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OPTIMAL LOCATION OF BIOREFINERIES

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INTRODUCTION

Biorefineries can be built as stand-alone systems or co-located with existing systems such as industrial plants or district heating systems. There are different criteria for selecting a suitable location for a biorefinery, for example closeness to raw material, product markets and heat sinks and sources or existing experiences and know-how. Further, the entire upgrading process from raw material to end products does not necessarily have to be located at the same place. Intermediate products could be produced and transported to other sites for further upgrading. Thus, the suitable location for a biorefinery depends on a trade-off between different parameters. Since biorefineries are not implemented to a large extent today and new technologies are constantly being developed, there is a need for studies that address questions such as how different overall performance parameters (overall efficiency, economic performance and GHG emissions reduction potential) are affected by the choice of location of the different stages in the biomass upgrading process, the pros and cons of different location options and what is of specific importance to consider concerning the location of biorefineries. It is relatively easy to quantify the effect of parameters such as transportation distances for raw materials and products or the degree of heat integration. The effect of other parameters are more difficult to quantify, e.g. experience and know-how concerning handling of the raw material, the processes or the products.

This chapter describes different criteria for selecting the location of biorefineries. Examples of biorefinery concepts are presented together with a discussion of the pros and cons of different candidate locations. One important driving force for location of biorefineries which could improve the overall efficiency significantly is the opportunities for heat integration, which will be in special focus in the latter part of this chapter. A methodology for quantifying the possibilities for heat integration within and between different processes is described and an example that

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illustrates the consequences of different locations with different possibilities for heat integration is presented.

CRITERIA FOR SELECTING A LOCATION FOR A BIOREFINERY

There are a range of factors that affect the suitable location of a biorefinery plant. *Closeness to raw material* shortens the transportation distances and thereby the emissions and costs associated with distribution of the raw material. Closeness to a harbour could be a way of enabling longer transportation distances at reasonable costs. Also *closeness to product markets and users* could shorten transportation costs. It should be emphasised that the energy density often is much higher for products than for raw materials, thereby enabling more efficient transportation. Possibilities to implement *large-scale production*, economies of scale, would benefit most processes. *Heat integration* of the biorefinery with an existing industrial process or a district heating system could enable excess heat to be used or delivered resulting in less fuel use and thereby reduced heating costs within or outside the biorefinery (see also Chapter 11). Opportunities for *re-use or co-use of existing process units* reduce the investment costs. In the long run, however, it might be better to adjust the processes to the new raw materials and products to achieve higher efficiency. Opportunities to *use existing infrastructures* such as raw material handling systems also reduce the investment cost. There is a significant difference in building an entirely new plant than to add a new process to an already existing plant.

To be able to use e.g. existing process units is not only a question of reduced investment costs. It could also lead to reduced technical risks of implementing biorefinery concepts since the experience and know-how concerning operation (of a part) of the process already exists. In the same way, there could be opportunities to *capitalize on experience and know-how* concerning the raw material and its supply and the products and their markets. Finally, the availability of *financial capital* and willingness to invest is a critical factor.

BIOREFINERY TECHNOLOGIES AND ASSOCIATED SUITABLE LOCATIONS

First we can start by making a distinction between biorefineries that can be located relatively freely and biorefineries that are a natural part or an extension of an existing process. Most biorefinery technologies belong to the first category. However, a number of the technologies that are described in Chapter 6 belong to the second category. These technologies extract valuable products from the material streams in a kraft pulping process, e.g. extraction of hemicelluloses from the wood, extraction of lignin from the black liquor and gasification of black liquor. Gasification (and a certain degree of raw gas cleaning) and extraction steps must take place at the pulp mill, but further upgrading of these components to valuable products such as biofuels, chemicals or materials could be carried out elsewhere. However, there are a number of significant benefits of locating upgrading of the syngas from black liquor gasification at the mill. For example, the gasification process including upgrading to biofuels has a steam surplus whereas the mill has a need for process steam and thereby efficient heat integration can be achieved.

We now return to the first category which includes most biorefinery technologies. For example, the two key conversion processes described in Chapter 2, i.e. gasification (excluding gasification of black liquor) and fermentation of lignocellulosic feedstock, can be located in many different places.

In total, gasification processes have a significant heat surplus. Therefore heat integration with other industrial processes or district heating systems can improve the economic performance as well as the GHG balances of the integrated system as a whole. However, for solid biomass gasification there is no natural integration with another process as in the case of black liquor gasification. Further, there are a limited number of heat sinks that are large enough and that are able to accept excess heat all year around. Several studies show the efficiency gains that can be achieved by integrating motor fuel production via gasification of solid biomass with pulp and paper mills rather than building them for stand-alone operation.[1] Furthermore, it has been shown that integration with a pulp and paper mill generally constitutes a more attractive option for solid biomass gasification plants compared to integration with a district heating system due to a longer operating time.[2] However, the excess heat from gasification processes generally has a very high temperature which makes it suitable for power generation or combined power and heat generation, and it is therefore also possible to make use of the excess heat of stand-alone plants.[3]

Production of ethanol, either as a biofuel or intermediate product, is the most discussed product of the fermentation pathway. Producing lignocellulosic ethanol requires steam. This steam demand could be satisfied by firing process by-products in a combined heat and power (CHP) plant, thereby achieving autonomous operation in stand-alone mode without the need for external fuel. However, these plants have a substantial excess of low temperature heat (below approximately 100°C) and therefore location close to a district heating network could be beneficial. If the plant is located close to a pulp mill with excess steam, the by-products from the ethanol process could be used for other purposes than heating. For example, the lignin could in the future perhaps be used for valuable materials. There is a lignocellulosic ethanol process developed that is similar to the kraft pulping process and that to a large extent can use existing equipment at a kraft pulp mill (see Chapter 6). This could be a way to e.g. introduce lignocellulosic ethanol production at a lower cost.

It is important to study if and how the design of different biorefinery process units could be changed in order to increase the internal heat integration and/or the opportunities for heat integration with different types of industrial processes. For example, the characteristics of the ethanol process may then be changed and the amount of low temperature excess heat could be reduced.

1 See e.g. McKeough, P., and Kurkela, E. (2008). Process evaluations and designs in the UCG project 20042007. VTT, Espoo, Finland and Joelsson, J.M., et al. (2009). CO_2 balance and oil use reduction of syngas-derived motor fuels co-produced in pulp and paper mills. 17th European Biomass Conference & Exhibition, Hamburg, Germany, 29 June – 3 July, 2009.

2 Wetterlund, E. et al. (2011). Systems analysis of integrating biomass gasification with pulp and paper production – Effects on economic performance, CO_2 emissions and energy use. Energy 36(2), pp. 932-941.

3 See e.g. Isaksson, J. et al. (2012). Integration Of Biomass Gasification With A Scandinavian Mechanical Pulp And Paper Mill - Consequences For Mass And Energy Balances And Global CO_2 Emissions. Energy 44(1), pp. 420-428.

CO-LOCATION OF BIOREFINERIES WITH THE PULP AND PAPER INDUSTRY

In a Swedish perspective the pulp and paper industry is a major industry (more than 10% of the export and approximately 50% of the industrial energy usage in Sweden) that accounts for a large share of potential sites for co-location of biorefineries. There are several reasons why the pulp and paper industry is especially interesting for co-location of biorefineries including closeness to biomass resources, long-term experience and well-developed infrastructure for handling large volumes of biomass, access to heat sinks and/or heat sources (depending on the type of mill) and, for some biorefinery technologies, existing process units and experience concerning their operation. Possible disadvantages of co-location with the pulping industry could be long distances to and lack of knowledge about the products and their markets, e.g. motor fuels or chemicals, as well as limited possibilities to deliver (more) low temperature excess heat to district heating networks. As described in the previous section and in Chapter 6, some biorefinery technologies utilise streams from pulp mill processes and must consequently be located at a mill (at least partly). Furthermore, for the reasons listed above, it may also be attractive to co-locate other biorefinery technologies, such as gasification of solid biomass or lignocellulosic ethanol production, at pulp and paper mills.

Another industry, closely related to the pulp and paper industry, is the saw mill industry. Existing saw mills are potential integration sites with e.g. closeness to and experience regarding handling of the raw material.

CO-LOCATION OF BIOREFINERIES WITH THE PETROCHEMICAL AND OIL REFINERY INDUSTRY

There are several examples of biorefinery technologies, mainly those involving gasification and fermentation pathways, which could be of interest for co-location with other large process industries (see also Chapter 2). Industries such as oil refineries and petrochemical complexes are today based on fossil feedstocks and are exploring options to integrate renewable feedstock into their operations. There are a number of advantages resulting from co-locating biorefineries at oil refinery and petrochemical cluster sites. In addition to general integration advantages such as making use of existing infrastructure, these industries can often use biorefinery products (intermediates) such as Fischer-Tropsch crude, syngas and ethanol directly as feedstocks in their production processes (see also Chapter 3). Furthermore, there are often substantial opportunities for heat integration with the biorefinery processes, and these industries have experience and know-how concerning the (final) products and their market. Possible disadvantages could be long distances to and lack of experience of handling large biomass resources. This could be managed by undertaking the first biomass upgrading stages at a pulp and paper mill. One example of this type of multi-location biorefinery could be production of Fischer-Tropsch crude from gasified black liquor or gasified woody biomass at a pulp and paper mill which is then transported for further upgrading to finished Fischer-Tropsch motor fuels (diesel and gasoline) at an oil refinery.[4] The pulp and paper industry takes care of the initial handling of large volumes of biomass, while the oil refinery handles a feedstock that is relatively similar to crude

4 See e.g. Isaksson, J. et al. (2012). Integration Of Biomass Gasification With A Scandinavian Mechanical Pulp And Paper Mill - Consequences For Mass And Energy Balances And Global CO_2 Emissions. Energy 44(1), pp. 420-428.

oil implying that they can accomplish the final upgrading stages with relatively small changes to their existing process units. Thus, this type of cooperation uses existing infrastructure and process units, and builds upon decades of knowhow about the raw material and its supply, production processes and the products and their market. Furthermore, production of Fischer Tropsch fuels requires large scale in order to be profitable, and this can be accomplished at the oil refinery.

When co-locating biorefineries with these industries it is possible that existing processes are operated in almost the same ways as they are today but with a feedstock that is produced from biomass instead of from fossil fuels. However, it may also be that a different process is preferable if biomass is the raw material and that the existing process units are modified or used to a lesser extent and need to be complemented by other processes or process units. Consider for example a petrochemical plant that uses natural gas in order to produce syngas. Natural gas could be produced via gasification of biomass (so-called substitute natural gas, SNG) and could thereby replace a certain part of the fossil natural gas used.[5] However, from an efficiency point of view it would be better to use the syngas produced from biomass gasification directly in the petrochemical plant and not take the route via SNG. Yet, for other reasons such as security of supply and minimising technical risks it could nevertheless be preferably to use SNG (which could be substituted with fossil natural gas if problems occur).

CO-LOCATION OF BIOREFINERIES WITH OTHER PROCESS INDUSTRIES OR DISTRICT HEATING SYSTEMS

The iron and steel industry is the third category of energy-intensive process industries in Sweden. The variety of options to use biomass in the iron and steel industry is limited, but very large amounts of biomass could be used due to the magnitude of the energy flows of the host process plant (see Chapter 2). All types of industrial processes could of course consider integration with a biorefinery for heat integration purposes only, i.e. without exchanging any material flows or using any existing process units. For biorefineries with large amounts of low temperature excess heat, the possibility for integration with a district heating system could be crucial in order to reach profitability. The possibilities for delivering industrial excess heat to a district heating system is limited, and it could be interesting to explore other options for usage of low temperature excess heat, such as electricity production using an organic Rankine cycle (ORC).

ESTIMATION OF HEAT INTEGRATION POTENTIAL THROUGH PINCH ANALYSIS

Through increased heat integration within and between different biorefinery processes, and between biorefinery processes and existing industrial process plants, biorefinery products can be produced with a lower usage of fuel for process heating purposes. This section gives an introduction to how heat integration potentials can be estimated using pinch analysis.

5 See e.g. Arvidsson, M. et al. (2012). Integration opportunities for substitute natural gas (SNG) production in an industrial process plant, Chemical Engineering Transactions, pp. 331-336.

Process integration refers to systematic methods for designing integrated production systems with a focus on efficient energy use and reducing the environmental load. Pinch analysis[6] is the most frequently used process integration methodology and allows the user to set energy targets for an industrial process, i.e. the minimum amounts of heat that must be added and removed (i.e. cooled) in a process, as well as the maximum amount of heat that can be recovered internally through exchanging heat. Thereafter, pinch technology provides guidelines for designing heat exchanger network to maximise heat recovery, as well as guidelines for retrofitting existing heat exchanger networks. Pinch analysis is a methodology that is very useful when complex industrial processes are to be analysed in order to save energy and money. This technology came into use in the end of the 1970s and has since then been developed further into a useful tool for grass root design and retrofit of industrial processes.

The minimum temperature difference, DT_{min}, is the lowest temperature difference between the hot stream (a stream that requires cooling) and the cold stream (a stream that requires heating) that can be accepted in a heat exchanger and its value is determined by economic considerations.

Industrial processes are normally composed of many hot and cold streams. They can be represented graphically using composite curves. The hot and cold composite curve is constructed by calculating the heat content of all hot and cold streams respectively in the various temperature intervals. The goal is to establish energy targets (i.e. minimum heating and cooling demands as well as maximum possible internal heat recovery) for a given value of DT_{min}. Figure 8.1 presents an example of composite curves for a process with two different values of DT_{min}. Where the two curves overlap, internal heat exchanging is possible and heat can be transferred from the hot to the cold streams. Where the two curves do not overlap, external heating or cooling must be used. Note that although there are many streams in the system, in general the minimum allowable temperature difference between hot and cold streams (DT_{min}) occurs at one point only. This point is called the pinch.

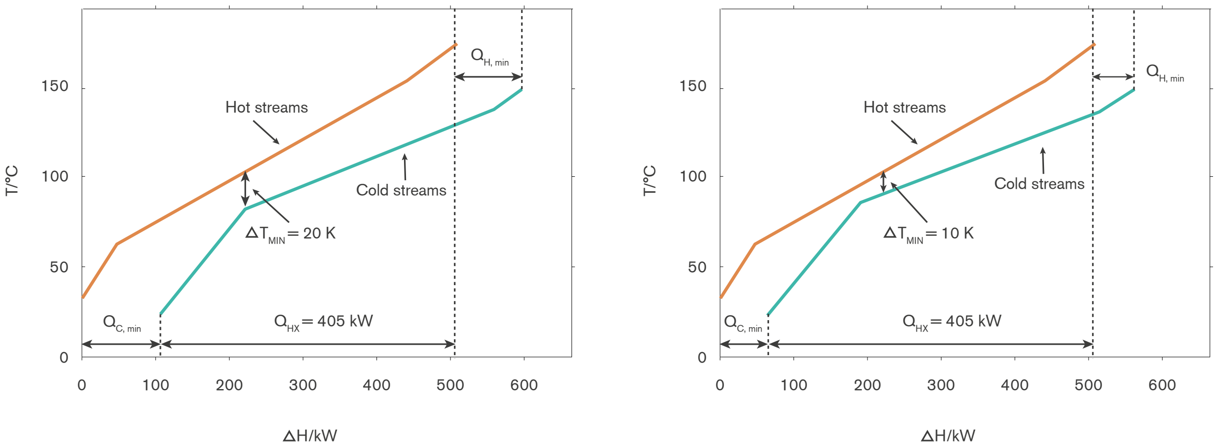

Figure 8.1 Examples of representations of composite curves for a process using two different values of the minimum temperature difference, DT_{min}.

6 For an extensive description of the pinch analysis methodology, see e.g. Kemp, I. (2007). Pinch Analysis & Process Integration - A user guide on process integration for the efficient use of energy. Butterworth-Heinemann, Oxford, UK.

From the figure we can see that for a DT_{min} of 20°C, the maximum possible internal heat recovery (heat exchange between hot and cool streams), Q_{HX}, is 405 kW, the minimum heating demand $Q_{H,min}$ is 80 kW and the minimum cooling demand $Q_{C,min}$ is 100 kW. When DT_{min} is decreased to 10°C the maximum possible internal heat recovery, Q_{HX}, is increased to 450 kW, thereby decreasing the minimum heating demand, $Q_{H,min}$, to 40 kW and the minimum cooling demand, $Q_{C,min}$, to 60 kW. Thus, by reducing DT_{min} we also reduce the energy utility costs, since we need less heating (typically steam) and cooling (typically water). On the other hand, we increase our capital costs, since the reduced driving force (DT_{min}) means that the necessary heat exchanger area increases. The DT_{min} value for which the sum of the energy and capital cost reaches its minimum is therefore the optimal value that should be chosen for the design. It should also be noted that flat behaviour is usually observed around the optimum value of DT_{min}, thus there are often a number of heat exchanger network solutions with costs close to the optimum value. This implies that there is often a significant degree of freedom available for the network designer.

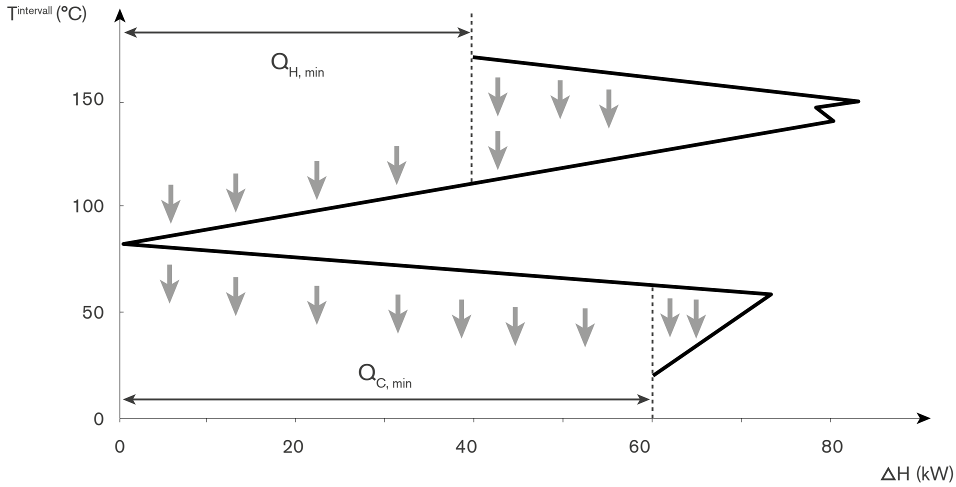

Figure 8.2 Example of a Grand Composite Curve (GCC).

Another way to represent the heat flows in a process in a temperature-enthalpy diagram is to construct a Grand Composite Curve (GCC) for a certain value of DT_{min}. Figure 8.2 shows an example of a GCC (for the same process as in Figure 8.1 with a DT_{min} value of 10°C). The point of contact between the curve and the y-axis is the pinch. Above the pinch, the process has a net deficit of heat and below the pinch the process has a net surplus of heat. The curve also shows areas where there is a net excess heat available at temperatures above levels where there is a net heat deficit. These areas indicate opportunities for process-to-process heat recovery, often referred to as heat recovery pockets.

In order for a process heat exchanger network to reach the energy target, it cannot contain any violations of the following three golden rules of pinch analysis:

- Do not transfer heat through the pinch.
- Do not cool process streams with cold utility above the pinch.
- Do not heat process streams with hot utility below the pinch.

To transfer heat through the pinch means that heat is transferred from a system with a deficit of heat to a system with a surplus of heat. The same amount of heat must therefore be added with external heaters and the same amount must therefore also be cooled with external coolers. To cool above the pinch means that heat is extracted from a system, which has a deficit of heat. The same amount of heat must therefore be added from hot utility. To heat below the pinch means that heat is added to a system that already has an excess of heat. The same amount of heat must therefore be cooled with cold utility.

Pinch analysis is commonly used when investigating retrofit options of existing heat exchanger networks. The energy targets are compared with the existing energy usage in order to estimate the possibilities for savings. In retrofit situations it is usually not profitable to modify the existing heat exchanger network in order to reach the energy target. In greenfield design situations, for example when building a new biorefinery process, it is likely more profitable to design the process energy system so as to be closer to the energy targets for the selected value of DT_{min}.

By studying the results from a pinch analysis, particularly the GCC of the process, the opportunities for heat integration of new technologies and processes can be identified. This type of analysis is usually called a background/foreground analysis. The GCC of the existing process is considered as the background and the foreground is constituted by the GCC of the new technology or process. Thus, by for example studying the GCC for a pulp mill process and the GCC for an ethanol plant, an estimation of the potential for heat integration between the processes can be identified.

ILLUSTRATING THE GAINS OF BIOREFINERY CO-LOCATION

This section shows an example that illustrates the consequences of co-locating different steps in a biomass conversion chain with each other and also in connection to an existing industrial process site.

Ethylene is used to a large extent in the petrochemical industry and is mainly produced using natural gas as feedstock (see Chapter 3 for information about how ethylene is used). One way to produce ethylene from a renewable feedstock is catalytic dehydration of bio-ethanol. The example presented here, taken from studies by Hackl et al. (2011)[7] and Arvidsson and Lundin (2011)[8], quantifies the energy consequences of co-locating the ethanol production plant and the ethanol dehydration plant producing ethylene. In addition, the consequences of co-locating

7 Hackl, R. et al. (2011). Process integration study of a biorefinery producing ethylene from lignocellulosic feedstock for a chemical cluster. 6th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems.
8 Arvidsson, M., and Lundin, B. (2011). Process integration study of a biorefinery producing ethylene from lignocellulosic feedstock for a chemical cluster. MSc Thesis, Chalmers University of Technology.

these processes at a petrochemical cluster site are also investigated. The site considered is located in Stenungsund, on the west coast of Sweden. The ethanol process considered uses lignocellulosic feedstock. Figure 8.3 illustrates the studied cases with different degrees of integration between the new processes and the new processes and an existing chemical cluster.

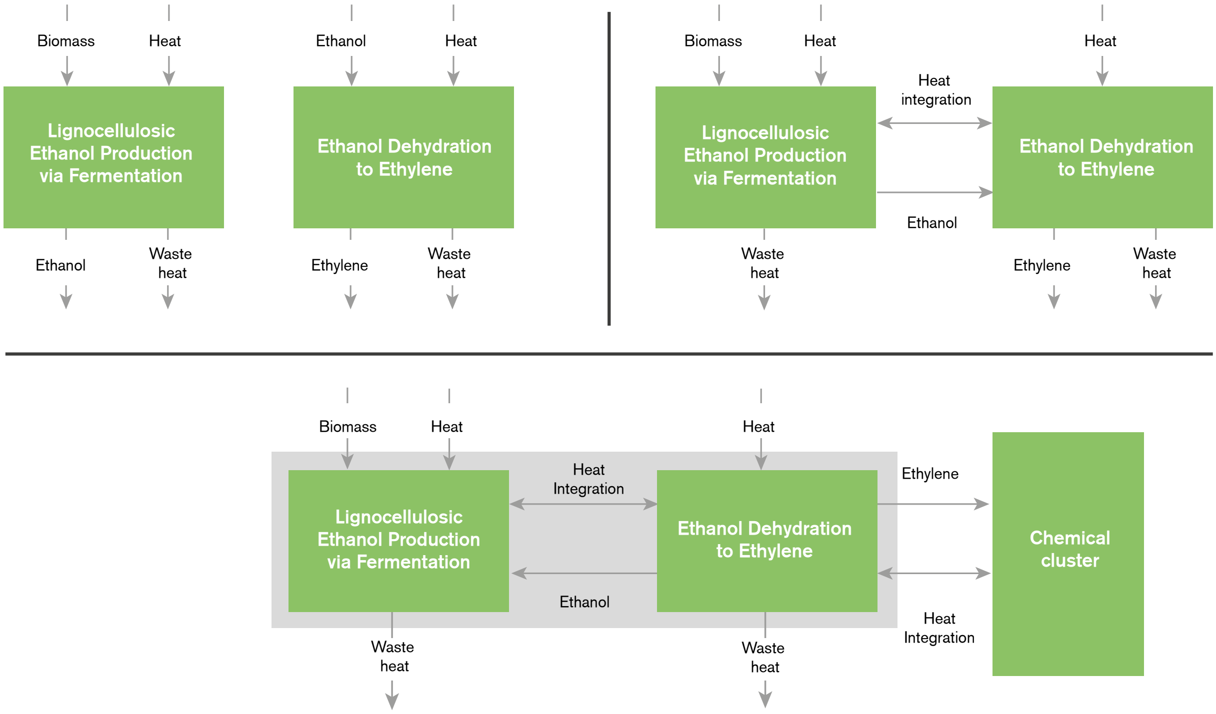

Figure 8.3 Illustration of the studied cases; upper left (base case, Case 1): no integration between ethanol and ethylene processes, upper right (Case 2): heat and material integration between the two processes, lower right (Case 3): heat and material integration between the two processes and the existing chemical cluster.

Figure 8.4 shows the GCC for the ethanol production process (producing 337 MW ethanol from 758 MW wood fuel) and the GCC for the ethanol dehydration process (producing 307 MW ethylene from the ethanol produced in the first process). If these processes are operated separately (Case 1), the combined minimum heating demand for producing renewable ethylene for the chemical cluster is 131 MW (112 + 19 MW).

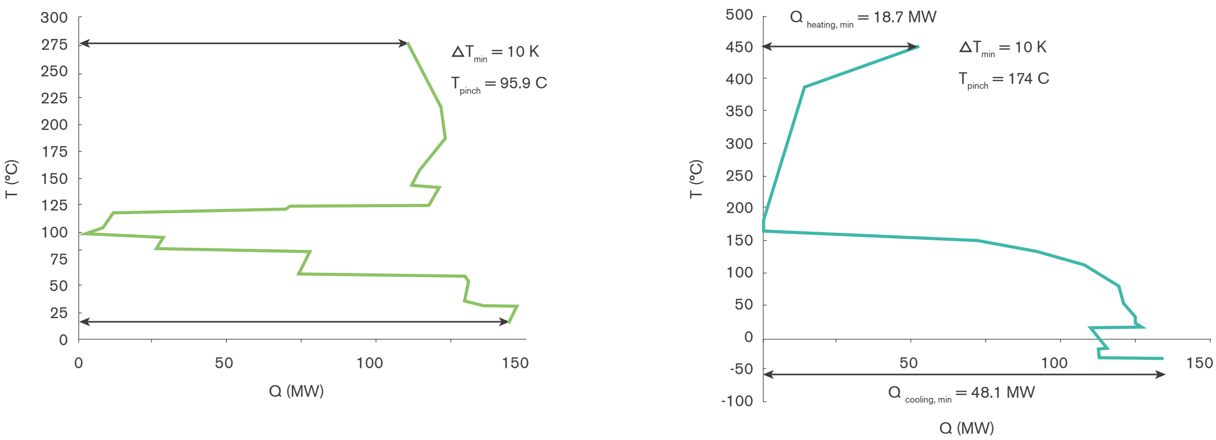

Figure 8.4 GCCs of the ethanol production process from lignocellulosic biomass (left) and ethanol dehydration process (right).

If the two processes are instead co-located (Case 2), the minimum heating demand is reduced to 82 MW. Excess heat from the ethanol dehydration process is used to cover a part of the heat demand in the ethanol process, as illustrated in Figure 8.5. Furthermore, co-locating these plants means that ethanol can be directly delivered to the dehydration plant in the vapour phase, thereby avoiding the energy costs of condensing the vapour in the ethanol process and then revaporizing it at the inlet of the dehydration process.

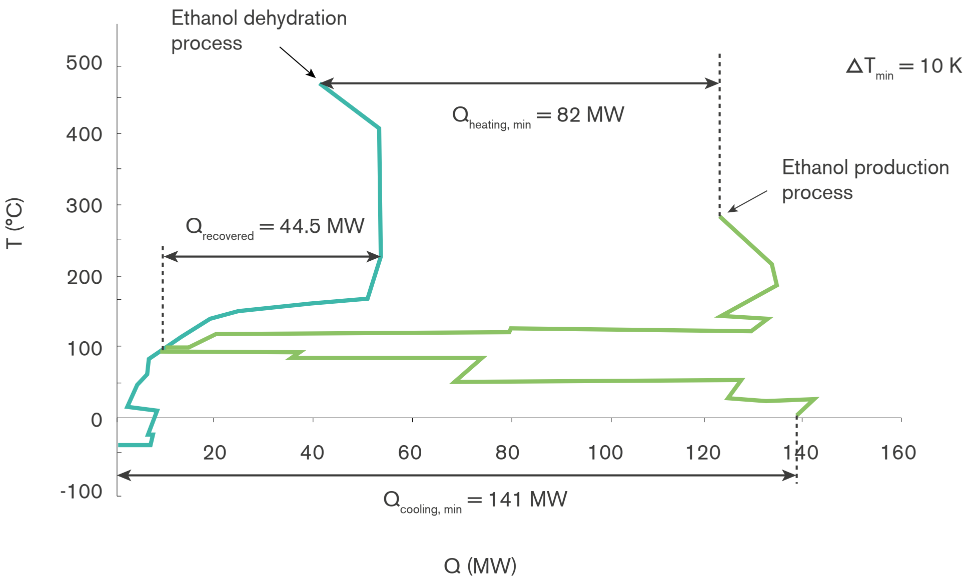

Figure 8.5 Background/Foreground analysis of the ethanol production and ethanol dehydration process; direct delivery of ethanol between the processes is accounted for in the stream data.

If the processes also are co-located with the chemical cluster (Case 3), an additional 18 MW heat can be saved by using excess heat from the chemical cluster. This is illustrated in Figure 8.6.

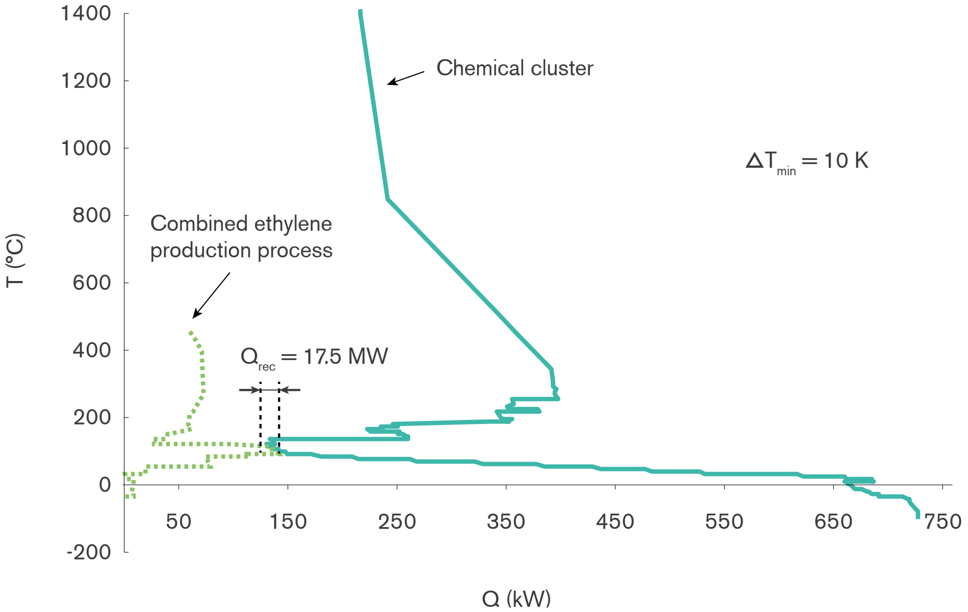

Figure 8.6 Heat integration analysis of the existing chemical cluster with the combined ethylene production process.

Altogether the maximum achievable savings by co-locating these processes amount to 66 MW corresponding to 51%. The cooling demand is also reduced by 55 MW corresponding to 28%. Table 8.1 summaries the minimum heating and cooling demands for the studied cases.

It is not only about co-location, but also doing the correct design. Maybe it is not worth designing a heat exchanger network going all the way to minimum heating demand in any of the cases. However, achievable savings by co-locating the processes will likely be approximately the same but with higher heating demands for each case.

Table 8.1 Summary of process integration results.

	Overall minimum heating demand (MW)	Overall minimum cooling demand (MW)
Separate processes (Case 1)	131	196
Heat and material integrated processes (Case 2)	82	141
Integration with chemical cluster (Case 3)	65	141**
Maximum achievable savings	66	55

**the 17.5 MW of cooling that can be saved in the chemical cluster are allocated to the luster and not to the combined ethylene production process

The different heating demands will result in different net usage of biomass in the different cases (assuming that biomass fuel is used to satisfy the heating requirements of the different processes). 758 MW of biomass is used to produce 307 MW of ethylene. In addition, by-products in the form of different fuels are produced, altogether 489 MW. Part of these fuels are used internally in a CHP plant to cover the heating demand of the process/es and at the same time co-generate electricity. Thus, more fuel is used for this purpose in the base case (Case 1) where the two processes are located separately compared with the integrated cases (Cases 2 and 3). Table 8.2 presents the energy balances for the studied cases. As can be seen in the table, the net usage of biomass can be decreased by 107 MW, corresponding to more than 20% if the processes are colocated with each other and the chemical cluster. However, at the same time the electricity generation decreases from 57 MW to 27 MW.

Table 8.2 Energy balances for the studied cases. Ethylene is also presented as an energy flow. All energy flows in [MW].

	Case 1. Separate processes	**Case 2. Heat and material integrated processes**	**Case 3. Integration with chemical cluster**
Biomass (LHV)			
Input	758	758	758
By-products	489	489	489
By-products used for energy purposes	264	185	156
Net biomass**	**-533**	**-454**	**-426**
Electricity			
Production	57	35	27
Usage	32	32	32
Net electricity	**25**	**3**	**-5**
Ethylene (LHV)	**307**	**307**	**307**

** -(Input – (By-products – By-products used for energy purposes))

It is reasonable to assume that Case 1 will be located with relatively short transportation distance for the biomass feedstock, but longer transport distance for the ethanol (assuming that the dehydration plant is located within the chemical cluster but no heat integration possibilities with the chemical cluster is considered). In Case 2, ethylene is transported instead of ethanol. In case 3 it is reasonable to assume that the transport distances for the biomass feedstock is longer, but no transport of either ethanol or ethylene is necessary. Given this assumptions and a worst case scenario with only road transportation by truck, the consumption of diesel fuel for transportation could increase with approximately 3 MW[9] if comparing Case 3 with Case 1 (5 MW in Case 3 compared to 2 MW in Case 1). This is because the weight of a certain amount of ethanol (and ethylene) in terms of energy is substantially lower.

What would then total efficiency be for these different cases considering both on-site and off-site energy use? The efficiency for the different cases is calculated by dividing ethylene produced by primary energy use (biomass, fuel for electricity (credit for export) and fuel for diesel production). The results show that the efficiency is clearly higher in Case 3 compared with Case 1, approximately 70% compared with 64%.[10] Thus, the loss of electricity production and increase of diesel usage is significantly lower (also in terms of primary energy) compared with the decreased use of biomass in Case 3 compared to Case 1.

The profitability of producing ethylene from woody biomass instead of natural gas will primarily be dependent on the required investment cost, future prices of

9 Assuming that one truck consumes 4,1 MJ diesel/km, that one truck transports 293 GJ biomass, 883 GJ ethanol and 1513 GJ ethylene and that the transport distances (km) are 150, 450 and 0 in Case 1, 150, 0 and 450 in Case 2 and 450, 0 and 0 in Case 3 for biomass, ethanol and ethylene respectively.

10 Assuming a fuel-to-electricity efficiency of 45% and a fuel-to-diesel efficiency of 80%.

natural gas and wood fuel, and possible revenues from policy instruments promoting production of renewable chemicals and materials. The decreased wood fuel usage achieved in Case 3 compared with Case 1 could be crucial in order to reach profitability for renewable ethylene production.

Dehydration of ethanol to ethylene is a commercial process, while production of lignocellulosic ethanol is not. Therefore, renewable ethylene production could be introduced using bio-ethanol available today e.g. produced from sugar cane in Brazil. Thus, this situation will correspond to Case 1 (illustrated in Figure 8.4), where the ethanol process and the ethylene process are not co-located.

As has been shown, the main part of the heat integration is achieved by co-locating the ethanol and ethylene processes. These processes have large amounts of low temperature excess heat suitable for district heating production. Therefore, even larger heat integration opportunities could be achieved if these processes are co-located with a district heating network compared to if heat integrated with the chemical cluster. Naturally, the ideal situation is that both integration possibilities can be achieved at the same location. As has been mentioned, one can also investigate other alternatives for making use of low temperature excess heat such as an organic Rankine cycle.

CONCLUDING REMARKS

There are different criteria for selecting the location of biorefineries such as closeness to raw material, product markets and heat sinks and sources or existing experience and know-how concerning raw material, processes or products. Different locations could be suitable for different biorefinery technologies. There are general advantages when co-locating biorefineries with existing industries such as making use of existing infrastructure. In a Swedish perspective, the pulp and paper industry is a major industry that accounts for a large share of potential sites of interest for co-location of biorefineries. There are several reasons why the pulp and paper industry is interesting for co-location of biorefineries including long-term experience and well-developed infrastructure for handling large volumes of biomass. Possible disadvantages include lack of knowledge about the products and their markets. Industrial plants such as oil refineries and petrochemical complexes are based on fossil feedstocks and are currently exploring options to integrate renewable feedstock into their operations. There are a number of advantages when co-locating biorefineries at oil refinery and petrochemical cluster sites. These industries can often use biorefinery products directly as feedstocks in their production processes and they have experience and know-how concerning the (final) products and their market. Possible disadvantages could for example be long distances to and lack of experience of handling large biomass resources.

In this chapter pros and cons with different biorefinery locations have been described from different perspectives: technology and existing industry. From a societal perspective it is desirable that biomass is used in a way to achieve e.g. high overall efficiency and large GHG reductions in combination with businesses with sufficient profitability. It is easier to quantify the effect of certain parameters such as transportation distances for raw material or products or the degree of heat integration, whereas the effect of other parameters are more difficult to quantify, e.g. experience and know-how concerning handling of the raw material, the processes or the products. However, experience and know-how could be crucial in order to reduce different risks of implementing new biorefinery technologies and thereby increase the probability of commercialisation and technology diffusion. Thus, since different industries would enjoy different advantages when selecting a location for a biorefinery, co-operation between different industries where they each use their experiences and know-how could be a key to success. In the development of biorefinery industries, one can observe that for example industries that previously have not been in contact, now have joint interests and therefore have started to cooperate.

One important driving force for location of biorefineries is the opportunities for heat integration, which was the focus of the latter part of this chapter. An example has been included that shows the consequences of different locations with different possibilities for heat integration. The example illustrates that choosing the appropriate location for different parts of the biomass conversion chain in relation to each other and to existing industry could be very important and that heat integration possibilities could be more important than for example transportation distances for raw material. In order to reach sufficient profitability for biorefinery processes, co-location with possibilities for heat integration could be important.