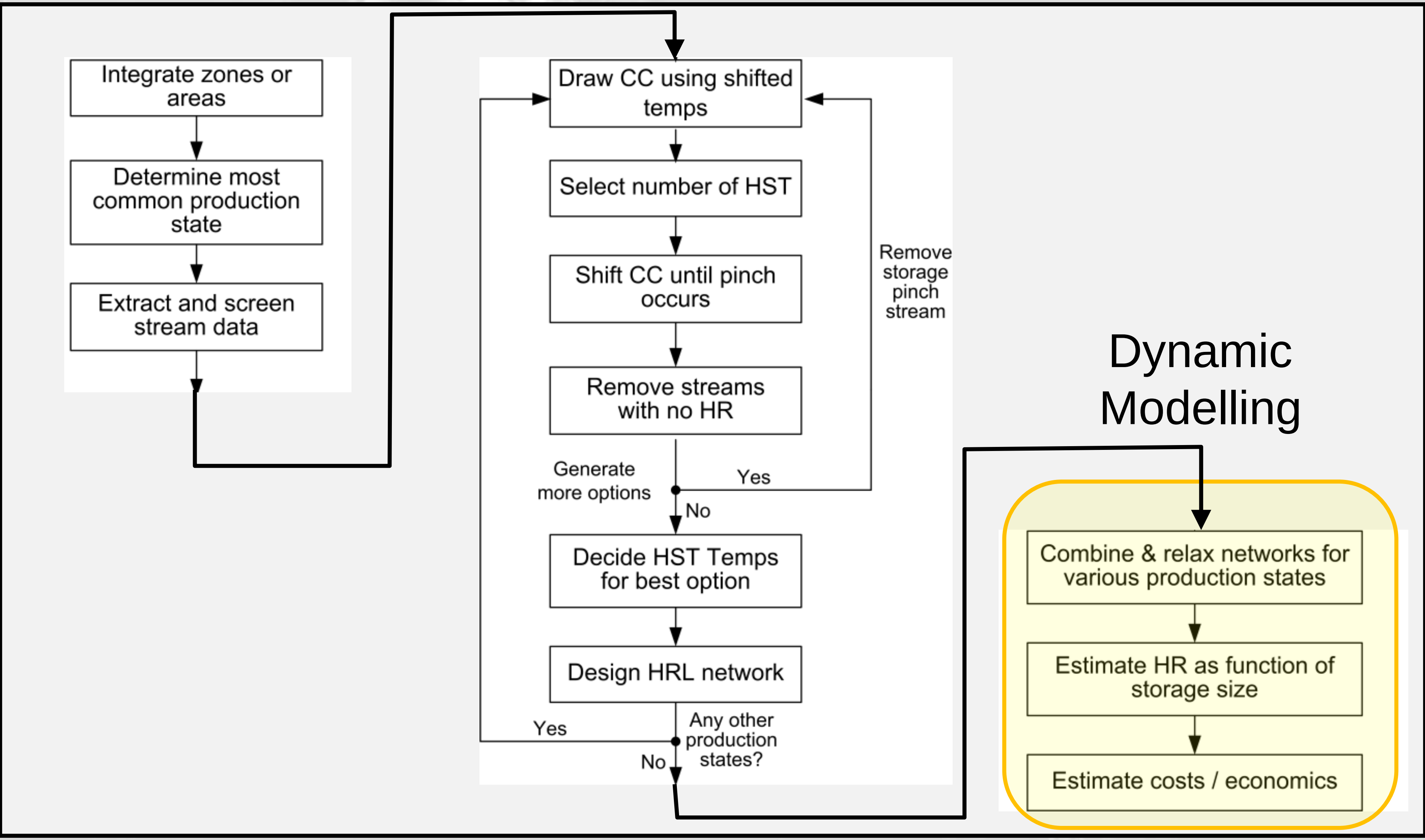
HRL Heat Exchange Network – State B



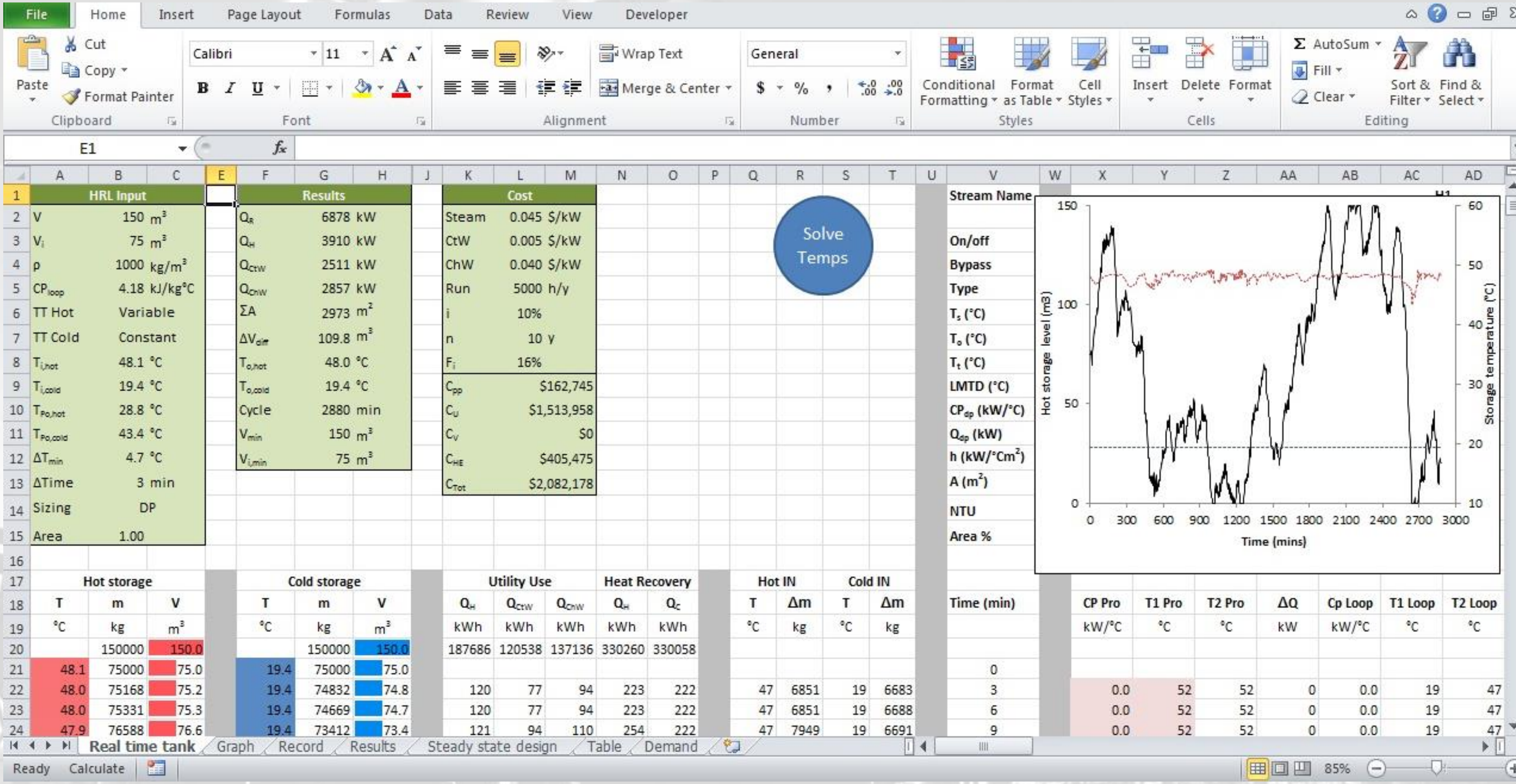
HRL Heat Exchange Network – State A + B



HRL Design Methodology



Spreadsheet Optimisation Tool



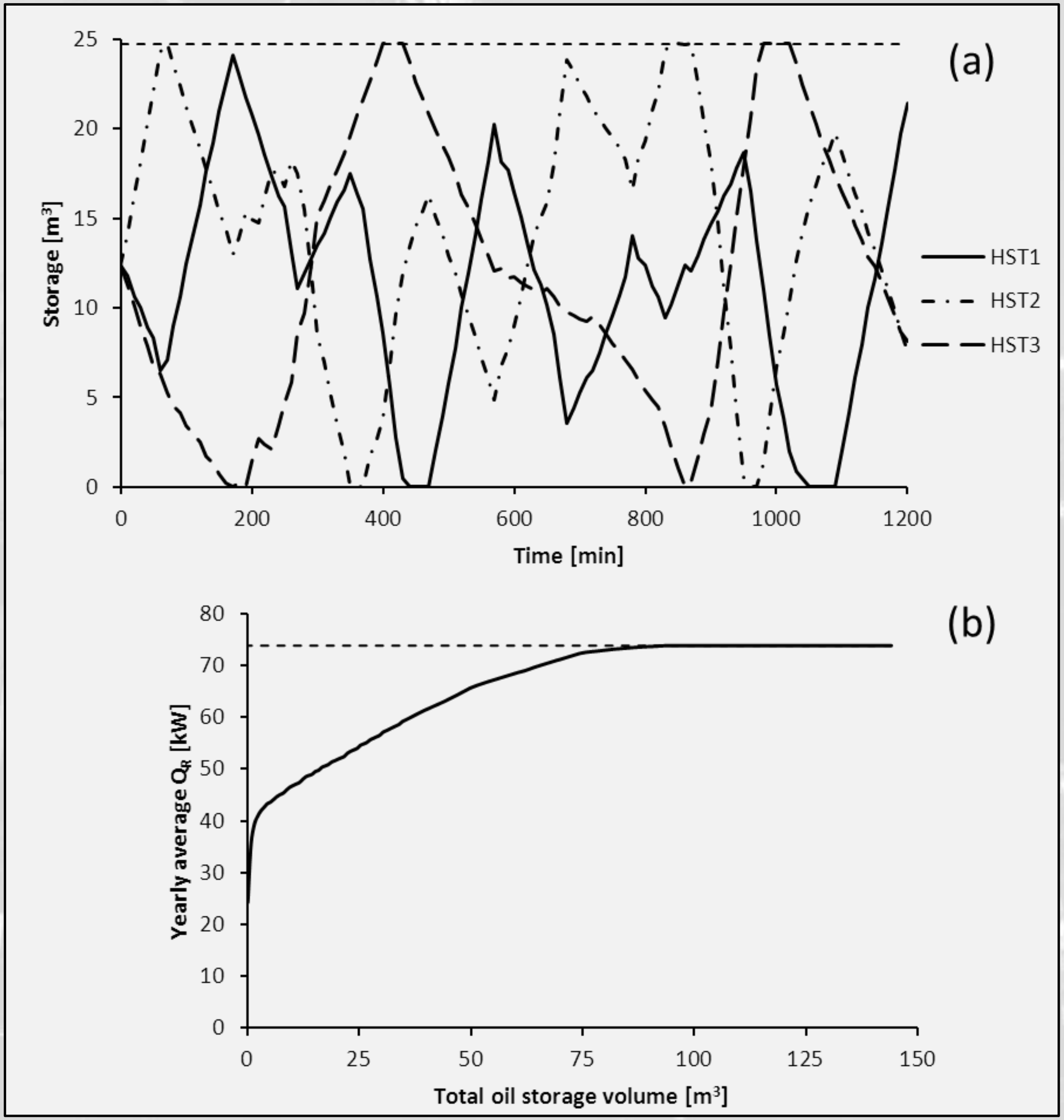
HRL Input			Results			Cost		
V	150	m^3	Q_R	6878	kW	Steam	0.045	$/kW
V_i	75	m^3	Q_H	3910	kW	CtW	0.005	$/kW
ρ	1000	kg/m^3	Q_{CtW}	2511	kW	ChW	0.040	$/kW
CP_{loop}	4.18	kJ/kg°C	Q_{ChW}	2857	kW	Run	5000	h/y
TT Hot	Variable		ΣA	2973	m^2	i	10%	
TT Cold	Constant		ΔV_{diff}	109.8	m^3	n	10	y
$T_{i,hot}$	48.1	°C	$T_{o,hot}$	48.0	°C	F_i	16%	
$T_{i,cold}$	19.4	°C	$T_{o,cold}$	19.4	°C	C_{pp}	$162,745	
$T_{Po,hot}$	28.8	°C	Cycle	2880	min	C_U	$1,513,958	
$T_{Po,cold}$	43.4	°C	V_{min}	150	m^3	C_V	$0	
ΔT_{min}	4.7	°C	$V_{i,min}$	75	m^3	C_{HE}	$405,475	
ΔTime	3	min				C_{Tot}	$2,082,178	
Sizing	DP							
Area	1.00							

Stream Name, On/off, Bypass, Type, T_s (°C), T_o (°C), T_t (°C), LMTD (°C), CP_{dp} (kW/°C), Q_{dp} (kW), h (kW/°Cm²), A (m²), NTU, Area %

Hot storage			Cold storage			Utility Use			Heat Recovery		Hot IN		Cold IN										
T	m	V	T	m	V	Q_H	Q_{CtW}	Q_{ChW}	Q_H	Q_C	T	Δm	T	Δm	Time (min)	CP Pro	T1 Pro	T2 Pro	ΔQ	Cp Loop	T1 Loop	T2 Loop
°C	kg	m^3	°C	kg	m^3	kWh	kWh	kWh	kWh	kWh	°C	kg	°C	kg		kW/°C	°C	°C	kW	kW/°C	°C	°C
	150000	150.0		150000	150.0	187686	120538	137136	330260	330058												
48.1	75000	75.0	19.4	75000	75.0										0							
48.0	75168	75.2	19.4	74832	74.8	120	77	94	223	222	47	6851	19	6683	3	0.0	52	52	0	0.0	19	47
48.0	75331	75.3	19.4	74669	74.7	120	77	94	223	222	47	6851	19	6688	6	0.0	52	52	0	0.0	19	47
47.9	76588	76.6	19.4	73412	73.4	121	94	110	254	222	47	7949	19	6691	9	0.0	52	52	0	0.0	19	47

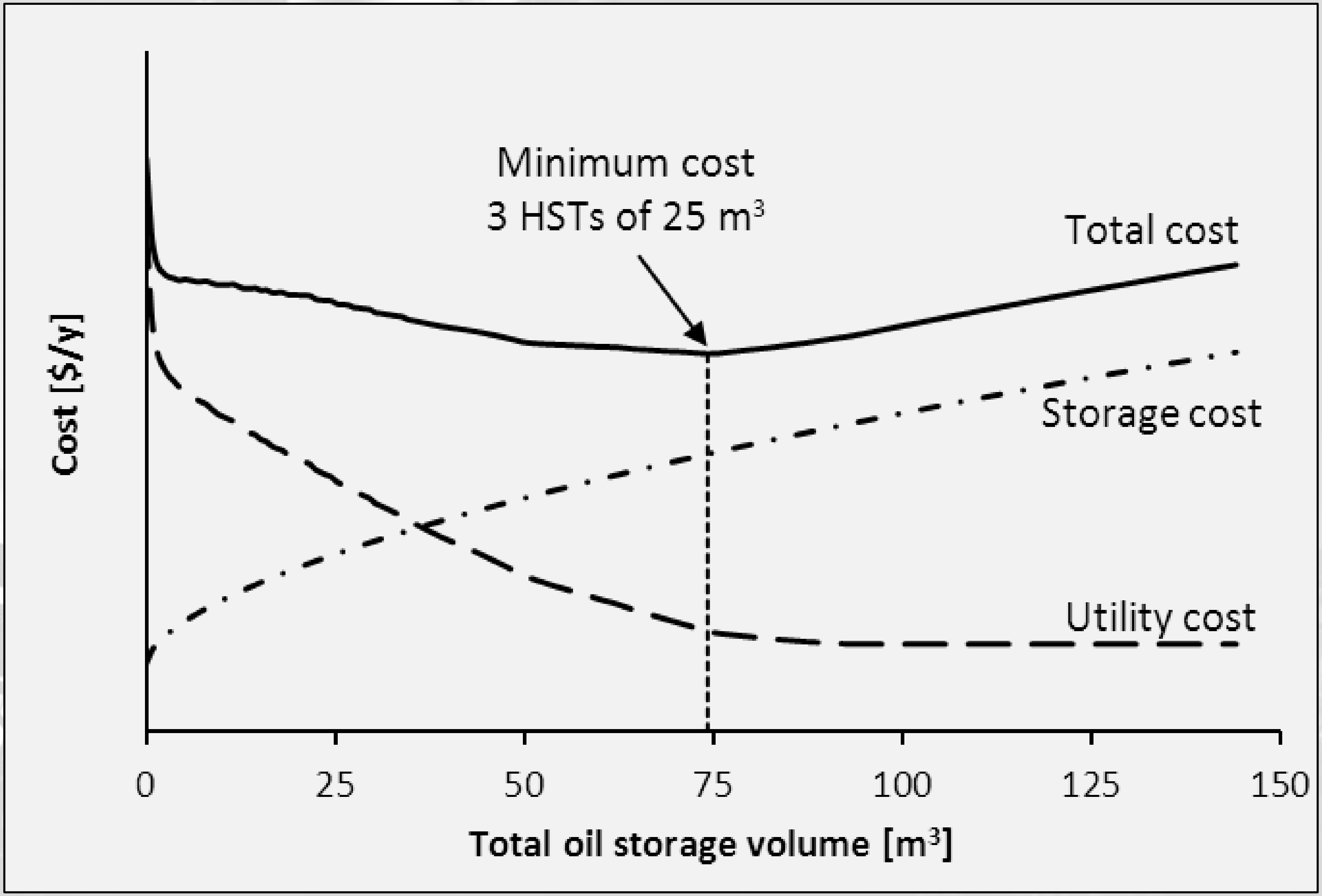
Real time tank | Graph | Record | Results | Steady state design | Table | Demand

Storage Levels & Annual Heat Recovery

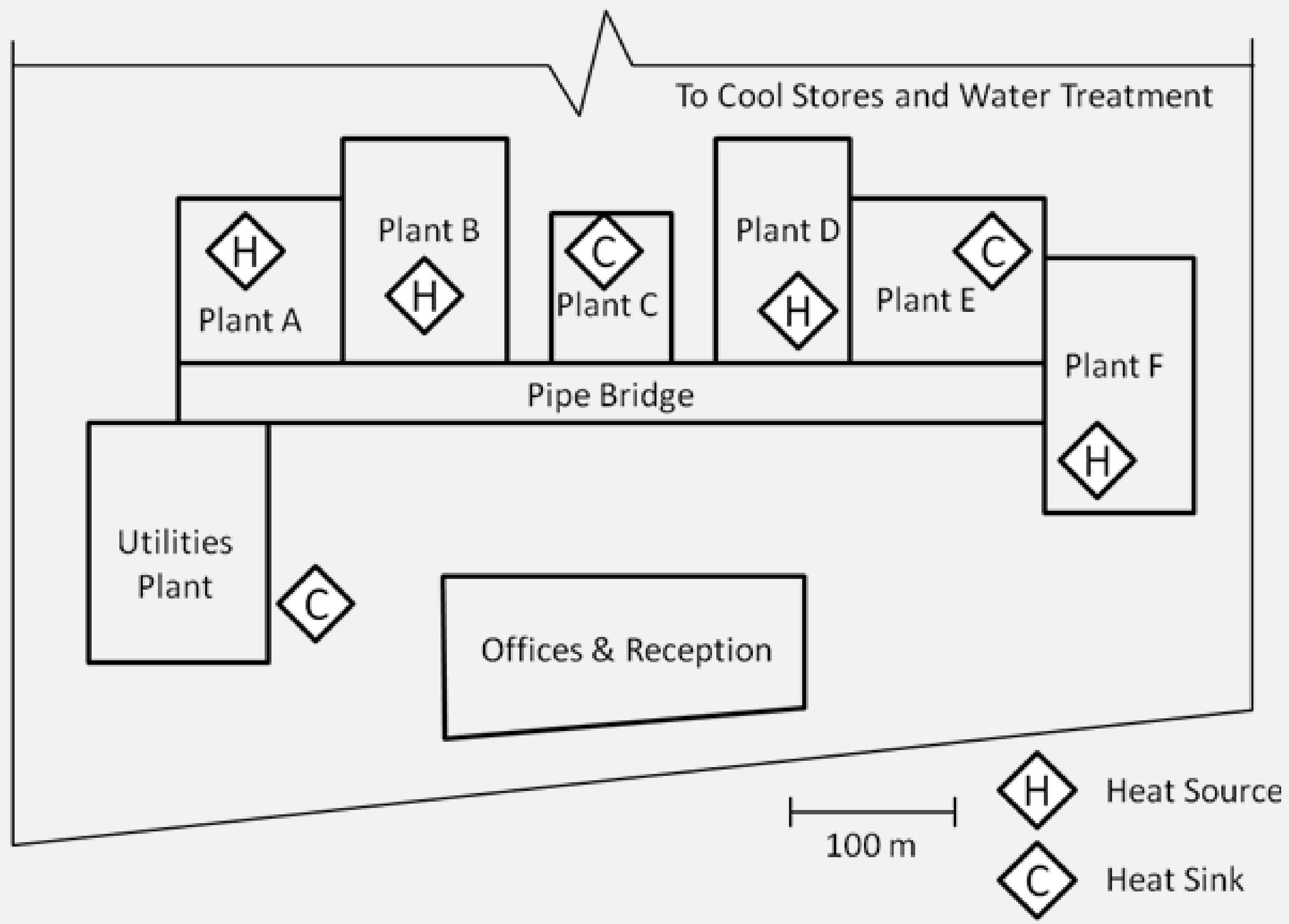


State A+B

Cost optimisation of storage tank size



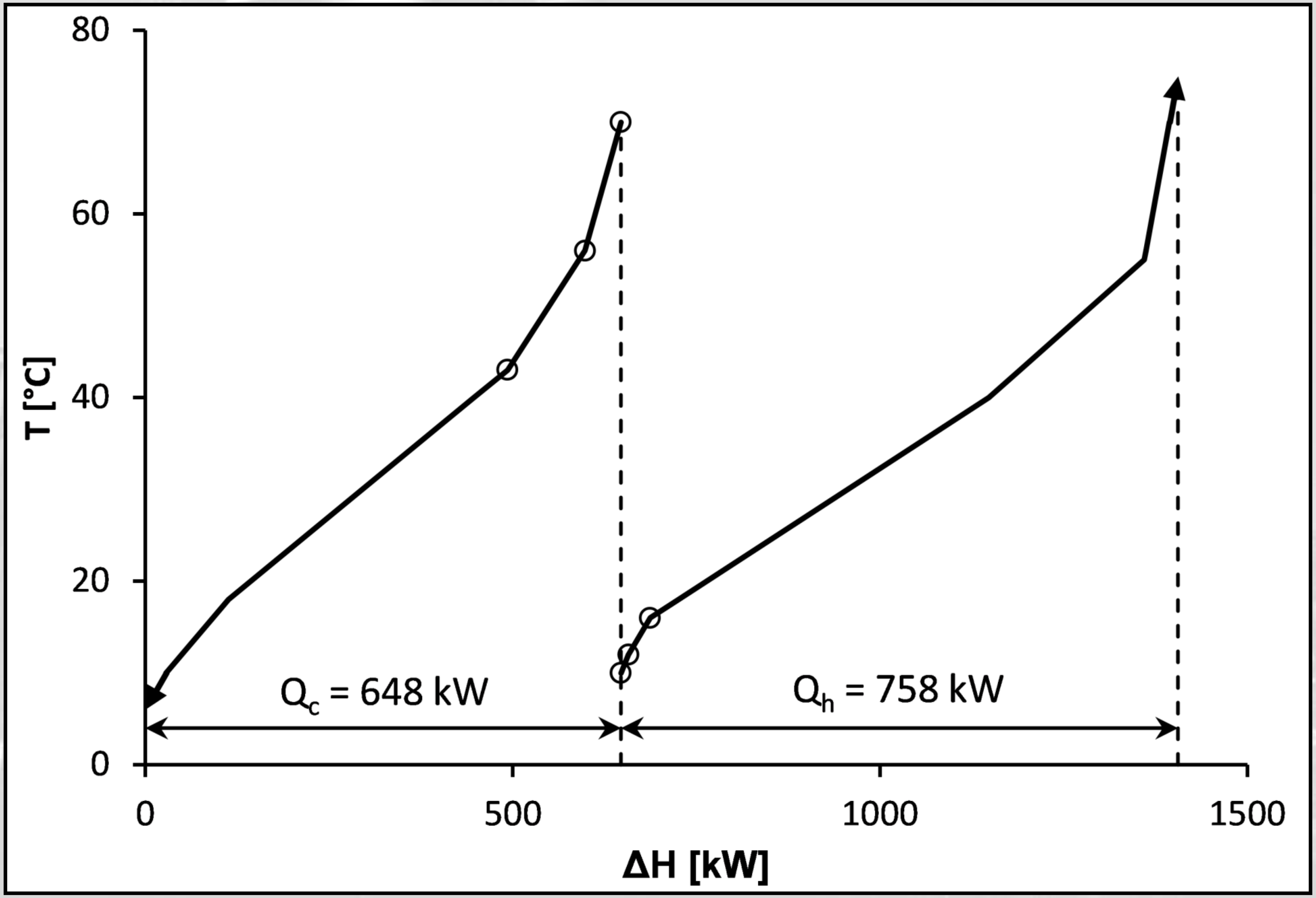
Case Study: Area Targeting of HRL



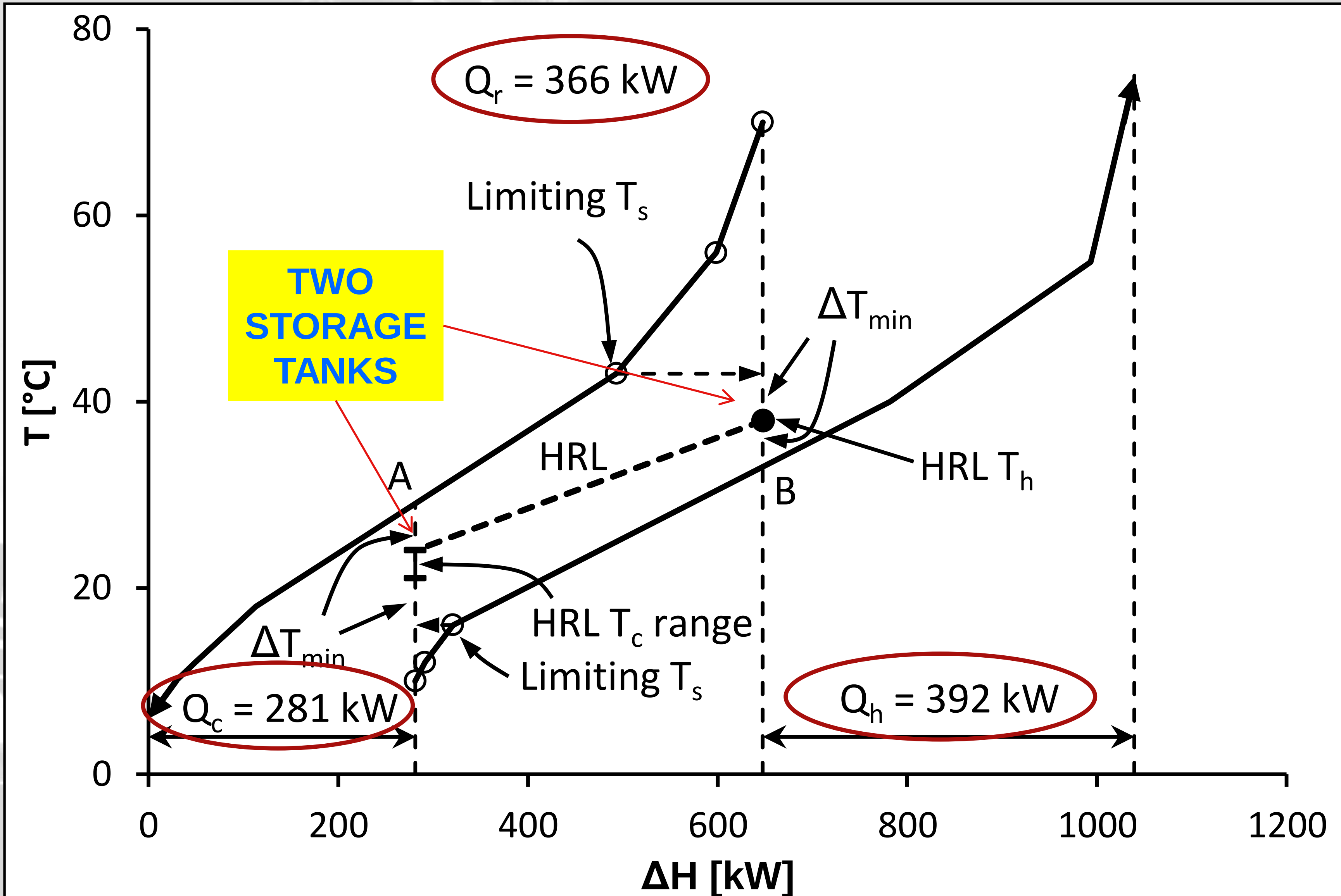
Extract Stream & Screen Data

Stream	T_s [°C]	T_t [°C]	CP [kW/°C]	Q [kW]
H1	43	6	7.1	263
H2	70	10	3.5	210
H3	56	18	4.6	175
C1	10	40	5.1	153
C2	12	75	2.3	145
C3	16	55	11.8	460

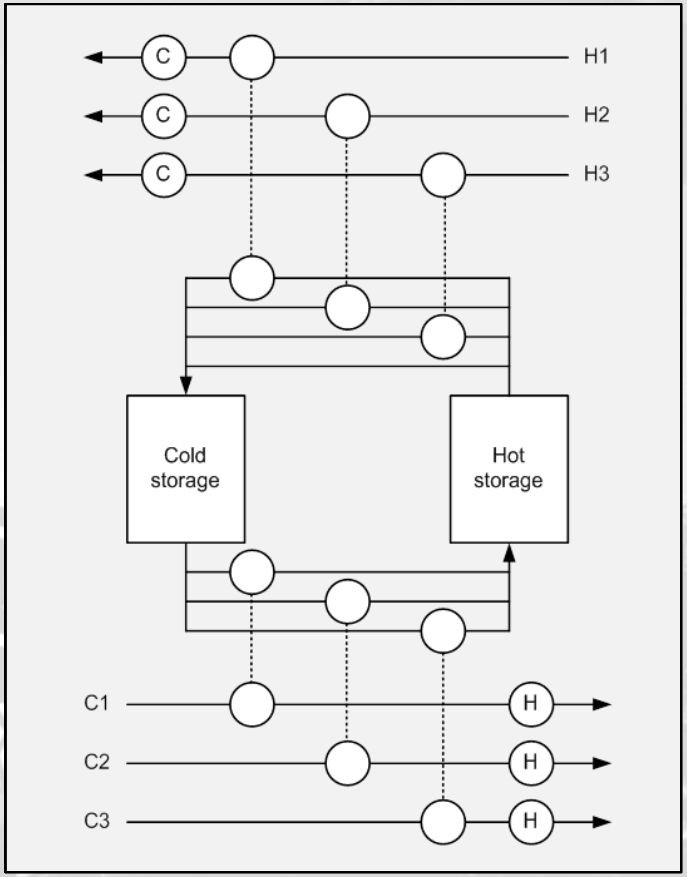
Inter-plant process Composite Curves

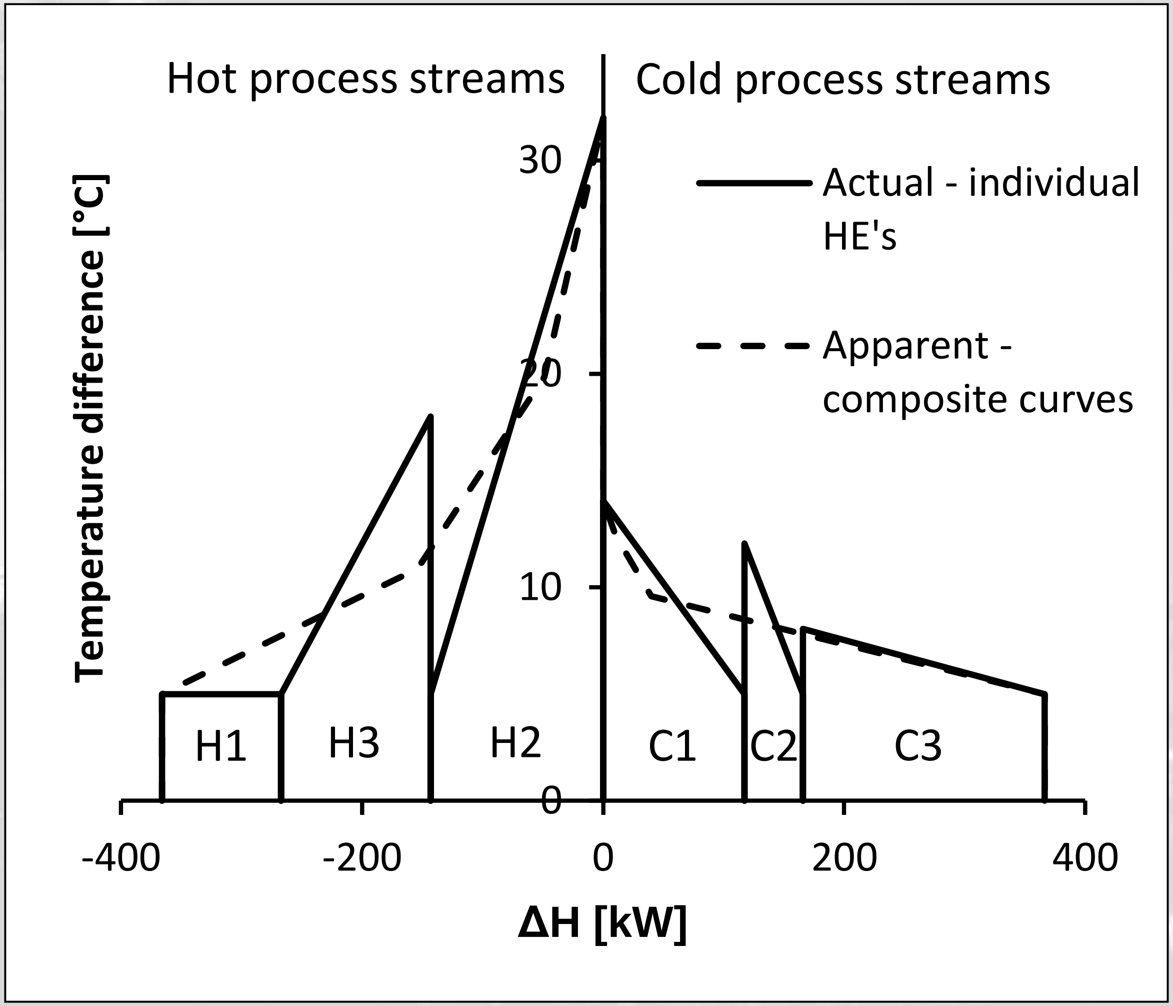


Maximum heat recovery using HRL



Apparent versus actual HX driving force

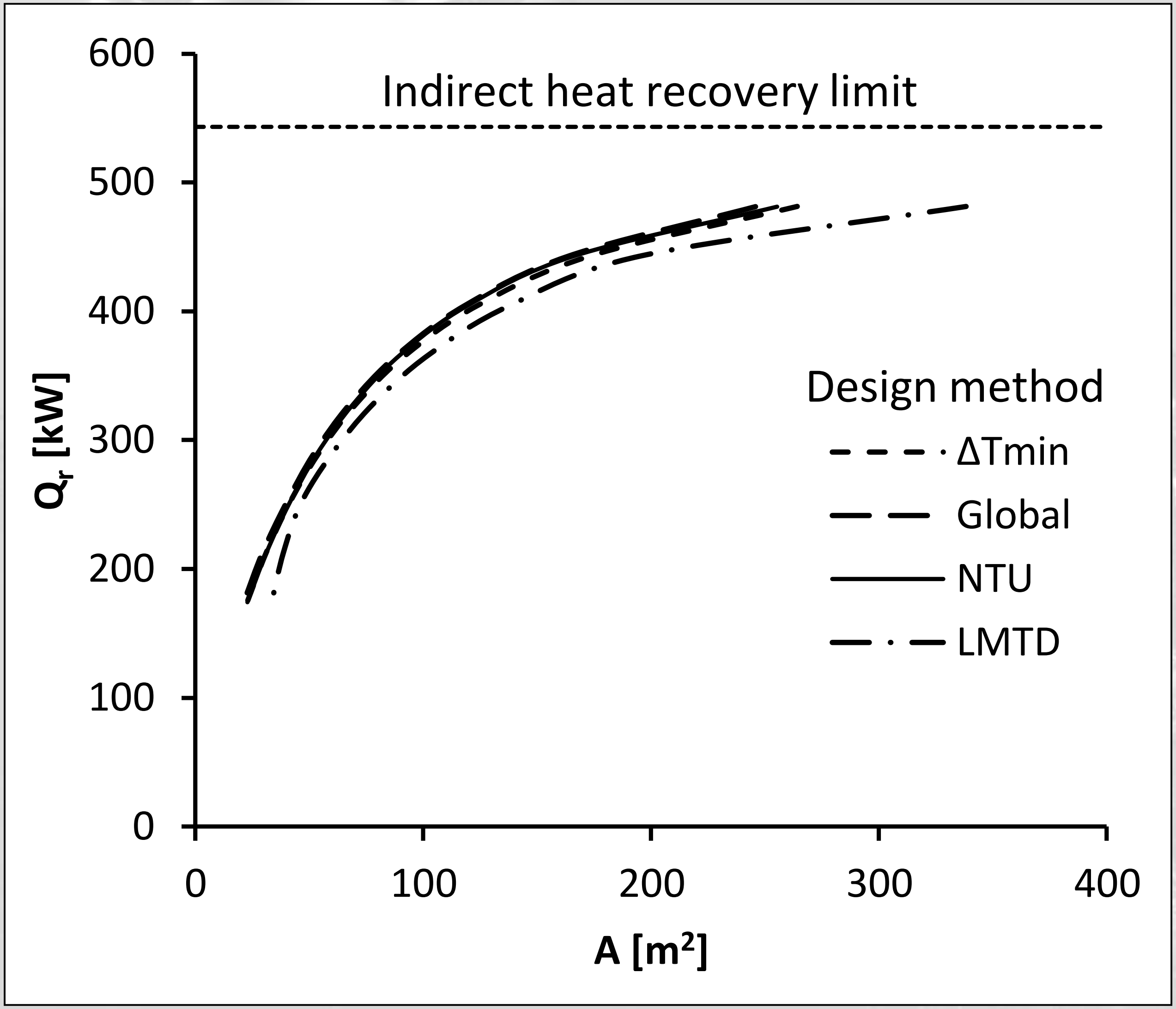




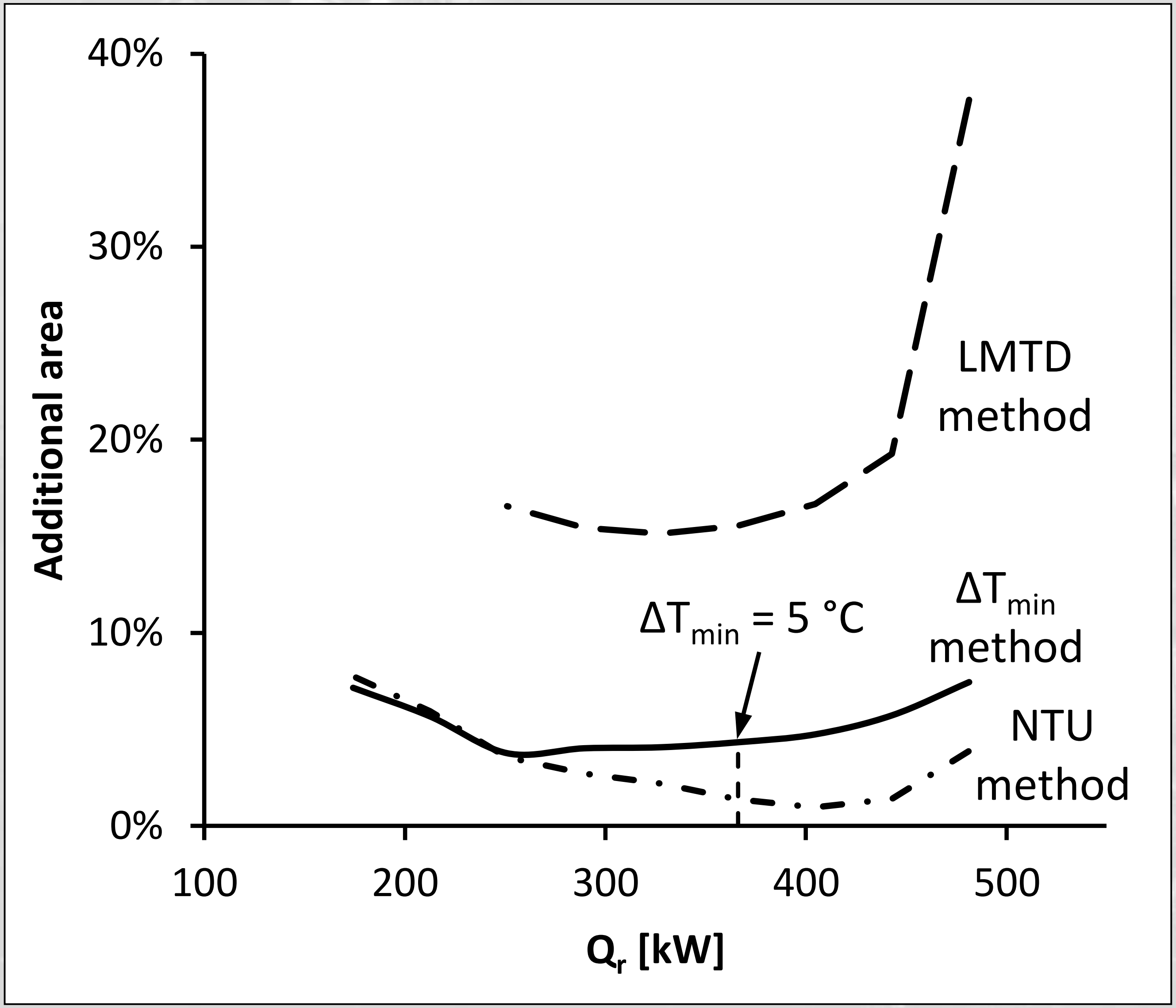
Area Targeting Methods

- dT_{min} method
  - Provides insight to the design
  - Defines the storage temperature levels and loop flow rate
  - Areas and HR result from dT_{min} choice (1 DoF)
- Global area optimisation for average state
  - 6 heat exchanger areas and 2 storage temperatures
  - 8 DoF
- Global area optimisation with constant NTU or LMTD
  - 1 NTU or LMTD and 2 storage temperatures
  - 3 DoF

HR versus Total Area



HX Area Design Method



Conclusions

- Stream and storage temperature selection is important
- Need to Optimise Heat Recovery / Area Trade-off to Maximise Savings
- dT_{min} method is effective and simple to apply
- Global optimisation of areas and temp selection can improve HR savings (same area) by 5%
- Dynamic modelling provides effective means for sizing storage capacity and predicting actual HR

Thank You

Questions?