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TSA II Stenungsund - Investigation of opportunities for implementation of proposed category A energy efficiency measures

Eva Andersson
Per-Åke Franck
CIT Industriell Energi
Chalmers Teknikpart
412 88 Göteborg
Tel: 031 772 3672

Roman Hackl
Simon Harvey
Division of Heat and Power Technology/Chalmers University of Technology
Kemivägen 4
412 96 Göteborg
Tel: 031 772 3861

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Eva Andersson
Per-Åke Franck
CIT Industriell Energi AB

Roman Hackl
Simon Harvey
Division of Heat and Power Technology
Chalmers University of Technology

This project was carried out in cooperation between the Division of Heat and Power Technology at Chalmers University of Technology, CIT Industriell Energi AB, AGA Gas AB, Akzo Nobel Sverige AB, Borealis AB, INEOS Sverige AB and Perstorp Oxo AB.

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SUMMARY

A Total Site Analysis (TSA) study of the chemical cluster in Stenungsund was conducted during 2010. This previous study is hereafter referred to as the TSA I study. The study was conducted by CIT Industriell Energi and the Division of Heat and Power Technology at Chalmers together with the participating cluster companies (AGA Gas AB, Akzo Nobel Sverige AB, Borealis AB, INEOS Sverige AB and Perstorp Oxo AB).

In the TSA I study, measures to increase energy efficiency by increased energy collaboration (i.e. increased heat exchange between the cluster plants) were identified. The measures were classified according to ease of implementation based on consultation with plant staff. In this report, conducted within the framework of the second stage of the TSA research project (hereafter referred to as the TSA II project) practical issues associated with implementation of the identified measures are investigated. The investigation is limited to category A measures, considered by plant staff to be relatively easy to implement from a technical perspective. A conceptual design of a possible hot water system for exchanging heat between the different sites is presented. Since the steam systems of the different plants are at present only partly connected, or not at all, the overall reduction in steam use that would results from introduction of a hot water system would lead to steam surplus at certain sites. Therefore introducing a hot water system is only beneficial if new steam lines are also implemented so that it becomes possible to exchange steam between the individual plant sites. The exchange of steam is only possible if steam demand and steam excess are at the same pressure level. To avoid excess steam at low pressure level, demand of low pressure steam must increase. In order to increase the possibility to use more low pressure steam, the opportunities to decrease utility steam pressure in individual process heaters are analyzed. The implementation of energy efficiency measures in the refrigeration systems is also investigated. In practice this can be achieved by changing steam as heating utility to a fluid that can operate below ambient. In addition to the steam saving, the heat transfer fluid can transport energy from the current cooling systems and decrease the amount of compressor work required to operate the existing refrigeration system units.

In order to achieve a reduction of purchased fuel for firing in boilers it is necessary to implement both a common site-wide circulating hot water system and a reduction of utility steam pressure used in several process heaters .

The results show that if all measures that are considered by plant energy engineers to be feasible by moderate changes are carried out as suggested, fuel usage in boilers could be reduced by 89 MW (corresponding to 200 MSEK/year if fuel gas is valued at 270 SEK/MWh and year-round operation is assumed).

A rough estimate of the total investment costs for the implementation of category A measures is 660 MSEK.

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1 BACKGROUND

A Total Site Analysis (TSA) was performed in a previous study (TSA I[1]) to evaluate the benefits of integration between the process energy utility systems within the chemical cluster in Stenungsund. The main conclusion was that, in theory, heat recovery from the constituent processes is sufficient to completely cover the heat demand at the site that is currently covered by boilers. This means that 125 MW of boiler steam can be saved and, in addition, a surplus of 16 MW of high pressure steam can be released and used for e.g. additional power generation. Note that these figures have been updated and slightly modified since the TSA I study.

Measures necessary to reach the full saving potential were identified in the TSA I study and include:

- Introduction of a circulating hot water system and a circulating heat transfer system below ambient
- Increased steam generation from excess process heat
- Reducing steam pressure level in process heaters to increase low pressure steam use
- Redistribution of steam between plants to avoid local steam surplus

The feasibility of implementing these measures was evaluated and ranked into category A, B and C.

The aim of this study is to present a conceptual design for measures that reduce the heat demand, and thus reduce fuel used in boilers. The conceptual design only includes category A measures (category A: considered by plant staff to be relatively easy to implement from a technical perspective).

The aim is also to present an economic evaluation including investment costs

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[1] Total Site Analysis (TSA) Stenungsund, Roman Hackl, Simon Harvey, Eva Andersson, Chalmers 2010

2 RESULTS FROM TSA I STUDY AND SUGGESTED MEASURES

2.1 Work procedure

The following steps were carried out to find the practical solutions in this report:

1. Collect data based on new information and reevaluation of measures from TSA I
2. Incorporation of new data in TSA curves
3. Analysis of curves to find measures necessary to avoid site pinch
4. List all process heaters that are suitable for heating with a hot water system and are considered possible to convert by moderate changes (category A, see 0).
5. Find heat sources for a hot water system that are category A
6. Design hot water systems and heat transfer system below ambient
7. Estimate the amount of utility steam generation that is no longer required for operation of category A process heaters
8. Check category A process heaters which could be operated using a lower steam pressure
9. Make a new Total Site Composite (TSC) curve including all category A measures
10. Check steam balance at individual plants where category A measures have been implemented
11. Investigate possibilities to redistribute steam
12. Obtain result: Category A with distribution of LP steam
13. Find further measures to avoid steam surplus

2.2 Updated data

Discussions after a preliminary presentation of practical solutions have resulted in updated evaluations of the different measures presented in TSA I. Some measures classified as category A have been reevaluated to category B and vice versa. The reevaluation has resulted in:

- Increased amounts of heat that can be delivered to a hot water system from heat sources categorized as A.
- Increased heating requirements in category A heat sinks which makes it possible to use more hot water to replace utility steam.
- Updated data for steam production associated with process cooling.

By-products that must be fired at the site, but not necessarily in the same boiler as used currently, are not included as a heat source in the TSC. Instead such by-product fuel streams are considered an internal fuel that can be fired in any boiler within the cluster. The difference is that the resulting steam production is not fixed at a given pressure.

Some minor adjustments of total steam use have also been made to better reflect the current steam use at different levels.

The updated data has been incorporated in the results presented hereafter.

2.3 Total Site Curve

Based on process stream data and the corresponding hot and cold utility streams used for heating and cooling these streams, the total site composites (TSC) curves shown in Figure 1 can be developed. The curves represent the current utility system. The red full line represents the hot process streams, which require cooling, the green dashed line represents the cold utilities used to cool the hot process streams. The blue full line shows the cold process streams, which need to be heated and the orange dashed line illustrates the hot utilities used to heat these cold process streams.

In Figure 1 it can be seen that 125 MW_{heat} from fuel fired in boilers is needed to cover the cluster's current heating demand. 653 $MW_{cooling}$ are necessary to cool the processes. 318 MW_{rec} of heat are recovered by the utility system.

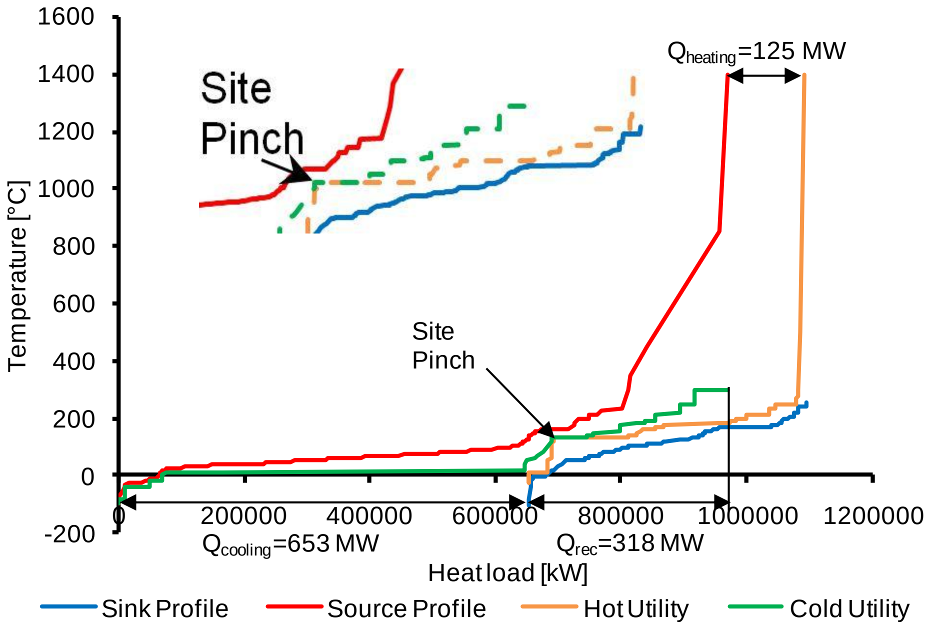


Figure 1 TSC of the chemical cluster in Stenungsund with its current utility system

2.3.1 Systematic analysis of TSC curve

In this section the systematic procedure followed to increase site wide heat integration via a common utility system using TSC is presented:

- The TSC curves of the current utility system (Figure 1) show a large gap between the hot utility curve and the sink profile (especially for process temperatures below 100 °C).
  → This leads to high exergy losses since the process streams are heated with utility at higher temperature than necessary.
- The source profile indicates that there is heat available (currently discharged) at suitable temperature to supply heat to the cold process

streams. Heat from hot process streams can be recovered in the circulating hot water system and delivered to cold process streams (between 50 and 100°C).

→ Detailed analysis indicates that steam used for process heating could be replaced by hot water.

Implementation of a hot water circuit implies that after a certain degree of increased heat integration a new site pinch is created, indicating that no further heat integration is possible. In practice the new site pinch implies that if more than 51 MW of utility steam is replaced with hot water there will be an overall excess of LP steam. This is because there will still be the same amount of 2 bar(g) steam recovered from process heat, but there is less demand since steam for heating purposes is replaced by hot water.

Further increase of heat recovery requires further shifting of the site pinch. This can be achieved as follows:

- Modify the operating conditions of certain process heaters. In this study we focused on steam heaters currently operated with MP steam but where it would be sufficient to operate with utility steam at 2 bar(g) → the steam level in these heat exchangers can be decreased → demand for LP steam is increased.
- Proceed as above until another site pinch is created, which makes it necessary either to lower the steam level in process heaters using higher pressure steam or steam from excess process heat can be recovered at higher levels.
- Both measures make it possible to shift the site pinch and increase the overlap of the TSC.
- The maximum theoretical heat integration is achieved, when ΔT between source profile/cold utility and hot utility/sink profile approaches ΔT_{min} (here ΔT_{min}=10 K)

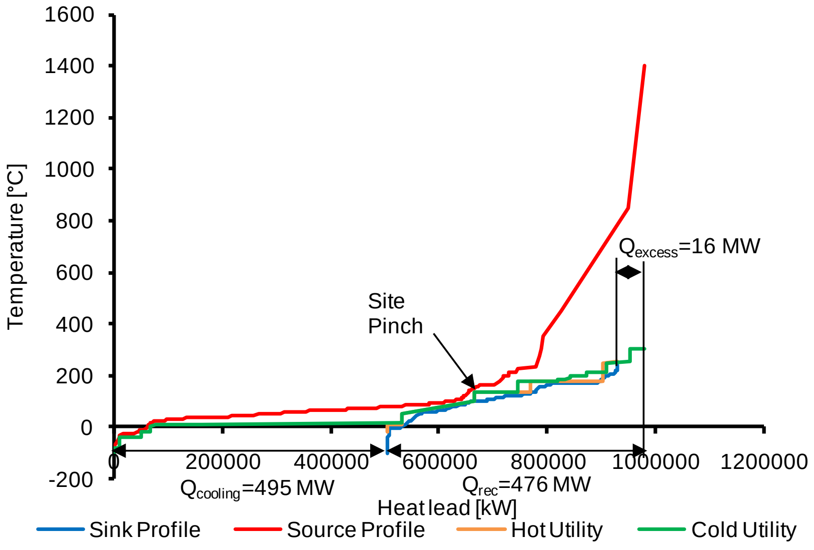


Figure 2 TSC after introduction of a utility system for maximum heat recovery

Figure 2 shows the cluster with a utility system modified in order to achieve maximum heat recovery. Several measures to recover the maximum amount of heat from the processes and re-use it for heating process streams elsewhere in the cluster are considered in this improved utility system. A circulating hot water system is suggested which could enable recovery of 133 MW of heat. Heat recovery to produce steam at 2 bar(g) can be increased by 25 MW. By doing this it is possible to save all the current utility demand (125 MW_{heat}). In addition, a surplus of 16 MW_{steam} can be produced from excess process heat. The amount of heat recovered by the utility system increases to 476 MW and the cooling demand decreases to 495 MW respectively.

2.3.2 Qualitative evaluation of specific measures

Specific measures to achieve a hot water system and changes in steam level use were identified by looking at stream data (process temperature, current utility and duty) of individual process heaters. The aim was to assess the feasibility of modifying process heaters in order to either reduce the pressure of utility steam required, or replace utility steam by hot water. Similarly, process coolers were examined with respect to feasibility to generate steam at higher pressure, or produce hot water.

A qalitative evaluation of the suggested measures was conducted together with plant experts to assess their feasibility. The measures were sorted into three categories:

A. Feasible, with moderate changes: Only the heat exchanger area and piping needs to be modified. No change to other equipment is necessary. Sufficient space is available to conduct the modifications and no additional pipe racks are needed.

B. Technically feasible: Besides modifying heat exchangers, changes to other process equipment must also be conducted. Examples of such changes or limitations include: a lack of space, additional pipe rack needs to be installed, heat exchangers are difficult to reach (top condensers, heat exchangers placed high above ground level etc.).

C. Not feasible: The suggested measure is not possible for other process reasons.

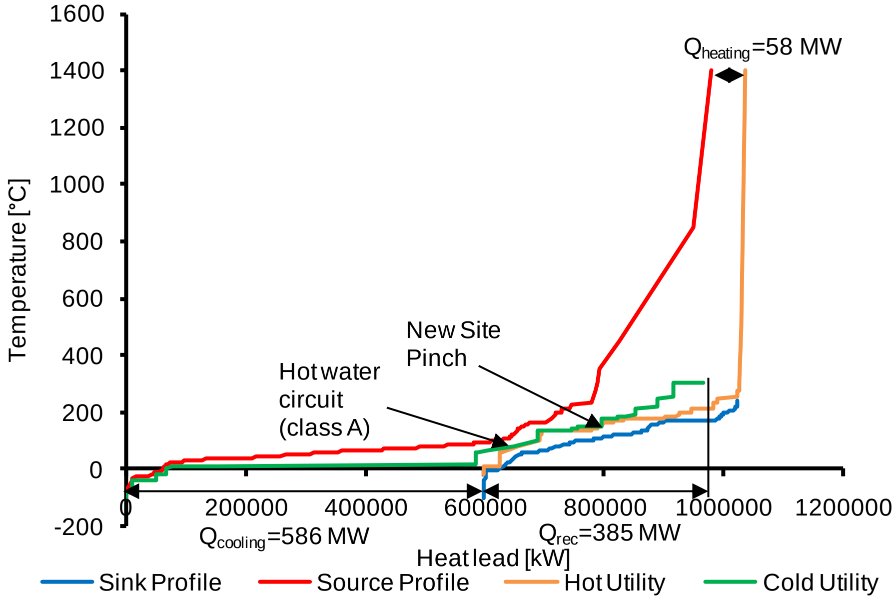


Figure 3 TSC after introduction of energy efficiency measures classified as "A"

If Category A measures are implemented the hot and cold utility curves will change. Figure 3 show the TSC with the new utility curves. The process curves can now overlap a little more before the new site pinch occurs. The new heat demand of the total site is 58 MW.

2.4 Steam to turbines

In this study we assume that mechanical drive turbines driving process equipment such as pumps and compressors (but not electricity generators) are essentially part of the process. This means that the steam expanding in these turbines is only available for that purpose and consequently not available for process heating and is therefore not included in the stream data. However, steam leaving such mechanical drive turbines after expansion, is available for use in the site wide utility system and are thus included in the Source Profile in the TSC that represents the sum of all heat available in process streams that must be cooled. This is illustrated in Figure 4.

The consequence of the assumption above is that potential benefits for the total site energy system that could be achieved by changing the configuration of the turbines, are not included in this study.

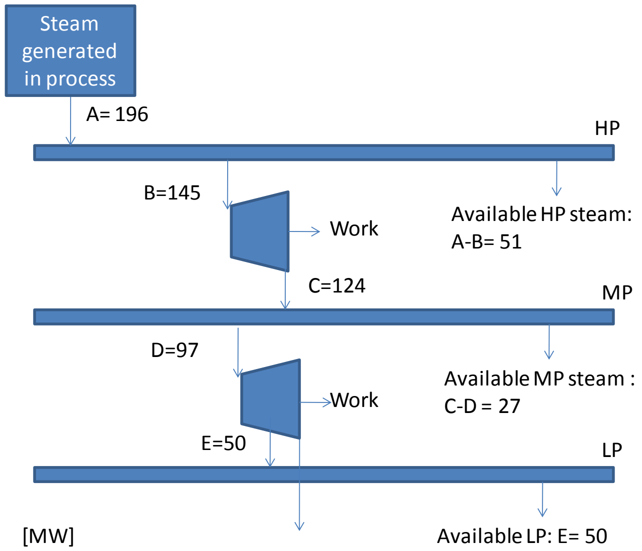


Figure 4 Illustration of how steam generated by recovery of process heat is calculated when the steam is used in mechanical drive turbines. Example: 196 MW of high pressure steam is generated with process heat, but only 51 MW is included in the Source curve since 145 MW is used in the mechanical drive turbine.

3 DETAILED DESCRIPTION OF SUGGESTED MEASURES

The measures suggested in the TSA I study will be described in more detail in this chapter:

3.1 Introduction of a circulating hot water system and a circulating heat transfer system below ambient

3.2 Increased steam generation from excess process heat and reducing steam pressure level in process heaters to increase low pressure steam use

3.3 Redistribution of steam between plants to avoid local steam surplus

3.5 Further measures to reduce fuel used for steam production in boilers

3.1 Design of heat transfer systems including Category A heat exchangers

3.1.1 Hot water systems

The introduction of a hot water circuit implies that process coolers have to be redesigned to use hot water instead of cooling water or air. Process heaters have to be redesigned for hot water instead of steam heating. The change of utility will lead to a lower temperature difference between the exchanged streams and larger heat exchanger areas will probably be needed. The use of plate heat exchangers can be one solution to reduce the physical size of the installation. For some heat exchangers only part of the heating or cooling can be made with the hot water system, and cooling water or steam will still be needed.

The temperature required in order to deliver heat to the heat sinks are at different levels, and to improve the use of recovered heat, the design of hot water systems at two temperature levels has been made, see Figure 5. One of the systems delivers heat at ~75-80 ^{o}C and the other at ~100 ^{o}C. The heat sources used contain more heat than required but some redundancy will be necessary to guarantee operation if heat exchangers are out of operation. If not needed, the excess heat can be cooled with cooling water.

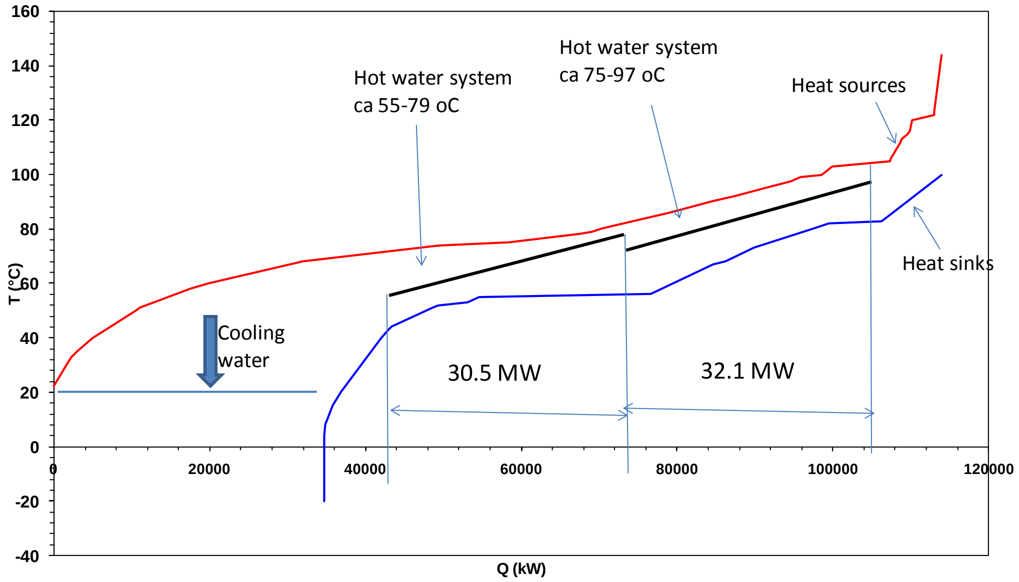


Figure 5 A graphic representation of the heat sources and the heat sinks. The hot water systems are divided into two systems, one at 55-79 °C that will transfer 30.5 MW and one 75-97 °C that can transfer 32.1 MW.

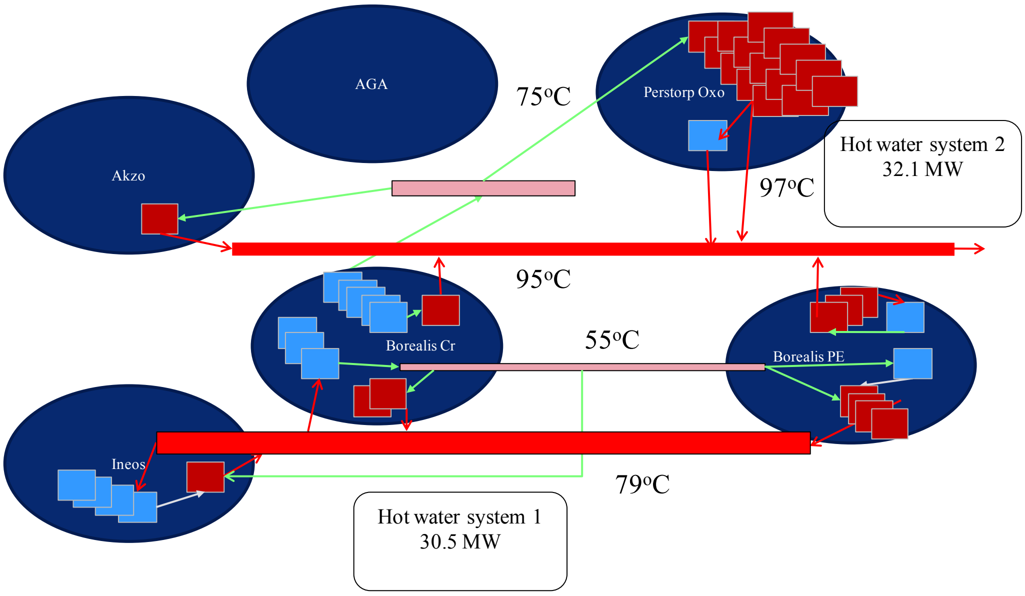
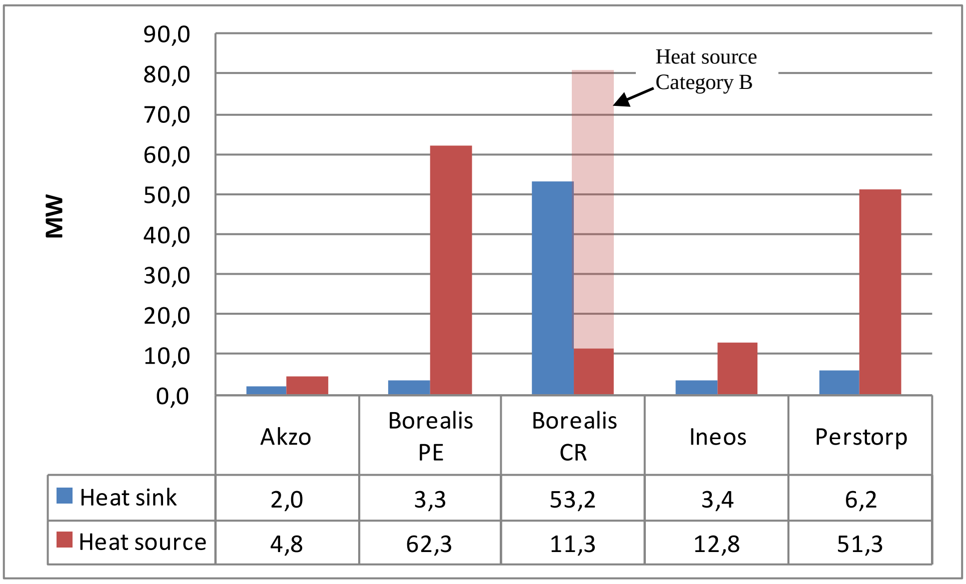


Figure 6 Hot water systems at two temperature intervals. The boxes show the number of heat sources (red) and heat sinks (blue) heat exchangers involved in the hot water systems.

It is important to note that categorization of process heaters and coolers can affect the topography of a site-wide circulating hot water system significantly. For example, there is significant amounts of heat available at the Borealis Cracker that is categorized as B (i.e. technically feasible, but requires significant changes). If this heat is considered as being available for use, no inter-site hot water system is in fact necessary, as shown in Figure 7. In order to make better choices regarding process heaters and coolers to be considered, it is necessary to conduct more detailed cost estimates of possible measures, which is beyond the scope of this study.



	Akzo	Borealis PE	Borealis CR	Ineos	Perstorp
🟦 Heat sink	2,0	3,3	53,2	3,4	6,2
🟥 Heat source	4,8	62,3	11,3	12,8	51,3

Figure 7 Summery of possible heat sources and heat sinks that are categorized as A measures. B measure at Borealis Cracker indicated in figure.

An inventory of category A heat sources and heat sinks (including heat sinks below ambient) at each plant is shown in Figure 7. The figure shows that there are possibilities to recover heat in a hot water system and deliver to heat exchangers that are identified as category A heat sinks at all the plants except at Borealis Cracker.

Figure 7 also shows that there is more hot water available that could be recovered and delivered to a district heating network or, even better, to heat sinks that have a demand all year. This type of investigation is however not included in the scope of this study.

The excess of hot water provides the opportunity to choose between heat sources and, after a more detailed evaluation and cost estimate, select the most cost effective measures.

The proposed system designs are based on the concept illustrated in Figure 8, with a header to which all the hot water is supplied and one header where all the cold water is collected and fed to the heat sources. Steam and cooling water can be used to reach the target temperature in case it cannot be achieved with the hot water system.

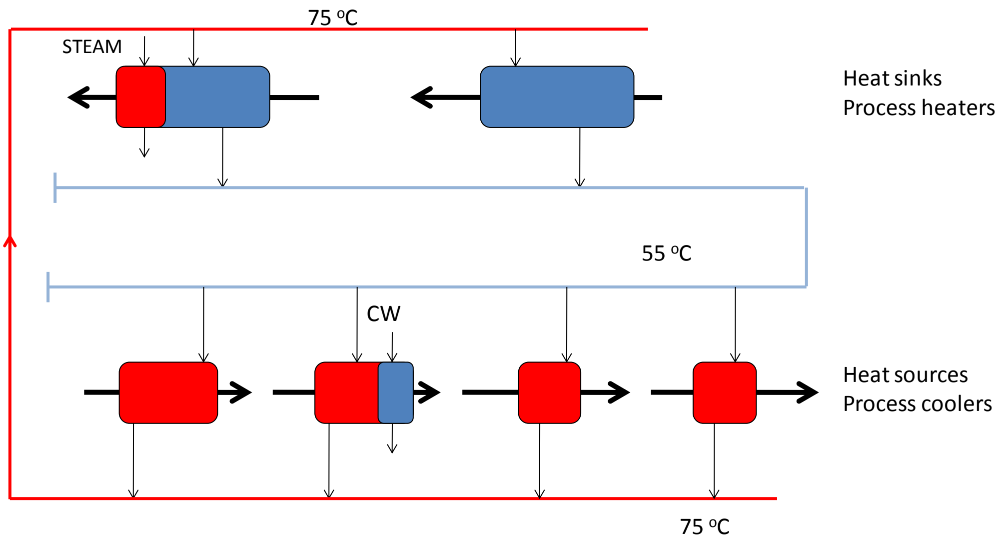


Figure 8 The hot water systems will have one line supplying the cooled water to the heat sources and one line supplying the hot water to the heat sinks. Additional cooling or heating may be necessary.

3.1.2 Heat sinks

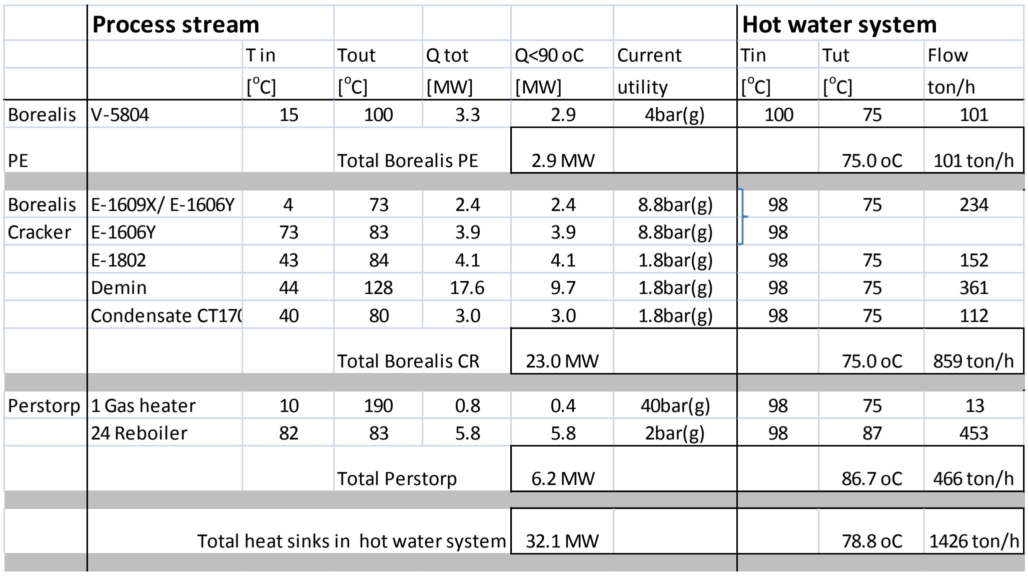
We have identified 15 process heaters, categorized as A, currently heated with utility steam or fuel gas but where the process stream temperature requirements could allow hot water to be used as heating medium instead. The heat sinks are listed in Table 1 and Table 2. If all these are heated with hot water, 60.0 MW of utility steam and 2.5 MW of fuel gas could become available.

In addition, six process stream heaters operating below 0 ^{o}C, using 4.4 MW steam as heating medium, can be heated with hot water. By introducing a new heat transfer fluid, the low temperature heat can instead be transferred from the current cold utility systems and thereby reduce the energy demand for compressor work in the refrigeration systems (see 3.1.6).

Table 1 Heat sinks that can be provided with heat from the hot water system at 79 ^{o}C

	Process stream						**Hot water system**		
		T in	Tout	Q tot	Q<70 oC	Current	Tin	Tut	Flow
		[^{o}C]	[^{o}C]	[MW]	[MW]	utility	[^{o}C]	[^{o}C]	ton/h
Borealis	HPPE4	-20	51	0.3	0.3	4bar(g)	55	20	6.4
PE			Total Borealis PE		0.3 MW			20.0 oC	6 ton/h
Borealis	E-1608	26	41	2.5	2.5	1.8bar(g)	79	55	90.4
Cracker	E-1890	52	53	3.1	3.1	1.8bar(g)	79	57	122.6
	E-1845 A/B	55	56	21.2	21.2	1.8bar(g)	79	60	977.7
			Total Borealis CR		26.8 MW			59.3 oC	1191 ton/h
INEOS	Air to dryer PM7	8	135	1.7	0.7	Flue	79	55	25.8
	Air to dryer PM8	20	240	7.0	1.3	Flue	79	55	64.3
	Air to dryer PM8	8	20	0.5	0.5	6bar(g)	79	55	
	Air to dryer PM9	8	170	1.6	0.5	Flue	79	55	19.2
	Fluid dryer	8	55	0.4	0.4	20bar(g)	79	55	14.4
			Total Ineos		3.4 MW			55.0 oC	124 ton/h
		Total heat sinks in hot water system			30.5 MW			58.7 oC	1321 ton/h

Table 2 Heat sinks that can be provided with heat from the hot water system at 97 °C

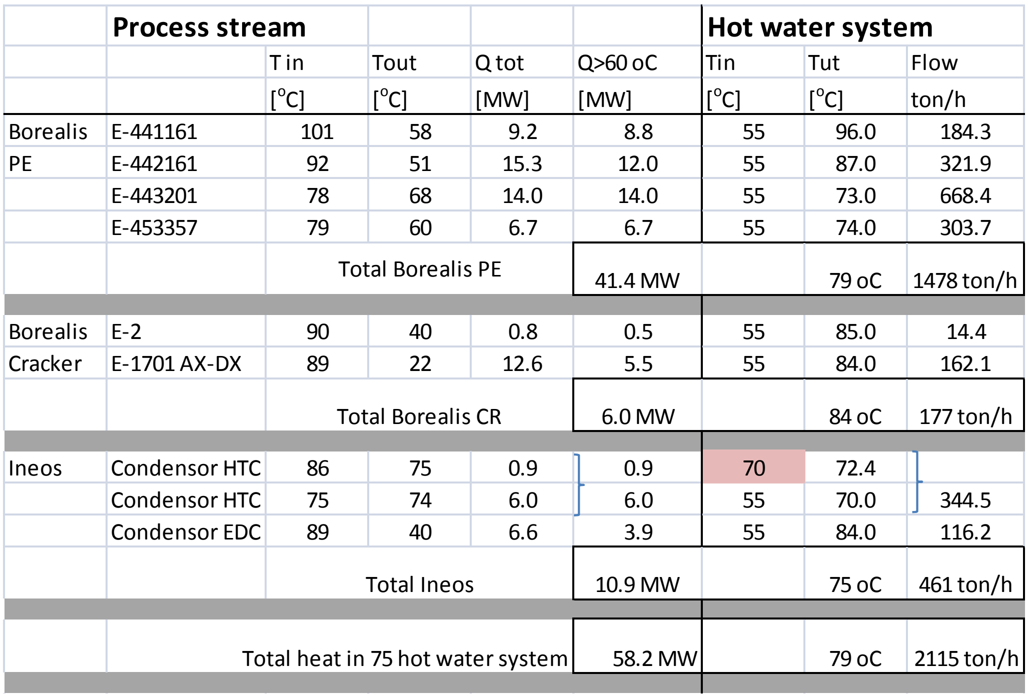


	Process stream						Hot water system		
		T in [°C]	Tout [°C]	Q tot [MW]	Q<90 oC [MW]	Current utility	Tin [°C]	Tut [°C]	Flow ton/h
Borealis	V-5804	15	100	3.3	2.9	4bar(g)	100	75	101
PE			Total Borealis PE		2.9 MW			75.0 oC	101 ton/h
Borealis	E-1609X/ E-1606Y	4	73	2.4	2.4	8.8bar(g)	98	75	234
Cracker	E-1606Y	73	83	3.9	3.9	8.8bar(g)	98		
	E-1802	43	84	4.1	4.1	1.8bar(g)	98	75	152
	Demin	44	128	17.6	9.7	1.8bar(g)	98	75	361
	Condensate CT17(	40	80	3.0	3.0	1.8bar(g)	98	75	112
			Total Borealis CR		23.0 MW			75.0 oC	859 ton/h
Perstorp	1 Gas heater	10	190	0.8	0.4	40bar(g)	98	75	13
	24 Reboiler	82	83	5.8	5.8	2bar(g)	98	87	453
			Total Perstorp		6.2 MW			86.7 oC	466 ton/h
	Total heat sinks in hot water system				32.1 MW			78.8 oC	1426 ton/h

3.1.3 Heat sources

Table 3 and Table 4 include all the heat sinks and suggested heat sources. All heat exchangers included are categorized as A, but all category A heat sources are not listed. The tables show that there is still a surplus of heat that can be generated. The cost of the hot water system can be reduced by selecting the least costly installations. Excess heat can be used for other purposes such as electricity generation in an ORC(Organic Rankine Cycle) unit and/or delivery to a district heating network.

Table 3 Heat sources suggested for the hot water system at 79 °C



	Process stream					Hot water system		
		T in [°C]	Tout [°C]	Q tot [MW]	Q>60 oC [MW]	Tin [°C]	Tut [°C]	Flow ton/h
Borealis	E-441161	101	58	9.2	8.8	55	96.0	184.3
PE	E-442161	92	51	15.3	12.0	55	87.0	321.9
	E-443201	78	68	14.0	14.0	55	73.0	668.4
	E-453357	79	60	6.7	6.7	55	74.0	303.7
		Total Borealis PE			41.4 MW		79 oC	1478 ton/h
Borealis	E-2	90	40	0.8	0.5	55	85.0	14.4
Cracker	E-1701 AX-DX	89	22	12.6	5.5	55	84.0	162.1
		Total Borealis CR			6.0 MW		84 oC	177 ton/h
Ineos	Condensor HTC	86	75	0.9	0.9	70	72.4	
	Condensor HTC	75	74	6.0	6.0	55	70.0	344.5
	Condensor EDC	89	40	6.6	3.9	55	84.0	116.2
		Total Ineos			10.9 MW		75 oC	461 ton/h
	Total heat in 75 hot water system				58.2 MW		79 oC	2115 ton/h

Table 4 Heat sources suggested for the hot water system at 97 °C

	Process stream					**Hot water system**		
		T in	Tout	Q tot	Q>80 oC	Tin	Tut	Flow
		[°C]	[°C]	[MW]	[MW]	[°C]	[°C]	ton/h
Akzo	E-6641	115	113	0.5	0.5	75	110	12.5
			Total Akzo		0.5 MW		110 oC	13 ton/h
Borealis	E-421433 /434	106	50	0.6	0.3	75	101	9.8
PE	HPPE13	105	80	4.7	4.7	75	100	161.9
	HPPE25	105	103	6.6	6.6	75	100	226.2
			Total Borealis PE		11.6 MW		100 oC	398 ton/h
Borealis	E-1712 A/B	123	28	1.0	0.5	75	110	11.2
Cracker			Total Borealis CR		0.5 MW		110 oC	11 ton/h
Perstorp	6 Gas cooler	144	35	3.9	2.3	75	110	55.6
	9 Gas cooler	100	30	2.9	0.8	75	95	35.7
	14 Condensor	116	33	6.9	3.0	75	110	73.6
	16 Process cooler	100	82	16.6	16.6	76	95	752.5
	34 Condensor	105	33	1.5	0.5	75	100	17.9
	37 Process cooler	120	90	0.9	0.9	75	110	22.9
	38 Process cooler	112	60	0.7	0.4	75	107	12.0
	39 Process cooler	135	105	0.4	0.4	75	110	10.6
	47 Flash steem co	100	99	0.5	0.5	75	95	21.5
	49 Condensor	100	99	1.4	1.4	75	95	60.3
	52 Condensor	105	35	1.4	0.5	75	100	17.2
	56 Condensor	122	120	2.6	2.6	75	110	64.0
	58 Condensor	100	95	0.5	0.5	75	95	19.4
	65 Rx1 cooler	98	89	4.1	4.1	75	93	201.8
	66 Rx2 cooler	98	95	0.6	0.6	75	93	29.5
			Total Perstorp		35.2 MW		97 oC	1395 ton/h
		Total heat in hot water system			47.7 MW		98 oC	1816 ton/h

3.1.4 Hot water system operating between 55 and 79^{o}C

One way to construct a circulating hot water system operating between 55 and 79 ^{o}C is shown in Figure 9. The plants involved as heat sources and heat sinks are Ineos, Borealis polyethylene (PE) and Borealis Cracker (Cr). The figure also shows that if all the heat sources suggested are used there will be a heat surplus of 22 MW at 79 ^{o}C.

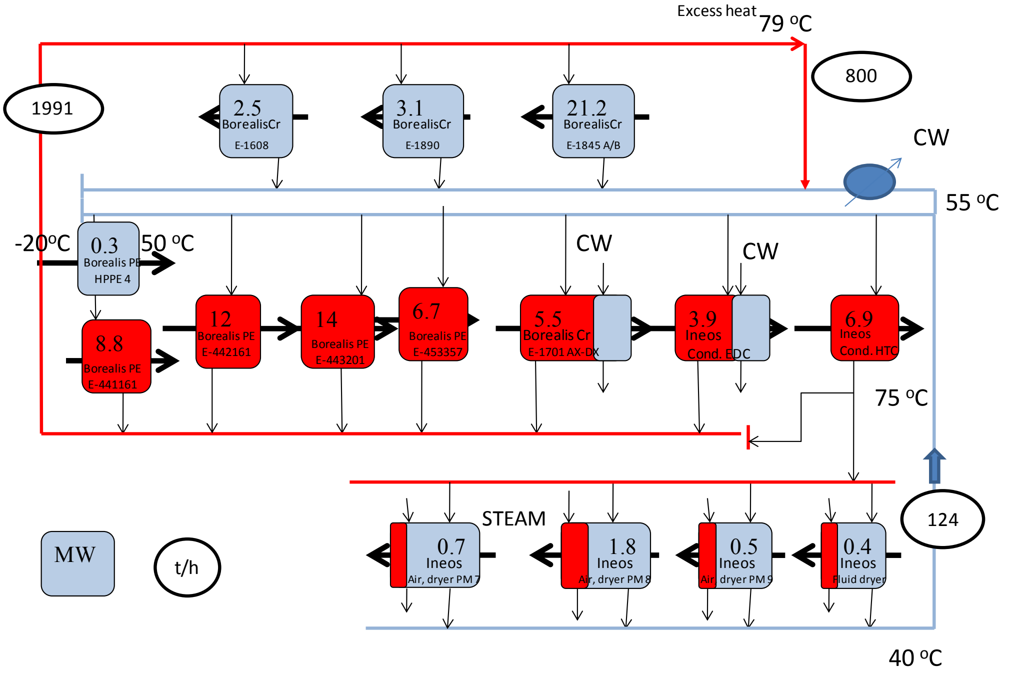


Figure 9 Suggested network for a circulating hot water system operating between 55 and 79 ^{o}C.

3.1.5 Hot water system operating between 75 and 97 °C

The suggested network operating with a supply temperature of ~100 °C is shown in Figure 10. Just as in the network at 75 °C, there is more heat recovered from process than needed for the heat sinks. Approximately 20 MW of 95 °C water is available for other use.

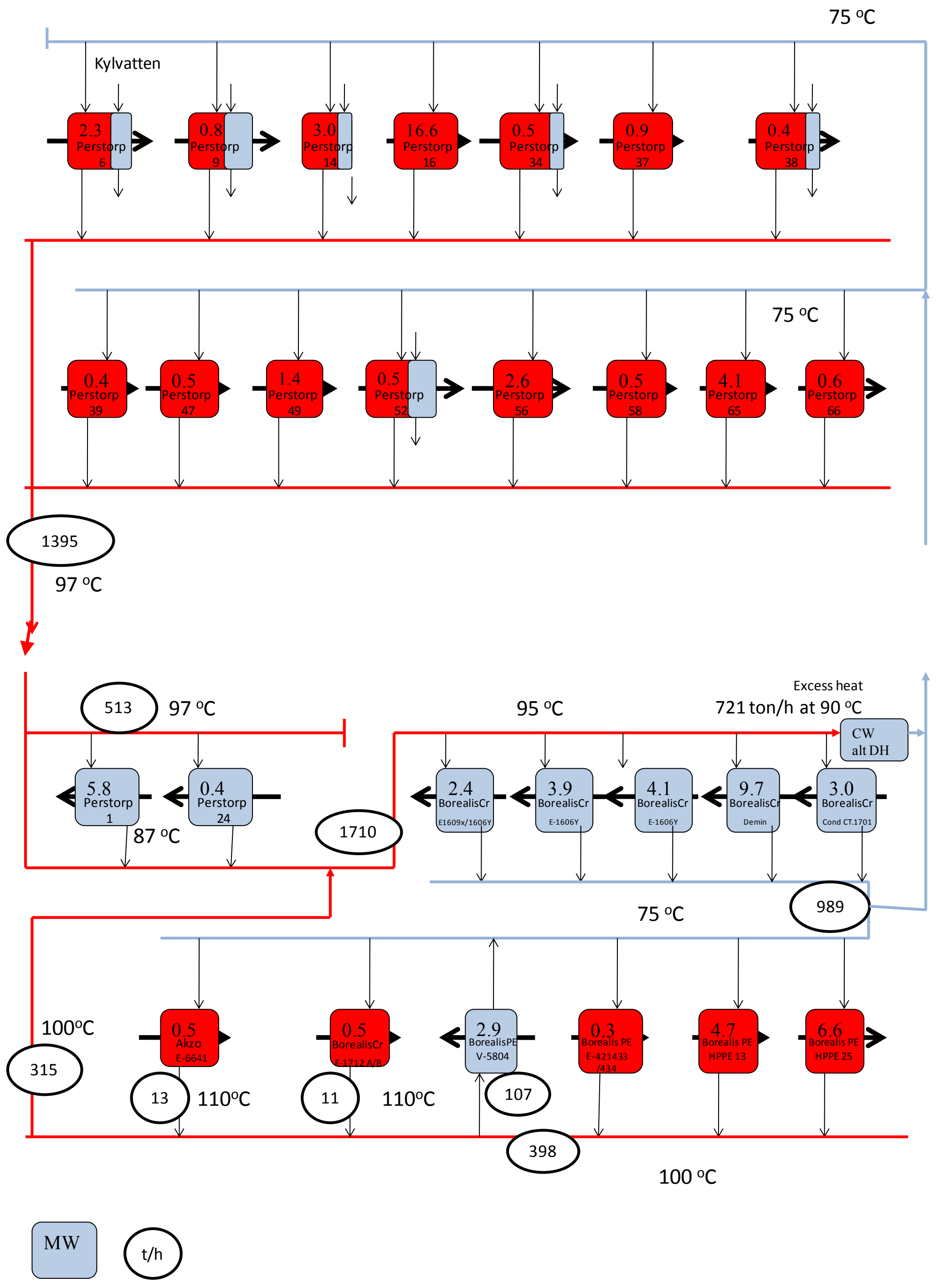


Figure 10 Suggested network for a circulating hot water system operating between 75 and 97 °C.

3.1.6 Heat transfer system below ambient temperature

Five process heaters that operate as heat sinks at sub-ambient temperatures are currently heated with steam. By recovering cooling capacity with a cooling media, both steam and compressor work in the refrigeration systems can be saved. In order to utilize the low temperature a system with a heat transfer fluid designed for low temperatures can be used. 5.4-6.2 MW of steam are currently used for these process stream heaters. There are some intermittent heaters involved and the higher load is when they are in service. The included heat exchangers are listed in Table 5 and a flow sheet is shown in Figure 11.

Table 5 Heat sinks that operate below ambient temperature

	Process stream					**Heat transfer system**		
		T in	Tout	Q tot	Current	Tin	Tut	Flow
		[°C]	[°C]	[kW]	utility	[°C]	[°C]	ton/h
AGA	O2 förångare	-135	20	657	28 bar(g)	25 oC	-95 oC	11,6
	N2 förångare	-150	20	150	28 bar(g)	25 oC	-95 oC	2,6
Akzo	E-113-07-1	-103	40	1000	20bar(g)	45 oC	-95 oC	15,1
	E-113-07-2	-103	40	1000	20bar(g)	45 oC	-95 oC	15,1
Borealis	E-735	-10	4	688	1.8bar(g)	25 oC	-8 oC	44,1
CR	E-736	-30	9	1031	1.8bar(g)	25 oC	-28 oC	41,2
	E-973	-40	3	667	1.8bar(g)	25 oC	-38 oC	22,4
	E-961/E-967	-85	20	1046	1.8bar(g)	25 oC	-83 oC	20,5

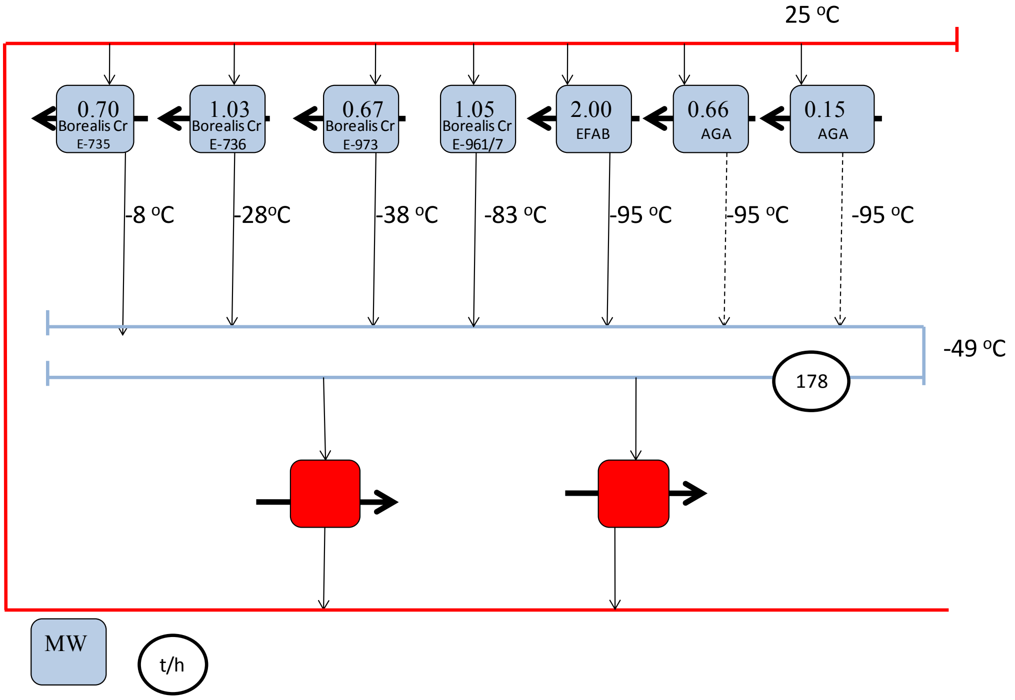


Figure 11 Sub-ambient circulating fluid system. A heat transfer fluid is required for temperatures below 0 °C. There are fluids (e g SYLTHERM) that can be used to -100 °C. The heat capacity of this media is 1.7 kJ/kg,K.

In addition to the steam saving, the heat transfer fluid can transport cooling energy from the current cooling systems and decrease the amount of compressor work required to operate the existing refrigeration system units.

Cooling utility at low temperature is costly to produce and there is an incentive to try to cool these low temperature hot streams with as cold streams as possible, Figure 12. This suggests that the streams with temperatures below -90^{o}C should be used in a separate system. A detailed design of how to use the cold heat transfer liquid has not been conducted.

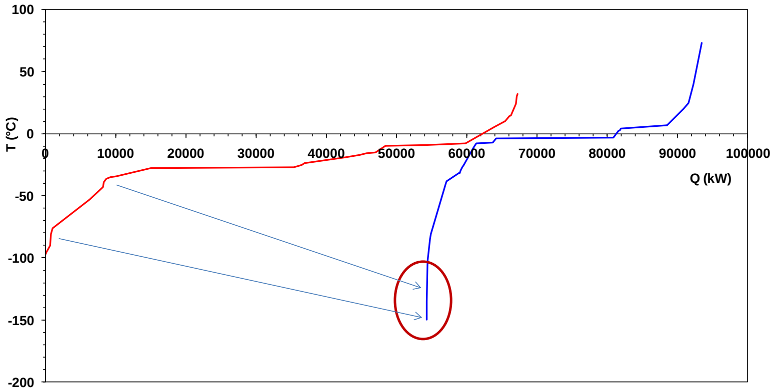


Figure 12 Energy demand for cooling at sub-ambient temperature increase drastically with decreasing temperature, thus heat sinks at temperatures below ambient is best used to cool heat sources at as low temperatures as possible.

3.1.7 Overview of consequences of new heat transfer systems

The introduction of hot water system and heat transfer fluid could avoid the use of steam and cooling water, see Figure 13. The heat from the heat sources, formerly emitted to the cooling water will now be used to heat the heat sinks. Some of the steam used to heat streams well below ambient can be replaced with heat from cooling systems. 65.4 MW steam and 2.5 MW fuel gas can be saved by introducing a hot water system and a heat transfer system.

There will be additional reduction in energy use in the cooling system, but this has not been estimated yet.

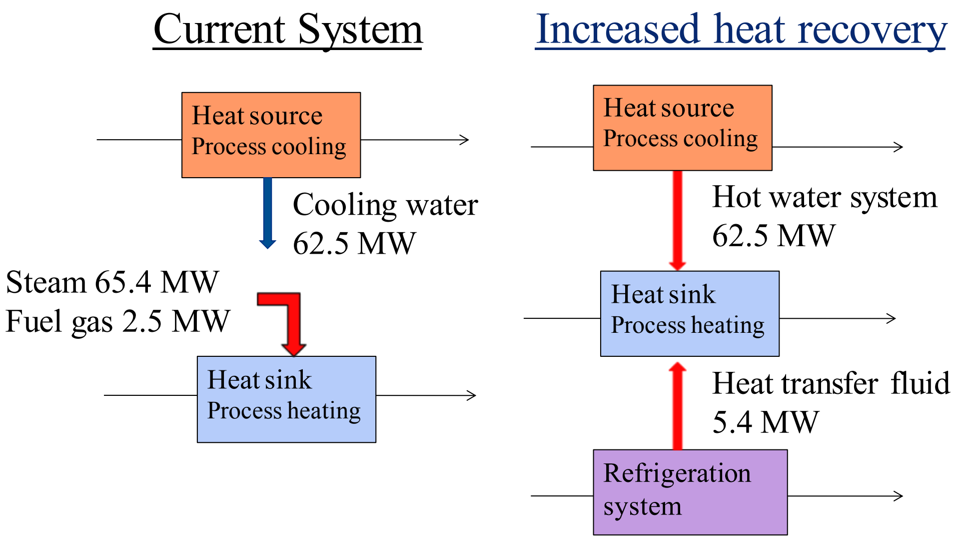


Figure 13 Introduction of hot water system and heat transfer fluid will avoid the use of steam and cooling water. The heat from the heat sources, formerly discharged to the cooling water will now be used to heat the heat sinks. Some of the steam used to heat streams well below ambient can be replaced with heat from cooling systems. 65.4 MW of steam and 2.5 MW of fuel gas can be saved by introducing a hot water system and a heat transfer system.

Table 6 Summery: Utility steam and fuel gas heating replaced by circulating heat transfer systems

[MW]	Steam	Fuel gas
Steam replaced by hot water system	60.0	
Steam replaced by heat transfer fluid below ambient	5.4	
Fuel gas replaced by hot water system		2.5
Total	65.4	2.5

3.2 Steam generation and change of steam pressure

3.2.1 Additional steam generation from excess process heat

Steam generation from excess process heat is well exploited already, but we have identified some process stream coolers, currently cooled by cooling water, where released process heat could instead be used to produce steam. The TSC curve indicates that an additional 25 MW of 2 bar(g) steam can be produced from recovered process heat. Table 7 lists the three process coolers categorized as A that can generate an additional 5.8 MW of steam.

Table 7 Stream data for heat sources that can be cooled with boiler feed water and generate 5.8 MW of steam.

		Tin	Tut	Q [kW]	Current utility
Borealis PE	HPPE26	228	210	1600	CW
Borealis PE	HPPE11	160	145	3550	Air
Ineos	Flue gas, cracker furnace	231	100	700	Air

3.2.2 Reducing steam pressure for process stream heaters

Process stream heaters that use utility steam at a higher pressure than necessary, considering the process stream temperature requirements, were identified and categorized in the TSA I study. One benefit of reducing steam use at higher levels is that the potential for co-generation of electric power increases. A more important reason to reduce steam pressure is that increased steam demand at lower pressure also facilitates use of excess steam from other plants. Replacing higher utility steam pressure with 1 or 2 bar(g) steam where possible in category A process stream heaters could increase the use of low pressure steam by approximately 20 MW. Hence these are necessary measures to be able to make use of the surplus steam.

A list of suggested changes can be found in Appendix A.

3.2.3 New steam users

Use of low pressure steam can also be increased by replacing other heating media.

Flue gas air heaters, currently using heat from fired fuel gas, can be partly be heated with hot water and steam, and this will increase the use of low pressure steam. 2.5 MW of hot water and 2.8 MW of low pressure steam will reduce the fuel gas use by 5.3 MW, see Figure 14.

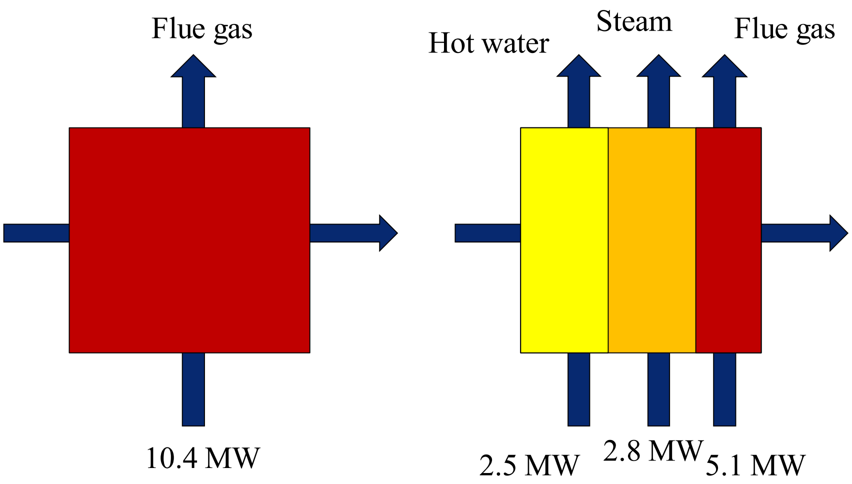


Figure 14Flue gas heating of air for use in dryers can be replaced by hot water and steam

The total effect of the measures suggested in 3.2 is summarized in Table 8.

Table 8 Summery: Consequences of changes in steam use

[MW]	Steam	Fuel gas
Steam generated from process heat	5.8	
Increased low pressure steam use when using steam at lower pressure level	20	
Fuel gas replaced by steam	+2.8	-2.8

In Table 9 we summarize the results so far, there is a potential to reduce steam production in boilers with external fuel by 68.4 MW. This would together with other reductions in fuel gas savings add up to 90.8 MW of avoided use of external fuel. The analysis assumes that there is a common utility system and the reduction in external fuel use depends on a redistribution of steam within the cluster.

Table 9 Summery of 3.1 and 3.2

	[MW]
Steam use reduction due to hot water system, Table 6	65.4
Steam generation from process heat, Table 8	5.8
Steam use increase, Table 8	-2.8
Potential reduction of steam generation	68.4
Corresponding savings in fuel gas with a boiler efficiency of 0.8	85.5
Other savings of fuel gas: replaced by hot water	2.5
replaced by LP-steam	2.8
Total reduction of fuel gas	90.8

3.3 Redistribution of steam between plants

Part of the steam supplied to the steam system is generated by excess process heat. If process generated steam is sufficient to cover the process demand at one plant, steam use reduction at that plant will not correspond to boiler fuel savings, unless the steam can be redistributed and used elsewhere within the cluster.

3.3.1 Re-distribution of LP steam within the cluster

Figure 15 shows how LP steam can be distributed within the cluster. The black dashed lines represent new low pressure steam lines which must be constructed between the plants.

Most of the gaseous by-products from production processes at Perstorp are currently used as boiler fuel for steam production on-site. This steam production is however not necessary if Perstorp can receive 40 MW of low pressure steam from other plants within the cluster. From a total site perspective, it is better if this fuel is used in another boiler within the cluster for production of steam at a higher pressure level, thereby providing the opportunity to co-generate additional electricity, for example.

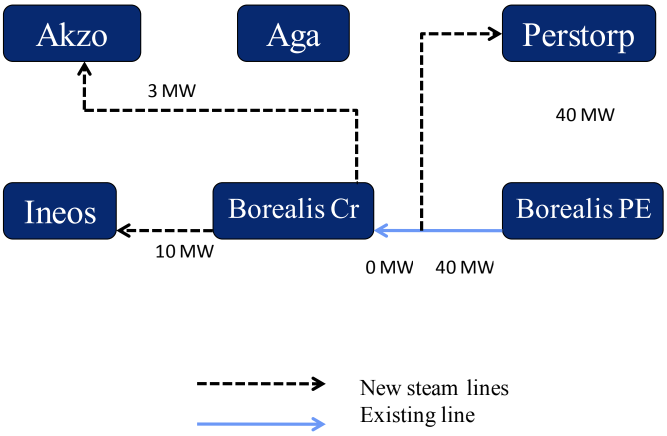


Figure 15 The steam surplus of low pressure steam at Borealis can be delivered to the other plants. The heat flows indicated in the figure are the amounts of steam that can be distributed if the category A measures are implemented.

The steam distribution schematic shown in Figure 15 is based on the steam balances that apply if all the category A measures are implemented.

3.4 Results if category A measures are implemented together with redistribution of LP steam

Identifying possible ways to save purchased fuel is the ultimate goal of a total site analysis. The results from the theoretical study indicate that the present external heat demand of 125 MW can be reduced to 58 MW if all category A measures are implemented, see Figure 3.

Using the data received for the current steam systems, steam produced in boilers is estimated to 126 MW. After low pressure steam redistribution, the steam demand from boilers could be reduced by 67 MW and the new steam production would be 59 MW. This includes steam from by-products from Perstorp (27 MW) that must be fired within the cluster (but not necessarily at Perstorp’s site).

The total potential for fuel reduction in Table 9 was 90.8 MW. Figure 16 shows where the use of external fuel will be reduced based on the individual steam balances, and the total reduction of fuel use would be 89.2 MW. The difference between actual and potential fuel reduction indicates that when these measures are implemented, there would be an excess of low pressure steam at the total site.

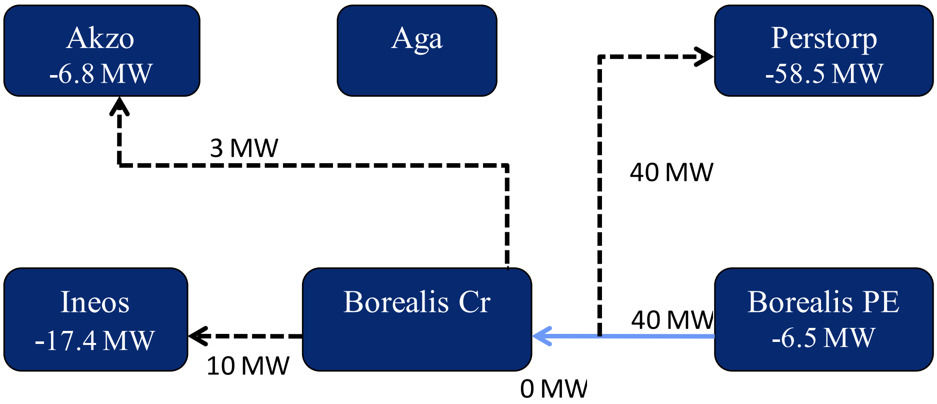


Figure 16 The reduction in fuel use after implementing all category A measures and after LP-steam has been redistributed within the cluster. Assumed boiler efficiency = 0.8.

3.5 Further measures to reduce fuel used for steam production

So far we have only assumed that LP-steam should be redistributed. If more process generated steam can be redistributed within the cluster there are possibilities to reduce fuel firing in boilers even further.

By examining the steam balances at the individual plant sites we identified the following possibilities to distribute steam at other steam levels:

Table 10 Steam demand that can be covered by steam from an external boiler

Steam from Borealis CR to:	HP	MP	LP	
[MW]	40 bar(g)	8.8 bar(g)	4 bar(g)	1.8 bar(g)
Akzo	15			3
Borealis PE	9			
Ineos	5	6		10
Perstorp		4	40*	

* Steam from Borealis PE

If steam would be distributed according to the calculated values in Table 10, there would not be a need for steam production from external fuels at other sites than Borealis Cracker(CR). At the Borealis Cracker plant, the steam production would increase by 22.5 MW. However, for the total site the steam generated with external fuel could be further reduced by 5.5 MW. Since there is a possibility to generate electricity when delivering 8.8 bar(g) steam the electricity generation would increase by 1.5 MW. The savings in fuel would be 6.9 MW.

Redistribution of steam at all pressure levels does not reduce the fuel used for steam production much, considering the investment cost. However, some options might be worth further consideration. MP steam from Borealis Cracker to Ineos does not involve long steam lines and could increase electricity production.

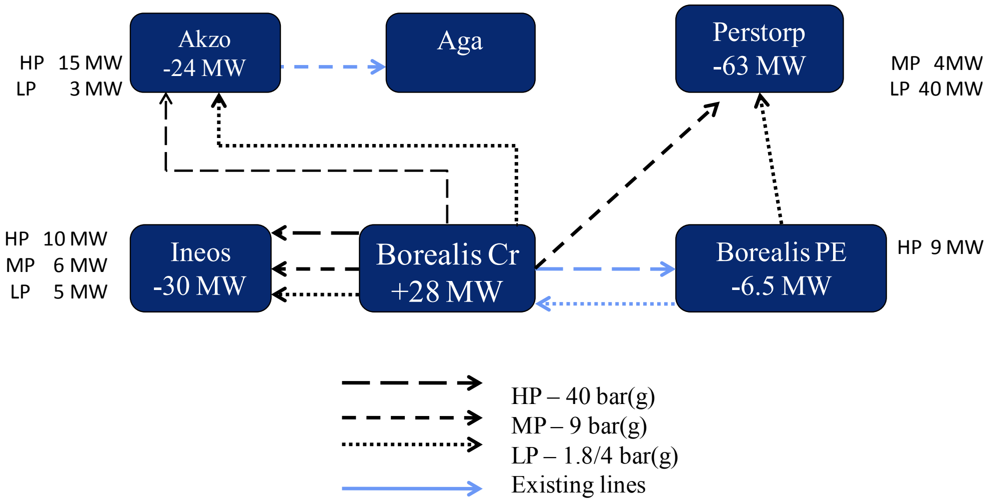


Figure 17 Fuels savings/increase at the separate sites if steam at all steam levels is distributed according to the figure.

4 SUMMARY OF RESULTS IF ALL CATEGORY A MEASURES ARE IMPLEMENTED

If all the proposed measures listed as category A are implemented fuel gas use can be reduced by 89 MW.

Implementation of the following measures is necessary to reach the potential savings:

- A hot water system and heat transfer circuit that will recover heat from process heat and deliver 65.4 MW heat to heat sinks currently heated by steam and 2.5 MW heat to heat sinks currently heated with fuel gas
- Utilizing process heat to generate 5.8 MW of steam
- Redistribution of low pressure steam within the cluster to avoid steam excess at one or several plants
- Conversion of identified process stream heaters (see Appendix A) where low-pressure steam can be used as heating medium, instead of the higher pressure steam used today. This will increase the possibility to transfer more low-pressure steam
- Gaseous by-product gases currently fired in Perstorp boilers must be fired in a boiler at a different process plant

If steam at pressures above low pressure steam can be redistributed the total use of fuel gas can be reduced further.

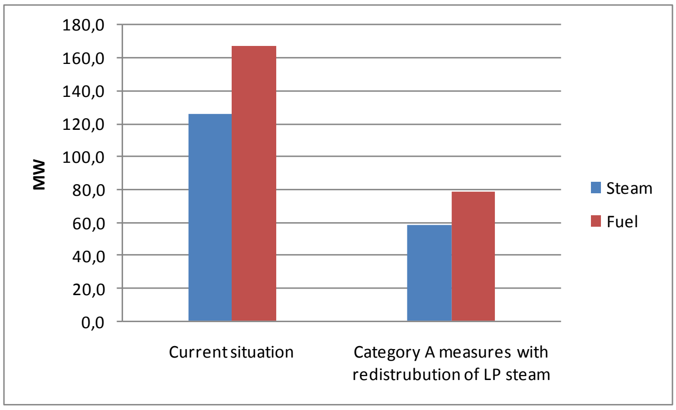
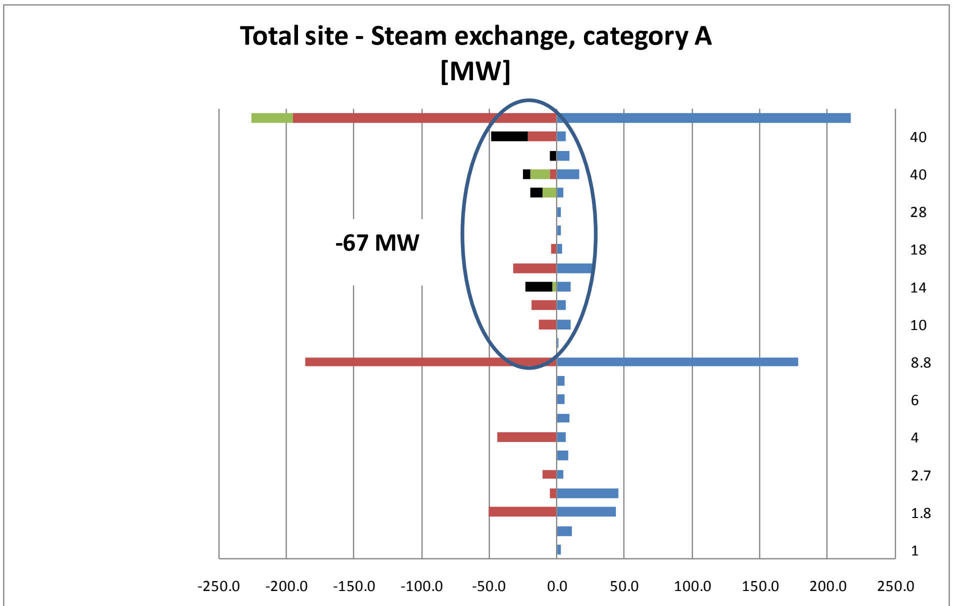


Figure 18 Resulting demand for steam and fuel when all category A measures are implemented

Figure 19 show the reduced steam production as black bars at different steam pressure levels. Also shown is the steam demand at each pressure level to the right (blue bar), steam generated from excess process heat or incineration of by-products (red bar), steam generated in boiler with external fuel (green bar) and avoided steam production after implementing category A measures (black bar).



Steam pressure, bar(g)	1	1	1.8	2	2.7	3	4	5	6	7	8.8	9	10	11	14	20	18	20	28	28	40	40	40	85
🟦 Steam demand[MW]	2.8	11.1	43.5	45.6	4.7	8.0	6.7	9.4	6.1	5.3	178.1	1.3	10.4	6.2	9.9	26.9	4.1	2.6	2.8	4.9	16.6	9.1	7.0	217.0
🟥 Steam gen. in process [MW]	0.0	-0.6	-50.0	-5.3	-10.7		-43.7	-0.7	-0.6	0.0	-185.		-13.4	-18.9		-32.4	-4.5	0.0	0.0	0.0	-5.5		-21.4	-195.
🟩 Steam gen. by external fuel [MW]															-3.6					-10.3	-14.0	0.0		-30.7
■ Avoided steam production [MW]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-19.6	0.0	0.0	0.0	0.0	-9.7	-5.4	-5.2	-27.2	0.0

Figure 19 The figure shows steam demand at each pressure level to the right (blue bar), steam generated in process by excess heat or incineration of by-products (red bar), steam generated in boiler with external fuel (green bar) and avoided steam production after implementing category A measures (black bar).

Figure 20 shows all the new suggested exchange of energy between the different process plants within the Stenungsund industrial cluster. The heat to the process heaters below ambient is not shown, since the heat sources have not been specified. Fuel from Perstorp and Borealis PE can go to any boiler and not necessarily to the Borealis Cracker.

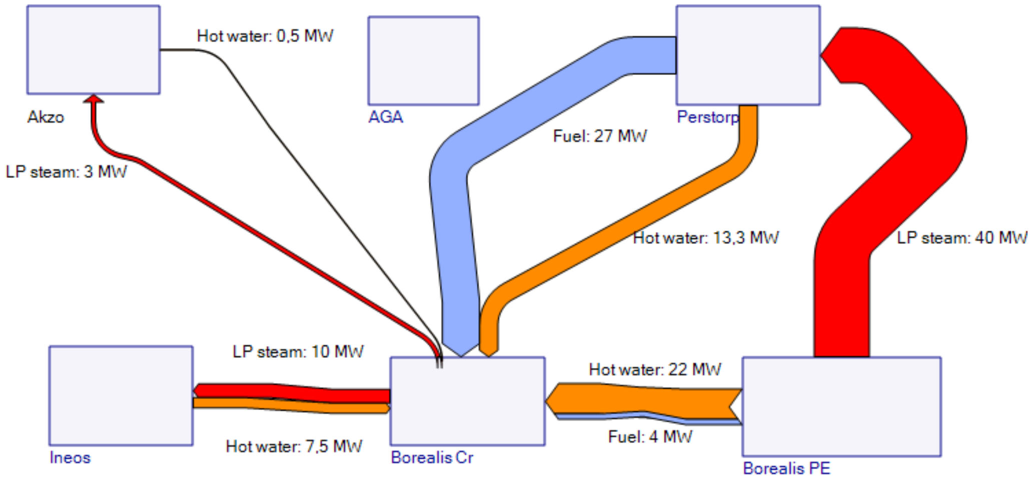


Figure 20 Energy transfer between the participating plants

Losses in long steam lines are neglected in this report but might have a significant influence on the amount of steam delivered between the plants. Therefore it should be taken into account in a later stage.

5 COST ESTIMATE

5.1 Investment

Investment in new heat exchangers, pipes for redistribution of steam, condensate return pipes, fuel and hot water distribution will be needed to implement all category A measures and to achieve the savings calculated in this report.

Further process design has to be carried out to find out in detail the size of new heat exchangers, possibilities to use old heat exchangers and to estimate other changes to the utility systems. To get an approximate estimate, the investment has been calculated with the following assumptions:

Table 11 Unit cost for heat exchangers and piping

Average cost of new heat exchanger	1.3 MSEK
Hot water pipes between plants	7 kSEK/m
Heat transfer pipes (below ambient)	10 kSEK/m
Steam + condensate pipes, diameter ~500 mm	35 kSEK/m
Steam + condensate pipes, diameter ~250 mm	15 kSEK/m
Fuel pipe	5 kSEK/m

Approximate heat exchanger areas were calculated for most of the included heat exchangers (listed in Appendix B) in order to estimate an investment cost to use at this stage. The area calculations are based on the temperature difference between the process stream and utility and with general values for heat-transfer coefficient for heat exchangers. There was no consideration taken to material requirements or other process specific requirements. The aim of such calculations was to get an approximate investment cost and not to be a first step in a process design.

To be able to heat and cool with new utility (hot water and heat transfer system), and to use lower steam pressure level in some exchangers, we assume that 62 new heat exchangers have to be installed.

Transfer lines for all the energy transferred within the cluster indicated in Figure 20 (hot-water system, heat transfer system below ambient, steam transfer and condensate return and fuel) are included in Table 12 using unit costs from Table 11.

The total investment adds up to 663 MSEK, see Table 12.

Table 12 Investment cost for the total project

	Total cost
Equipment	[MSEK]
Heat exchangers	80
Pumps	1
	81
Total cost, installed	198
Pipelines	
HW1	16
HW2	28
HTr	10
Steam/condensat Borealis PE-Perstorp	88
Steam/condensat Borealis Cr-Akzo	12
Steam/condensat Borealis Cr-Ineos	28
Fuel from Perstorp	13
	194
Total cost installed	393
Total cost inc. Design & Engineering	510
Total cost inc. 30 % contingency	663

5.2 Operation costs

If all Category A-measures are implemented there will be changes in operation costs, see Table 13. All costs are estimated assuming 8400 full load operating hour per year.

The reduction of steam use will result in a reduction of fuel fired in boilers and fired heaters. The reduction is 89 MW and the economic value of such savings is calculated with two values of fuel cost. One is the value today, 270 SEK/MWh, resulting in a reduction of operation cost of 200 MSEK/yr. The savings is also calculated with a future value based on the energy scenarios developed at Chalmers[2]. This future fuel price is set to 350 SEK/MWh and would result in a reduction of operation cost of 260 MSEK/yr. The fuel cost values include the cost for TEP (tradable emission permits), i.e. cost associated with CO_2 emissions in the EU Cap-and-Trade system.

The hot water system pump around and transportation of other fluids such as condensate and fuel requires electricity for pump work. The pump work is estimated to 700 kW. With an electricity price of 600 SEK/MWh, the annual cost would be 4 MSEK/yr.

Maintenance is calculated as 2 % of the total investment cost, 13 MSEK/yr.

The introduction of hot water systems would reduce the energy transferred to the cooling water system and where cooling towers are used, it would reduce the demand for make-up water. Considering the situation with limited fresh water available, this would be valuable to the cluster. This value has, however, not been translated to an income in this cost estimate.

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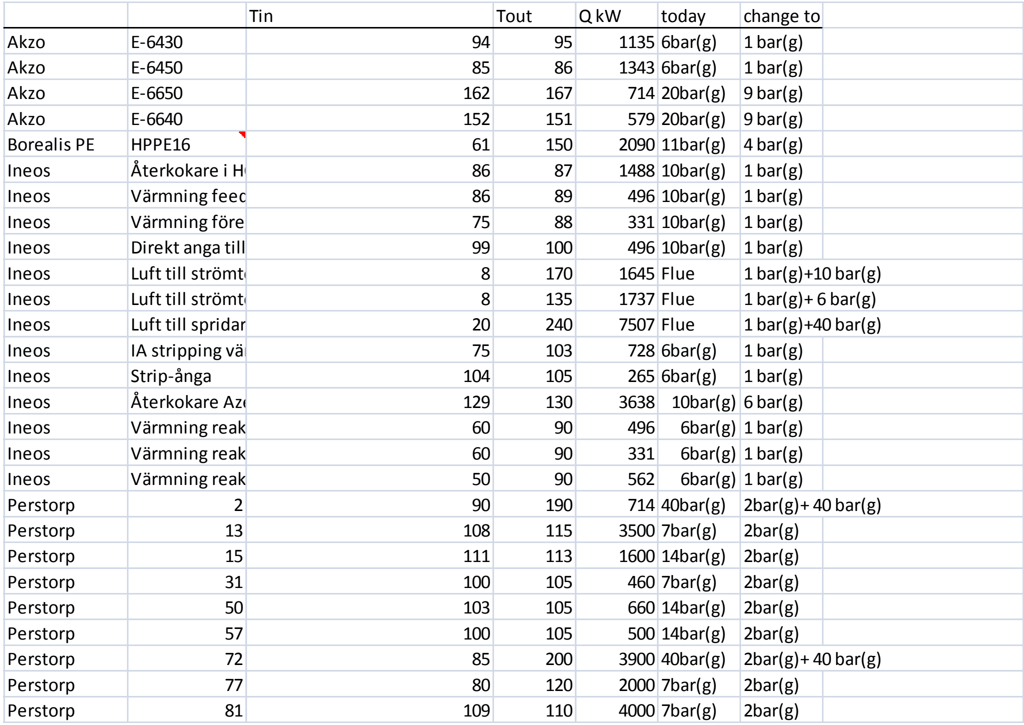
[2] Simon Harvey and Erik Axelsson. ”Scenarios for assessing profitability and carbon balances of energy investments in industry”. AGS Pathways report 2010:EU1. AGS, The Alliance for Global Sustainability, Chalmers, Göteborg, 2010

Table 13 Annual operation costs if Category A-measures are implemented. The operation cost is calculated using two values, todays price and a future fuel price.

Value of fuel saved		[SEK/MWh]	270	350
Electricity		[SEK/MWh$_{el}$]	600	800
Reduction in fuel use	-89 MW		-200	-260
Pump work	700 kW		4	5
Maintenance cost	2 % of investment		13	13
		Net per year, [MSEK/yr]	-183	-242

APPENDIX A

List of heat exchangers where steam pressure can be reduced, category A



		Tin	Tout	Q kW	today	change to
Akzo	E-6430	94	95	1135	6bar(g)	1 bar(g)
Akzo	E-6450	85	86	1343	6bar(g)	1 bar(g)
Akzo	E-6650	162	167	714	20bar(g)	9 bar(g)
Akzo	E-6640	152	151	579	20bar(g)	9 bar(g)
Borealis PE	HPPE16	61	150	2090	11bar(g)	4 bar(g)
Ineos	Återkokare i H	86	87	1488	10bar(g)	1 bar(g)
Ineos	Värmning fee	86	89	496	10bar(g)	1 bar(g)
Ineos	Värmning före	75	88	331	10bar(g)	1 bar(g)
Ineos	Direkt anga till	99	100	496	10bar(g)	1 bar(g)
Ineos	Luft till strömt	8	170	1645	Flue	1 bar(g)+10 bar(g)
Ineos	Luft till strömt	8	135	1737	Flue	1 bar(g)+ 6 bar(g)
Ineos	Luft till spridar	20	240	7507	Flue	1 bar(g)+40 bar(g)
Ineos	IA stripping vä	75	103	728	6bar(g)	1 bar(g)
Ineos	Strip-ånga	104	105	265	6bar(g)	1 bar(g)
Ineos	Återkokare Az	129	130	3638	10bar(g)	6 bar(g)
Ineos	Värmning reak	60	90	496	6bar(g)	1 bar(g)
Ineos	Värmning reak	60	90	331	6bar(g)	1 bar(g)
Ineos	Värmning reak	50	90	562	6bar(g)	1 bar(g)
Perstorp	2	90	190	714	40bar(g)	2bar(g)+ 40 bar(g)
Perstorp	13	108	115	3500	7bar(g)	2bar(g)
Perstorp	15	111	113	1600	14bar(g)	2bar(g)
Perstorp	31	100	105	460	7bar(g)	2bar(g)
Perstorp	50	103	105	660	14bar(g)	2bar(g)
Perstorp	57	100	105	500	14bar(g)	2bar(g)
Perstorp	72	85	200	3900	40bar(g)	2bar(g)+ 40 bar(g)
Perstorp	77	80	120	2000	7bar(g)	2bar(g)
Perstorp	81	109	110	4000	7bar(g)	2bar(g)

APPENDIX B

List of heat exchangers where area has been calculated to use as a basis for investment cost calculations. The current area is included in the table for a few heat exchangers.

HXTR	Location	Tin	Tout	m	Tin	Tout	Q	U	A current	A	HXTR costs	Comments
		[°C]	[°C]	[ton/h]	[°C]	[°C]	[kW]	[W/m2C]	[m2]	[m2]	[SEK]	
Hot water circuit (76/55)												
Heat sources												all HXTR use carbon steel
E443201	Borealis PE	55	73	668,4	78	68	13970	200		8343	11104006	Jacket reactor/Shell and tube assum
E443357	Borealis PE	55	74	303,7	79	60,5	6699	700		1824	2427999	Shell and tube single pass assumed
HPPE13	Borealis PE	55	100	90	105	80	4700	700		540	719137	Shell and tube single pass assumed
E-1701 AX-DX	Borealis Cr	55	84	162,1	89	60,5	5458	200		5202	6923731	Shell and tube single pass assumed
E-1703 A/B	Borealis Cr	55	77	142,6	82	60,5	3643	200		3472	4621318	Shell and tube single pass assumed
Kondensor HTC k	INEOS	55	70	344,5	75	74	6000	650	576	903	1202080	Shell and tube single pass assumed
Heat sinks												
E-1845 A/B	Borealis Cr	76	58	1060,3	55	56	21230	700		3550	4725392	Shell and tube single pass assumed
Preheat demin	Borealis Cr	76	60	326,2	44	73	6090	700		1120	1491051	Shell and tube single pass assumed
E-1609X/E-1606Y	Borealis Cr	76	51	81,6	4	73	2377	700		212	366016	Shell and tube single pass assumed
E-1890	Borealis Cr	76	59	163,1	52	53	3090	700		334	532387	Shell and tube single pass assumed
HPPE4	Borealis PE	58	31	8,2	-20	51	260	700		17	66548	Shell and tube single pass assumed
Luft till spridarski	INEOS	70	32	40	20	60	1771	200		807	1074395	Shell and tube single pass assumed
Luft till strömtork	INEOS	70	47	20	8	60	528	201		123	282831	Shell and tube single pass assumed
Luft till strömtork	INEOS	70	62	20	8	60	711	200		157	332742	Shell and tube single pass assumed
Hot water circuit (90/70)												
Heat sources												
6 Gaskylning	Perstorp	20	25	48,7	144	75	2967	200	116	981	1109380	U-tube assumed/ corr. factor 0,85
9 Gaskylning	Perstorp	70	95	28,5	100	75,5	1657	200	57	1579	1786685	U-tube assumed/ corr. factor 0,85
14 Kondensor	Perstorp	70	105	73,6	116	75	4655	650	268	941	1064681	U-tube assumed/ corr. factor 0,85
56 Kondensor	Perstorp	70	110	60,5	122	120	2600	650	92	153	282831	U-tube assumed/ corr. factor 0,85
37 Processkylare	Perstorp	70	110	21,6	120	90	930	500	41	129	240406	U-tube assumed/ corr. factor 0,85
39 Processkylare	Perstorp	70	110	9,3	135	105	430	500	8	41	113132	U-tube assumed/ corr. factor 0,85
47 Flashånga kon	Perstorp	70	95	17,2	100	99	500	1000	6	38	113132	U-tube assumed/ corr. factor 0,85
58 Kondensor	Perstorp	70	95	15,5	100	95	450	650	15	68	169698	U-tube assumed/ corr. factor 0,85
65 Rx1 kylare	Perstorp	70	93	153,5	98	89	4100	650		601	680472	U-tube assumed/ corr. factor 0,85
Rx2 kylare	Perstorp	70	93	22,5	98	95	600	650		74	169698	U-tube assumed/ corr. factor 0,85
Heat sinks												
E-1606Y	Borealis Cr	87	77	315,7	73	83,5	3875	200		5174	6886879	Shell and tube single pass assumed
E-1802	Borealis Cr	87	61	90,2	43	84	4055	200		2422	3223418	Shell and tube single pass assumed
1 Gasvärmare	Perstorp	101	87	22,6	10	90	357	200	13	71	169698	U-tube assumed/ corr. factor 0,85
24 Återkokare	Perstorp	101	89	428,5	82	83	5800	700	108	723	961890	Shell and tube single pass assumed
Cooling media transfer system												
Heat sources												
-												
Heat sinks												
LPG-heater	Borealis Cr	25	-8	44,1	-10	4	688	650		131	282831	Shell and tube single pass assumed
Propane heater	Borealis Cr	25	-28	41,2	-30	9	1031	650		236	366016	Shell and tube single pass assumed
Propylene heate	Borealis Cr	25	-38	22,4	-40	3	667	650		123	282831	Shell and tube single pass assumed
Ethylene vaporiz	Akzo Nobel	25	-95	35,3	-103	20	2000	700		448	632209	Shell and tube single pass assumed
Förångare, O2	AGA	25	-100	11,1	-135	20	657	700		61	183008	Shell and tube single pass assumed
Förångare, N2	AGA	25	-100	2,5	-150	20	150	700		11	49911	Shell and tube single pass assumed