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#SESAAU2019

ENERGY OPTIMISATION

PINCH ANALYSIS AND HEAT EXCHANGER NETWORK RETROFIT OF AN OIL REFINERY

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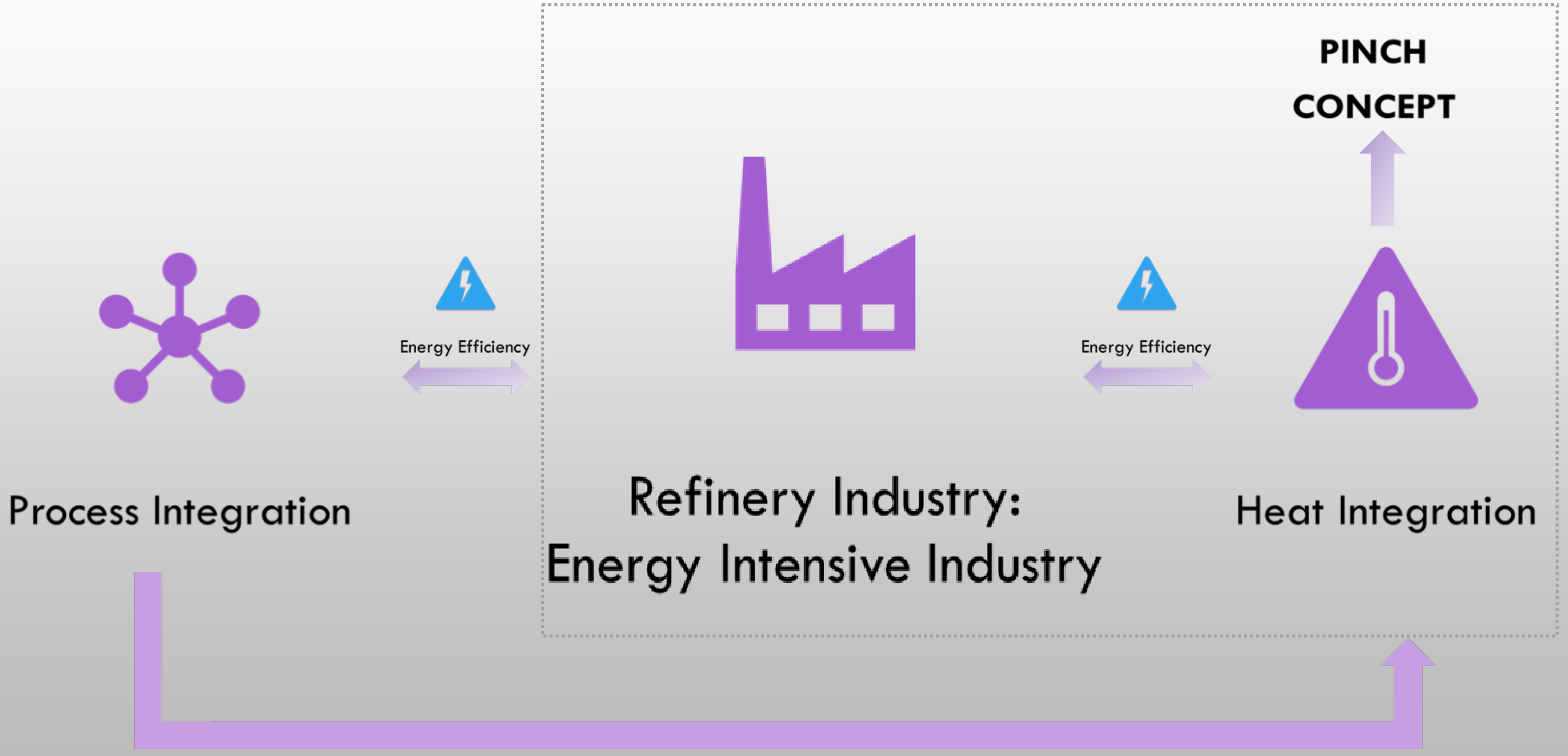
Agenda

- **Introduction**
- Data extraction
- Pinch analysis
- Heat exchanger network retrofit
- Feasibility of retrofits
- Uncertainty analysis
- Conclusion

Motivation

Climate Change ⟺ Energy Efficiency ⟺ Economic Incentives

Background



PINCH
CONCEPT
Energy Efficiency
Energy Efficiency
Process Integration
Refinery Industry:
Energy Intensive Industry
Heat Integration

Aim

Optimise Thermal Energy Consumption at Equinor Refining Denmark A/S

- Pinch Analysis
- Heat Exchanger Retrofit

Research Questions

- Energy targets ?
- Network performance ?
- Retrofits ?
- Feasibility of retrofits ?
- Robustness?

Scope

Pinch Study - Block 1 of the Refinery (May 2017)

Crude Preheating & Distillation

Thermal cracker & Visbreaker

Vacuum Distillation

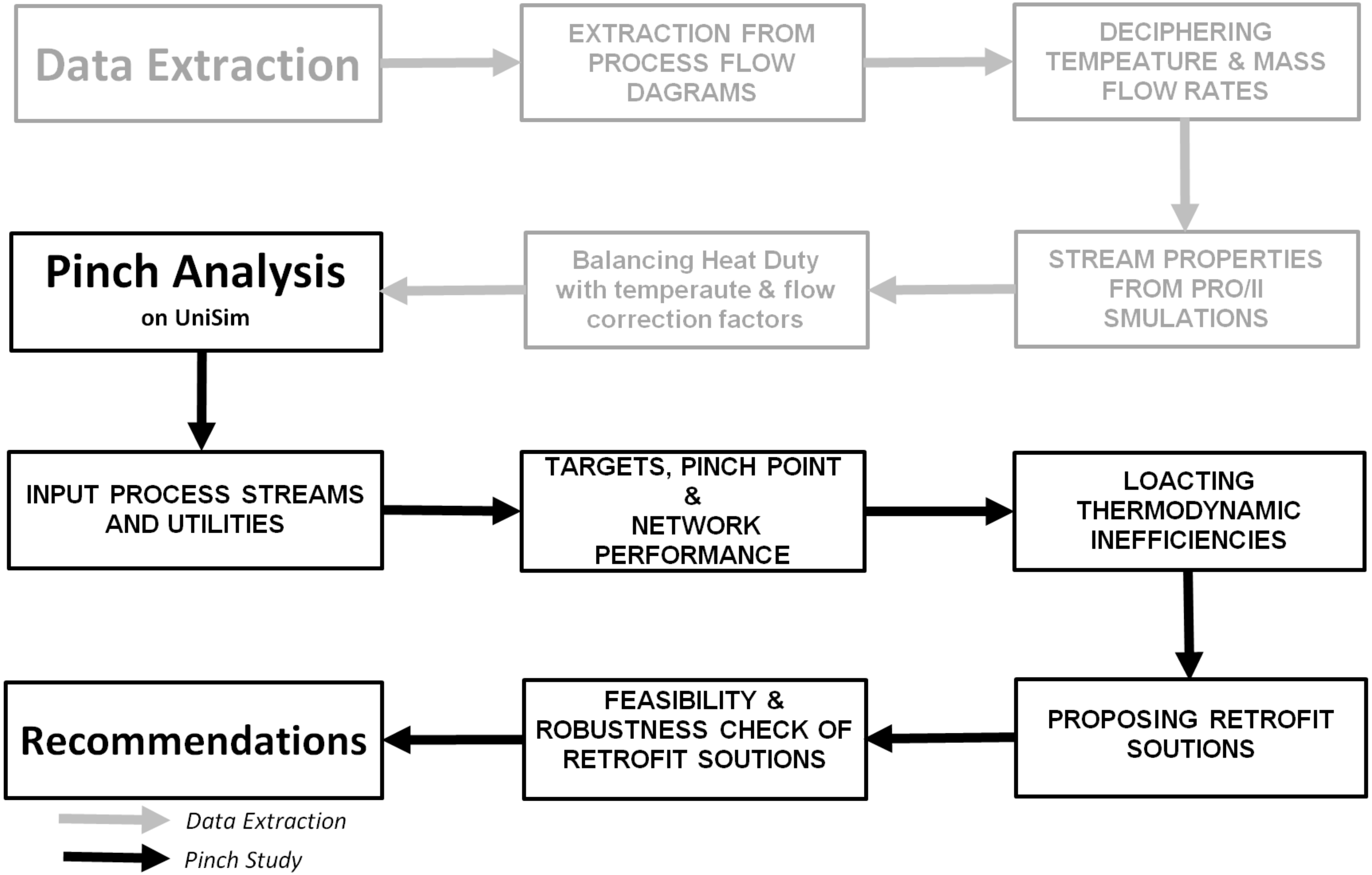
Rationale for Scope

Block 1 is thoroughly integrated

No prior pinch study preformed in block 1

Represents a typical futuristic scenario, after 2020

THESIS WORKFLOW



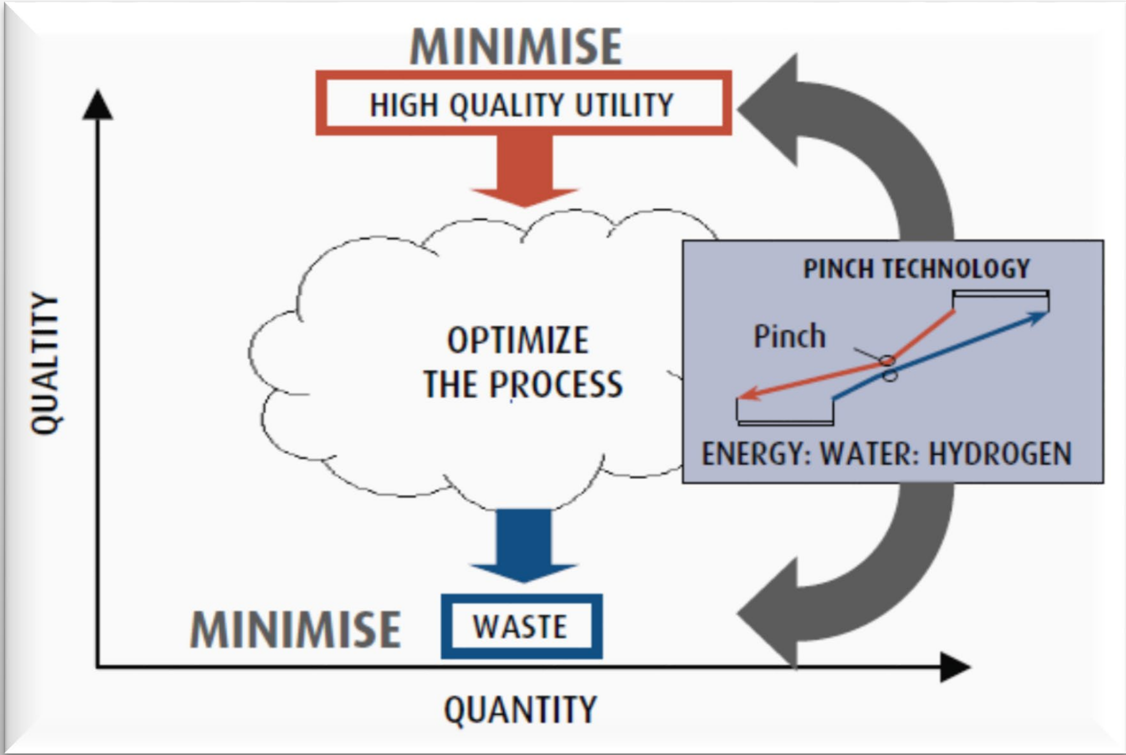
Data Extraction

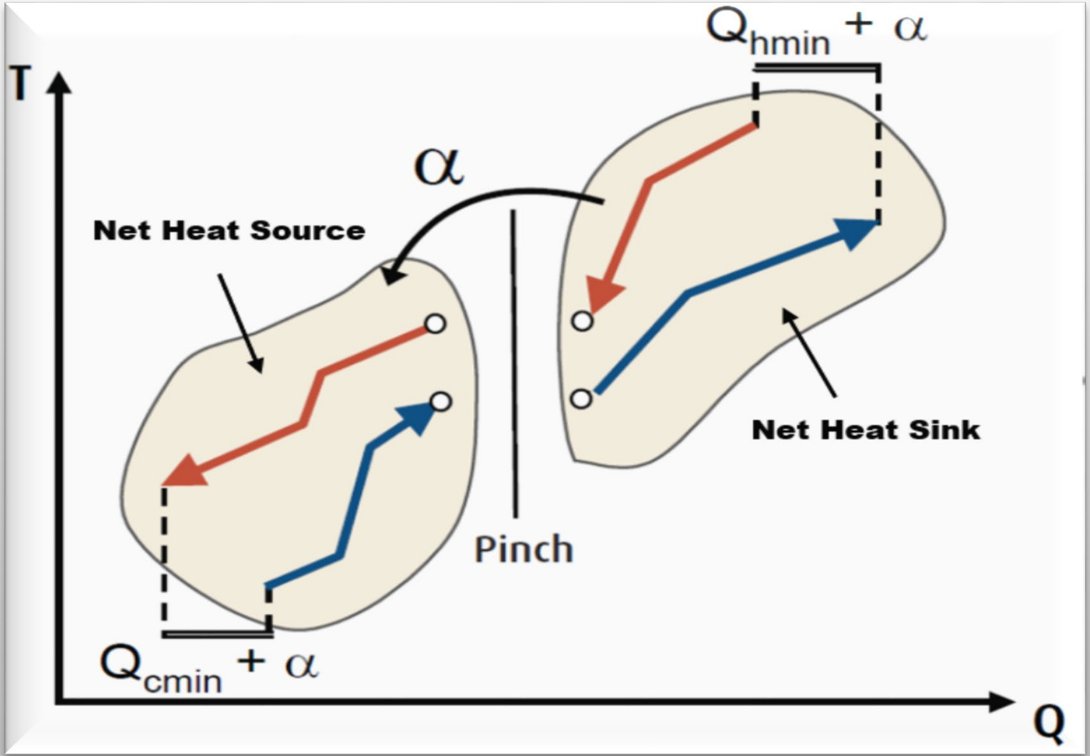
50 process streams

63 process heat exchangers

37 external utilities

PINCH ANALYSIS: BASICS



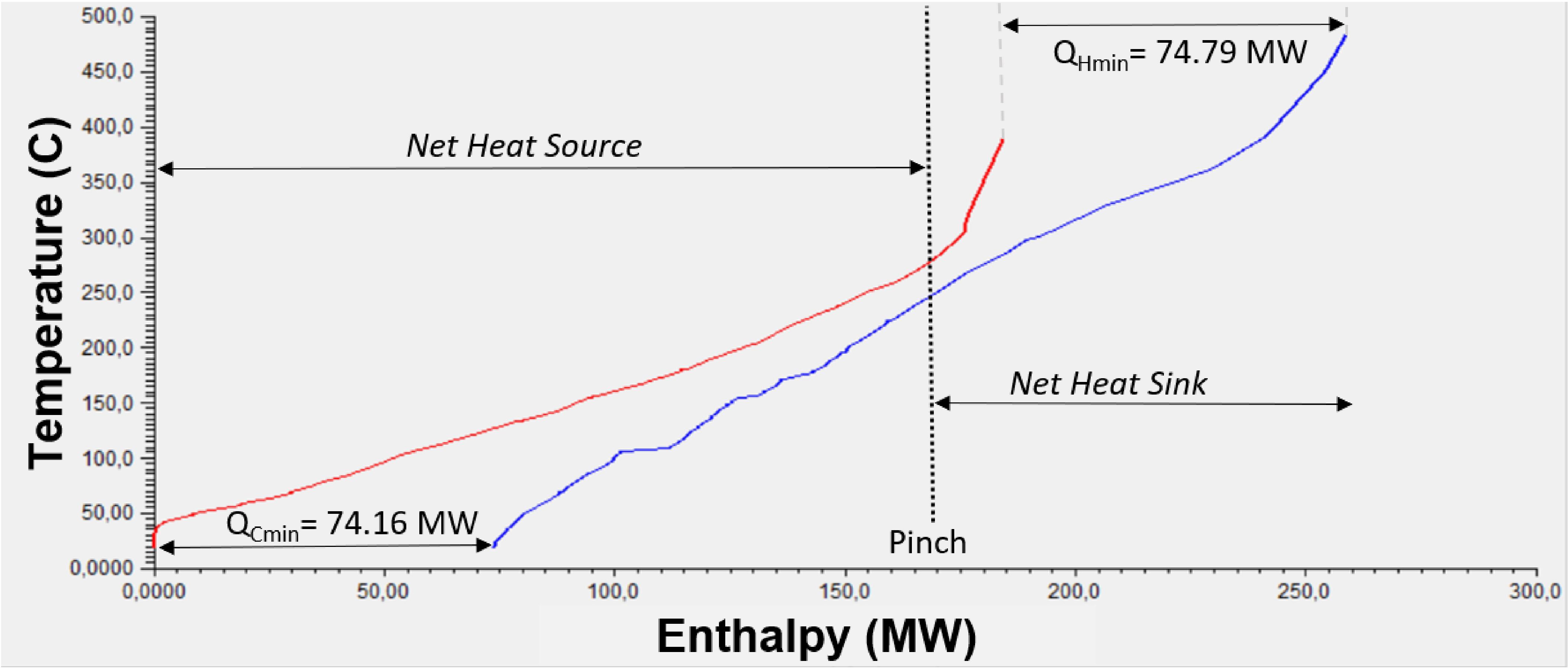


NO HEAT RANSFER ACROSS THE PINCH

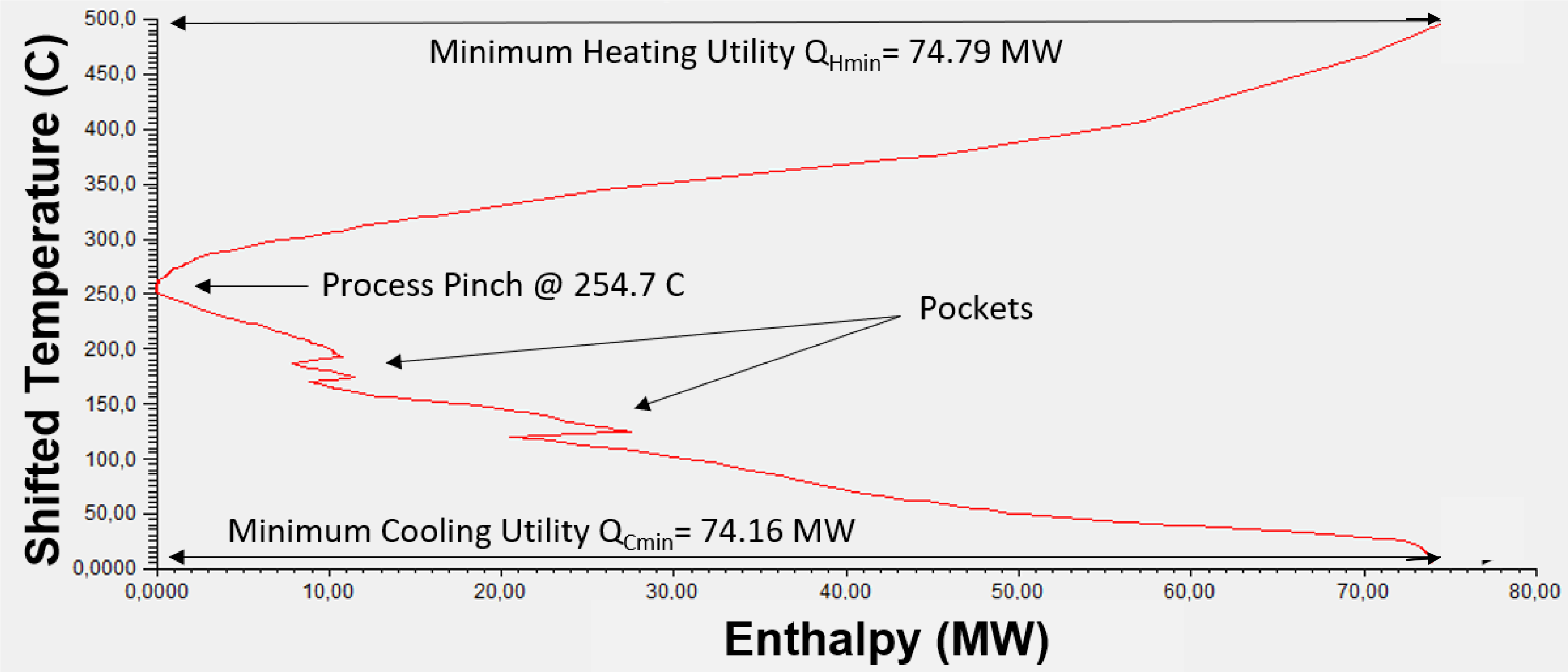
NO HEATING UTILITY BELOW THE PINCH

NO COOLING UTILITY ABOVE THE PINCH

Composite curves



Grand composite curve

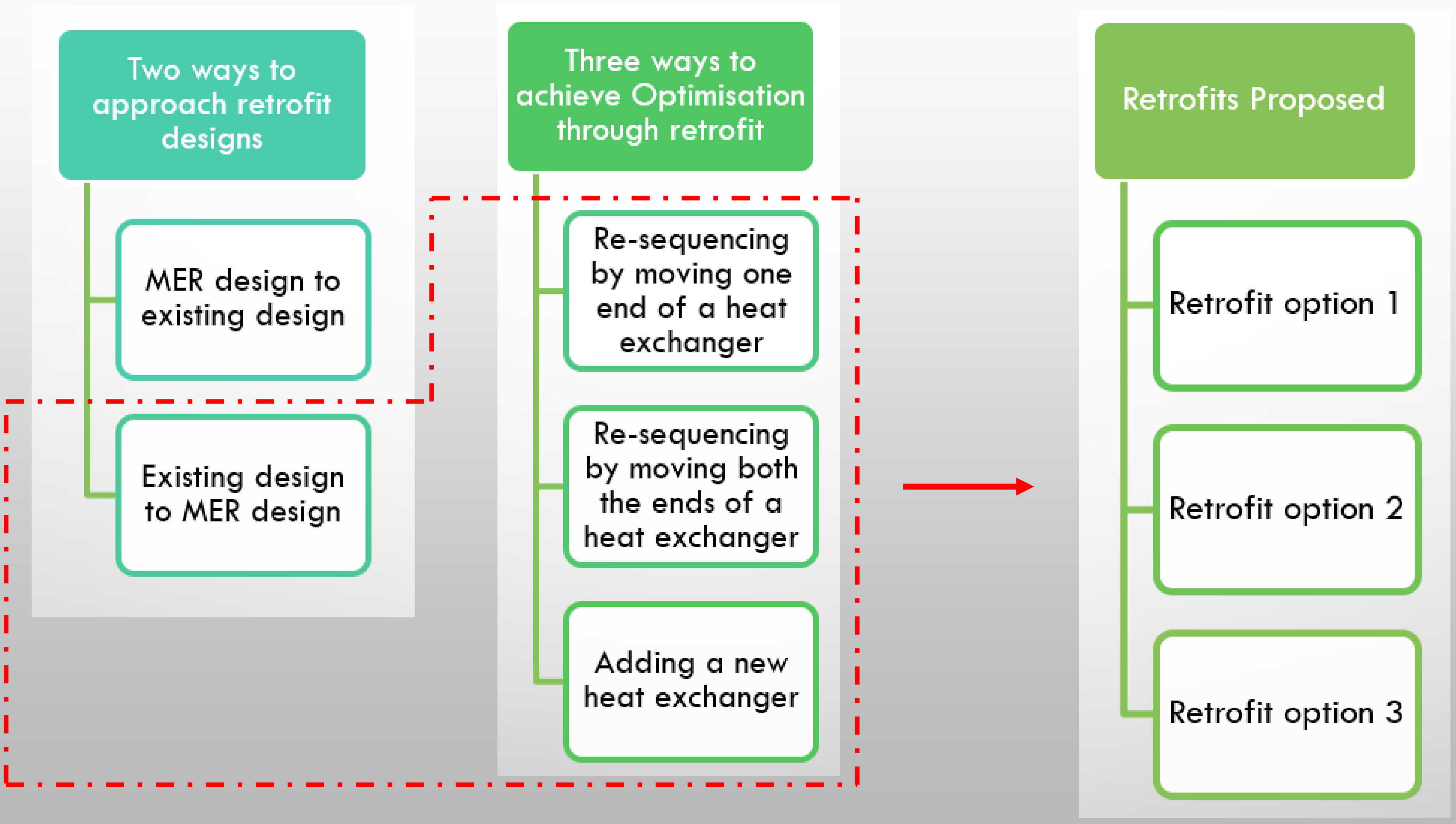


Network performance

Utility	Energy Targets	Network Performance
Heating	74.79 MW	89.90 MW
Cooling	74.16 MW	89.30 MW

HEX	Pinch Violations	Hot Streams	T_{in} (°C)	T_{out} (°C)	Cold Streams	T_{in} (°C)	T_{out} (°C)
H-202	2.24 MW	Fuel	-	-	DS Crude BCD	216	366
E-1016	1.29 MW	C-1001 Btm Quench	314	266	DS Crude BCD	209	216
H-1051	1.41 MW	Fuel	-	-	DS Crude BCD	216	356
TOTAL PINCH VIOLATIONS					12.80 MW		

Heat exchanger network retrofit



RETROFIT DESIGNS SUMMARY

Retrofit Designs	Energy Savings	Preheat Increase	Fuel Savings	
	MW	MW	MW	GWh/year
RETROFIT 1	**2.24**	**33.7**	**2.64**	**22**
RETROFIT 2	**4.65**	**36.1**	**5.47**	**46**
RETROFIT 3	**5.63**	**37.1**	**6.62**	**56**

Additional opportunities for heat recovery

HEX	Hot Streams	Heat Energy Lost	T_{in} (°C)	T_{out} (°C)	Utility
E-208 A-L	C-601 MPA	14.6 MW	144	50	Air
E-217 A-C	C-204 LVN	6.8 MW	84	49	Air
E-1004 A/B	C-1001 LVGO	6.6 MW	96	41	Air
E-609 A-C	C-601 O/H	5.5 MW	131	49	Air
E-607 C	C-604 VBHVGO	2.3 MW	173	154	CW

Economic feasibility

INVESTMENT COST

HEX cost based on Area

Installation costs of Piping, Instrumentation, Civil, Electrical

D&E, Contingency and offsites costs also included

FUEL PRICE

30$/MWh

NET PROFIT

COST SAVINGS

PAYBACK

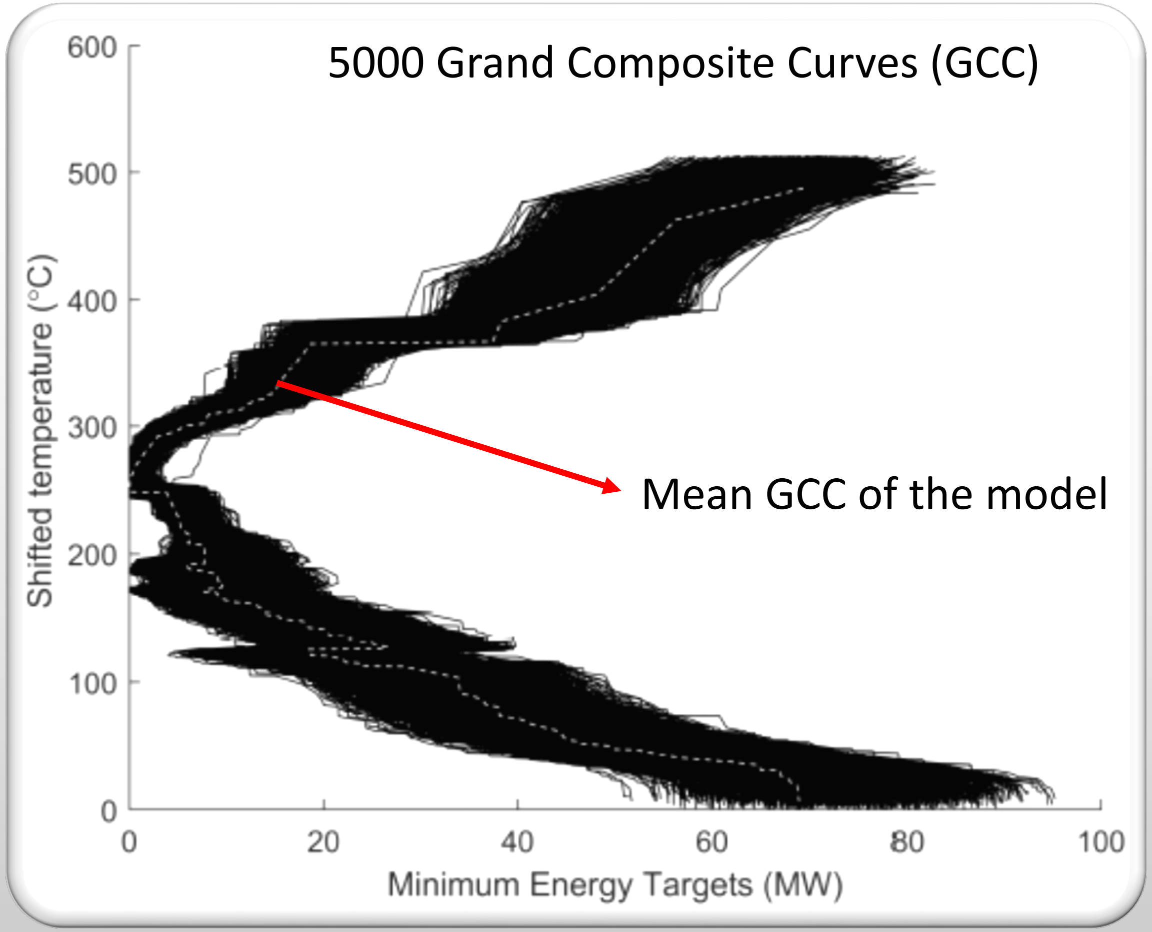
NPV_{15}

Economic & Environmental performance

Retrofit Designs	Investment Cost Million DKK	Simple Payback No. of Years	NPV15 Million DKK	Avoided Emissions Ktons CO_2 eq. per year
RETROFIT 1	**11.0**	**2.5**	**27.0**	**4.5**
RETROFIT 2	**37.9**	**4.2**	**43.8**	**9.4**
RETROFIT 3	**46.1**	**4.4**	**51.0**	**11.4**

Uncertainty analysis

- Monte carlo – random number generation
- Defining the uncertainty – 192 variables
- Uniform Distribution based on past trend
- 5000 samples generated



Parameters	Mean	Median	Standard Deviation
Minimum Heating (MW)	**73.2**	**73.0**	**4.1**
Minimum Cooling (MW)	**73.0**	**73.2**	**6.3**
Process Pinch (°C)	**254.2**	**254.5**	**9.3**

Output Results ROBUST w.r.t the defined uncertainty of input parameters

Conclusion

- STUDY DONE FOR MAY 2017
- NETWORK PERFORMANCE EXCEDDED ENERGY TARGETS BY 20%
- 3 RETROFIT ALTERNATIVES PROPOSED
- RETROFIT 3 IS THE BEST IN LONG TERM PERSPECTIVES
- RESULTS FAIRLY ROBUST TO UNCERTAINTY IN INPUT PARAMETERS
- LIMITATIONS WITH RESPECT TO OPERATING MODE, RAW MATERIALS, AND MARKET FLUCTUATIONS
- FUTURE WORK REQUIRED TO ACCOMPLISH ENERGY OPTIMIZATION

Thank you ☺

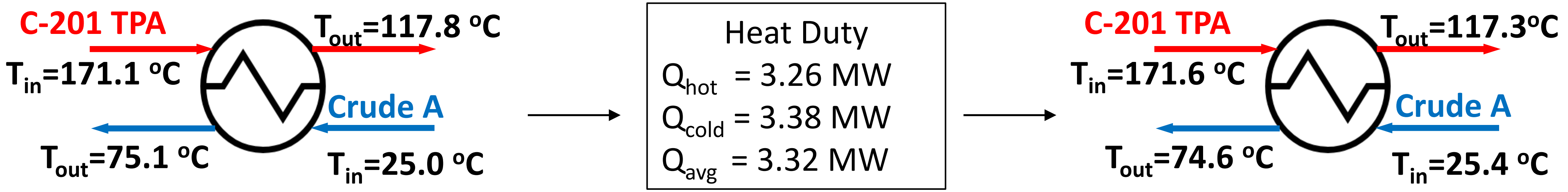
Back-up slides

Data extraction

Finding the measured data

- Inlet & Outlet temperatures and flow rates tags were identified from PID’s (80%)
- Day average data was taken for each day of the month of may
- An average was taken for all the days of the month
- For the unavailable/frozen data, one or more of the following was done(20%):
  - Data was taken from Heat4Transfer software, if not available
  - Data was calculated using flow & temperature balance in the respective PID, if not available
  - Data was taken from PRO/II simulations, if not available
  - Data was calculated using energy balance of the other side of the HEX.

Temperature correction factors



$$B = [abs(T_{in} - T_{out})^* A]$$

$$A = [(Q_{cal} - Q_{avg}) / Q_{cal}]$$

$T_{in,\,av} = T_{in} \pm B/2$ $\quad T_{out,\,av} = T_{out} \pm B/2$

HEX's	Streams	T_{in}	T_{out}	Flow	Cp_{in}	Cp_{out}	Cp_{avg}	Calcuated Heat Duty	Average Duty	% difference in duties	Temp. Correction Balance	Available T_{in}	Available T_{out}	Available Duty
		deg C	deg C	kg/hr	KJ/KG-C	KJ/KG-C	KJ/KG-C	MW	MW					
E-201	Crude A	25.0	75.1	121754.4	1.87	2.13	2.00	3.38	3.32	0.02	0.93	25.46	74.64	3.32
	C-201 TPA	171.1	117.9	90282.1	2.56	2.31	2.44	3.26	3.32	-0.02	-1.03	171.64	117.37	3.32
E-207C	Crude A	74.6	104.9	121754.4	2.13	2.24	2.18	2.23	2.24	-0.01	-0.16	74.64	105.06	2.24
	C-604 VBHVGO PA	224.0	190.6	100303.8	2.49	2.36	2.43	2.26	2.24	0.01	0.17	223.78	190.57	2.24
E-221	Crude A	105.1	133.7	121754.4	2.24	2.34	2.29	2.22	2.38	-0.07	-2.07	105.06	135.77	2.38
	C-201 MPA	242.3	185.4	62692.6	2.67	2.46	2.57	2.54	2.38	0.06	3.58	242.27	189.02	2.38

Mixed Streams

- For mixed streams(both liq & vap phase), heat duty was calculated as a product of the found flow rate and total enthalpy from simulations to take into account the latent heat.
- The specific heat value in this case is considered having a *psuedo value* representing the sensible and latent heat of the stream
- Also, for reboilers mass flow rate was evluated as:

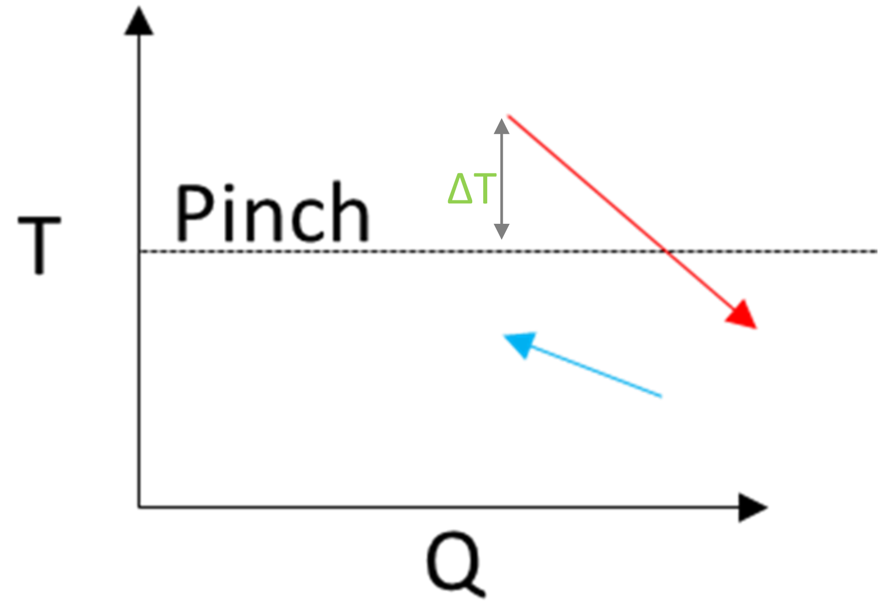
$$\dot{m}_{\text{reboiling side}} = \frac{\dot{Q}_{\text{reboiling opposite side}}}{\Delta h_{\text{reboiling side}}}$$

Stream Segmentation

- To account for the non-linear variation of specific heat with temperature, especially over a big temperature range, the streams were subdivided into fractions.
- The streams were segmented into smaller temperature ranges and each temperature range was allocated its respective Cp value to account for the non linearity.
- The difference was fairly visible in stream *C-1001 HVGO* that was not segmented and the results could be seen in Appendix F

HEX	Streams	Reconciled		Unisim		Streams	Reconciled		Unisim		Duty (MW)	
	Cold	T_{in} (C)	T_{out} (C)	T_{in} (C)	T_{out} (C)	Hot	T_{in} (C)	T_{out} (C)	T_{in} (C)	T_{out} (C)	Recon.	Unisim
E-201	Crude A	25.5	74.6	25.5	74.6	C-201 TPA	171.6	117.4	171.6	116.7	3.3	3.3
E-207C	Crude A	74.6	105.1	74.6	105.1	C-604 VBHVGO PA	223.8	190.6	223.8	190.6	2.2	2.2
E-221	Crude A	105.1	135.8	105.1	135.8	C-201 MPA	242.3	189.0	239.6	185.5	2.2	2.4
E-203	Desalted Crude A	135.8	152.4	135.8	152.4	C-201 MPA	269.7	241.9	269.7	239.6	1.6	1.3
E-207A	Desalted Crude A	152.4	178.8	152.4	178.8	C-604 VBHVGO PA	239.2	223.8	239.2	223.7	2.2	2.2
E-207B	Desalted Crude A	178.8	199.8	178.8	199.8	C-604 VBHVGO PA	251.7	239.2	251.7	239.2	1.9	1.8
E-230	Desalted Crude A	199.8	224.4	199.8	224.4	C-201 BPA	323.5	235.3	323.5	235.3	2.1	2.2
E-239	Desalted Crude A	224.4	239.3	224.4	239.3	C-604 VBHVGO PA	260.9	251.7	260.9	251.7	1.3	1.3
E-225	Crude B	20.0	65.7	20.0	65.7	C-201 TPA	156.6	136.0	155.8	135.0	2.2	2.2
E-226	Crude B	65.7	98.4	65.7	98.4	C-201 TPA	171.6	156.6	171.6	155.8	1.6	1.7
E-1015	Crude B	98.4	113.7	98.4	113.7	C-1001 HVGO	148.6	138.0	143.2	133.6	1.1	0.8
E-235 B	Desalted Crude B	112.0	129.3	112.0	129.3	C-201 MPA	179.2	161.3	179.0	161.5	0.7	0.8
E-235 A	Desalted Crude B	129.3	148.8	129.3	148.8	C-201 MPA	199.5	179.2	199.3	178.9	0.9	0.9
E-204 A	Desalted Crude B	148.8	171.1	148.8	171.1	C-201 MPA	269.7	228.8	269.7	228.0	1.2	1.0
E-204B	Desalted Crude B	171.1	193.9	171.1	193.9	C-201 HGO	332.9	246.4	332.9	246.4	1.2	1.1
E-222	Crude C	20.0	85.9	20.0	85.9	C-201 Kero	187.3	124.0	192.2	127.0	3.0	2.8
E-241	Crude C	85.9	103.8	85.9	103.8	C-201 MPA	189.0	169.3	185.5	166.5	0.9	0.8
E-223	Crude C	103.8	127.5	103.8	127.5	C-201 LGO	180.0	152.5	180.0	152.6	1.2	1.2
E-240	Desalted Crude C	112.0	125.3	112.0	125.3	C-201 BPA	202.7	151.6	202.6	151.6	1.6	0.9
E-234	Desalted Crude C	125.3	151.4	125.3	151.4	C-201 LGO	222.1	180.0	222.1	179.9	1.7	1.8
E-206	Desalted Crude C	151.4	165.6	151.4	165.6	C-201 LGO	244.4	222.1	244.4	222.1	1.1	1.0
E-1012A	Crude D	20.0	69.2	20.0	69.2	C-1001 LVGO	133.8	96.3	133.8	96.3	2.4	2.3
E-1012B	Crude D	69.2	96.6	69.2	96.6	C-1001 LVGO	155.0	133.8	155.0	133.8	1.4	1.4
E-242	Desalted Crude D	112.0	132.4	112.0	132.4	C-201 HGO	246.4	168.5	246.4	168.5	1.0	0.9
E-1013B	Desalted Crude D	132.4	147.3	132.4	147.3	C-1001 HVGO	203.8	164.3	195.2	154.1	0.8	0.7
E-1013A	Desalted Crude D	147.3	165.6	147.3	165.6	C-1001 HVGO	207.8	177.5	200.5	168.4	0.9	0.9
E-1002B	Desalted Crude D	165.6	182.1	165.6	182.1	C-1001 HVGO	234.7	207.8	230.1	200.5	0.8	0.8
E-1002A	Desalted Crude D	182.1	193.8	182.1	193.8	C-1001 HVGO	235.6	203.8	230.1	195.2	0.6	0.6
E-205	Desalted Crude BC	176.9	189.1	176.9	189.1	C-201 LGO	276.3	244.4	276.3	244.4	1.7	1.5
E-1014A	Desalted Crude BCD	191.1	201.5	191.1	201.8	C-1001 HVGO	250.0	238.5	248.0	234.9	1.6	1.8

Calculation of Cross Pinch



$$Q_{cross\ pinch} = m\,C_p\,\Delta T$$

Economic Evaluation

Investment Cost		Retrofit 1	Retrofit 2			Retrofit 3			
		E-NEW A	E-NEW B	E-NEW C	E-NEW D	E-NEW B	E-NEW C	E-NEW A	E-NEW D
a	US $ in 2010	28000	28000	28000	28000	28000	28000	28000	28000
b	US $ in 2010	54	54	54	54	54	54	54	54
Available Area	m2	353.69	496.64	496.64	219.6	496.64	496.64	352.9	106.5
Over Design	%	40%	40%	40%	40%	40%	40%	40%	40%
S(Area)	m2	495.17	695.30	695.30	307.44	695.30	695.30	494.06	149.10
n		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Purchased Equipment Cost	US $ in 2010	120490	166994	166994	80204	166994	166994	120242	49906
Purchased Equipment Cost	US $ in 2018	130325	180626	180626	86751	180626	180626	130057	53980
Purchased Equipment Cost	DKK in 2018	852328	1181294	1181294	567353	1181294	1181294	850575	353029
Installed Equipment Cost	DKK	3835478	5315823	5315823	2553090	5315823	5315823	3827588	1588631
Engineering Cost	DKK (@50% equipment cost)	1917739	2657912	2657912	1276545	2657912	2657912	1913794	794315
Contingency Cost	DKK (@50% equipment cost)	1917739	2657912	2657912	1276545	2657912	2657912	1913794	794315
Offsites Cost	DKK (@50% equipment cost)	1917739	2657912	2657912	1276545	2657912	2657912	1913794	794315
Fixed Capital Cost	DKK	9588695	13289558	13289558	6382725	13289558	13289558	9568971	3971577
Working Capital Cost	DKK (@15% fixed cost)	1438304	1993434	1993434	957409	1993434	1993434	1435346	595737
Total Retrofit Project Investment Cost	**MillionDKK**	**11.0**	**37.9**			**46.1**			
Savings		Retrofit 1	Retrofit 2			Combined Retrofit 1 and 2			
Energy Savings	MW	2.25		4.65			5.47		
Burner Efficiency	%	0.85		0.85			0.85		
Fuel Savings	MW	2.641176471		5.470588235			6.4352941		
Operation/year	days	350		350			350		
Energy Cost (GAS)	US $/MWh	30		30			30		
Final energy Cost (GAS)	DKK/MW	4352870.118		9015967.059			10605880		
Total Savings	**MillionDKK/year**	**4.4**		**9.0**			**10.6**		
Payback	**Year**	**2.533270865**		**4.204331845**			**4.3501921**		

Sensitivity Analysis

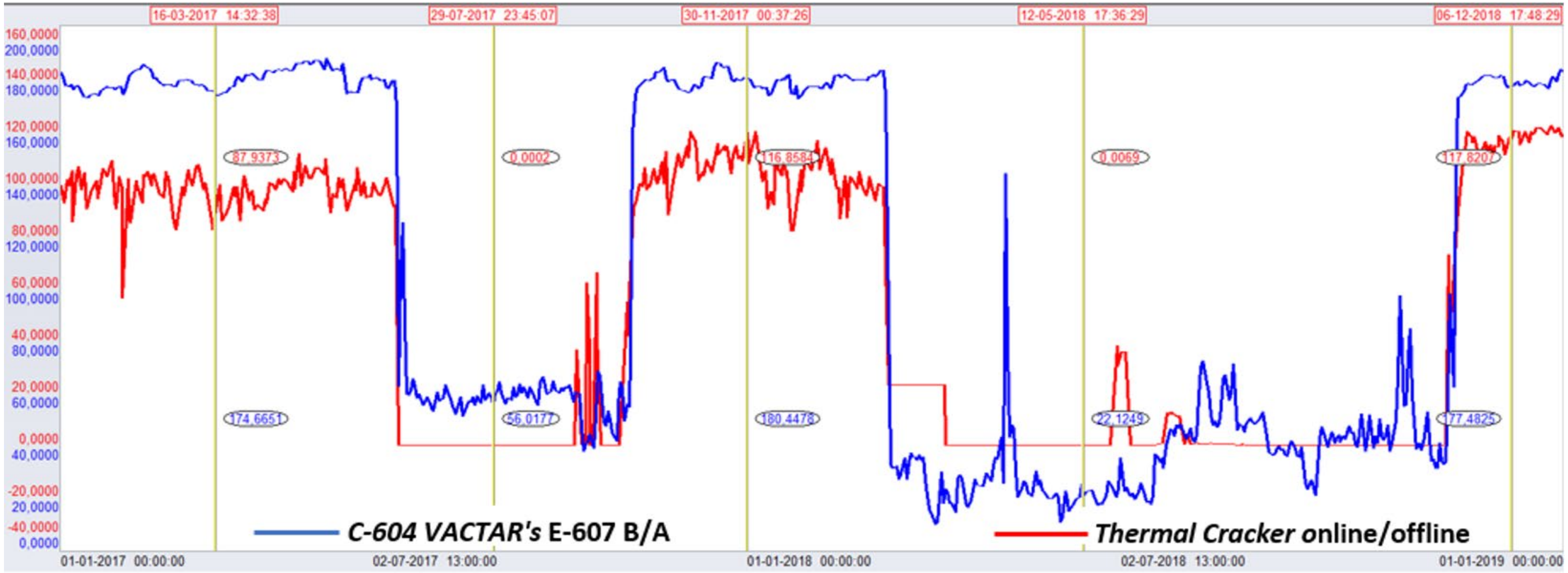
	Retrofit Option 1			Retrofit Option 2			Retrofit Option 3		
Percent Increase in Inv. Cost	Investment Cost Million DKK	ROI -	Payback Years	Investment Cost Million DKK	ROI -	Payback Years	Investment Cost Million DKK	ROI -	Payback Years
-10%	9.9	41%	2.3	34.1	26%	3.8	41.5	26%	3.9
0%	**11.0**	**37%**	**2.5**	**37.9**	**24%**	**4.2**	**46.1**	**23%**	**4.4**
10%	12.1	34%	2.8	41.7	22%	4.6	50.8	21%	4.8
20%	13.2	31%	3.0	45.5	20%	5.0	55.4	19%	5.2
30%	14.3	29%	3.3	49.3	18%	5.5	60.0	18%	5.7

Limitations

- *Thermal Cracker* operational mode of the refinery;
- The product requirement from the refinery changes from time to time according to the market demand. A change in the products will change the heat balance and thus the study will be done for a specific ratio of products;
- Similarly, according to market fluctuations, Equinor processes different crude oil feedstock. A change in the feedstock will change the heat balance of the plant and thus the study will be done for a crude oil feedstock;
- The data used for the study does not take into account seasonal variations into consideration. The heat balance of the plant would differ in the summer and winter months;
- Finally, the production capacity of the plant may vary due to market fluctuations and this will not be considered. Again, the heat balance would change according to the capacity.

C-604 VB HVGO PA Temperature

C-604 VACTAR Temperature



C-201 TPA Temperature