# THE VALUE OF EXCESS HEAT - PROFITABILITY AND $CO_2$ BALANCES

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## INTRODUCTION

Biorefineries produce many different types of products for a wide range of markets with specific characteristics (see e.g. Chapter 3). In this chapter we will discuss the implication of the availability of markets for one particular product, heat. Heat may be regarded either as waste or as a co-product of the process and the usability of heat depends largely on two issues: the temperature of the heat, and the opportunities for integrating the biorefinery with activities demanding heat, e.g. district heating systems or heat-demanding industrial processes (see also Chapters 2 and 5). The aim of the present chapter is to present and discuss the importance and limitations of integration with district heating systems (DH-systems) for the profitability and $CO_2$ mitigation potential of biorefineries.

All processes that refine biomass generate heat which either may be useful for keeping the process at a certain temperature, may be used in connected processes (process integration), can be used to supply an external heat demand (e.g. through a district heating grid), or has to be wasted. In the last case, when there is no use of the heat, generation of excess heat should be avoided. In the other cases, from an economic perspective, it is not certain that the amount of excess heat should be minimized. The revenues from heat sales determine the optimal amount of excess heat of different temperatures. Since the optimal heat production in a process depends on local heat demand conditions, also the optimal design of the biorefinery depends on local conditions and may thus be site specific.

It is not only the local conditions that determine the optimal use of heat. A systems perspective needs to be applied to take into account changes at higher system levels (see discussions in Chapter 1, 6 and 7). Issues related to the future development of the entire energy system will affect the desirability of different options. How much heat that will be needed in district heating systems; if available biomass resources will be used for biomaterials, biofuel, heat or power generation; how the cost of electricity will change, are all questions that affect how heat can, or should, be produced and used.

The main question to be answered in this chapter may be broken up in two sub-questions: *What is affecting the possibilities for profitable utilization of process waste heat? And, how might a profitable utilization of waste heat affect different biorefinery concepts and designs as well as $CO_2$ emissions?* These questions cannot be treated separately but are strongly interrelated.

Most of the current literature on this subject concerns Swedish conditions. Hence, we mainly use Swedish examples to illustrate general issues. However, at some points we also include a European perspective.

### THE VALUE OF EXCESS HEAT: AN ISSUE OF DELIVERY RESPONSIBILITY

The profitability of selling excess heat depends mainly on two factors: price and amount of heat that can be delivered. The amount and, especially, the price are in a real situation matters of negotiation. Hence, to be able to investigate the profitability of heat deliveries, one has to make assumptions about the price of heat, e.g. by relating to the heat production cost in the local heat production system. For instance, the price of the heat delivered can be set to the reduction in production cost of heat from other sources. Then, one can either base the production cost on running costs only, or include the capital cost. If the total cost, including capital cost, is used, the heat deliveries from the biorefinery should be as secure as if the local energy company would have invested in new capacity, i.e. the biorefinery has to take on *delivery responsibility*.

Delivery responsibility means, in this case, that the biorefinery always is ready to deliver a certain amount of heat if needed. In many cases deliveries of industrial excess heat does not come with a delivery responsibility. Instead, the industrial site delivers heat when there is excess heat available at the industry and there is a need of that heat in the district heating system. The reason that suppliers of excess heat are not willing to take on a delivery responsibility is that they prioritize the industrial process and want to have the possibility to stop heat deliveries if needed for their industrial process – to let the industrial process be dictated by heat deliveries can simply be a costly option.

If the supplier of excess heat does not have delivery responsibility, the distributer of district heating (the local energy company) has to have back-up plants to cover the energy demand when the excess heat is not delivered. This implies that the distributer of district heating needs to invest in spare capacity corresponding to the supply of excess heat. Thus, in this case excess heat will be compared to the running cost of these heat plants.

The running costs of base load production units can be very low. In Sweden for instance, waste incineration is common as base load in larger district heating system, which has negative running costs (there is a cost associated with not incinerating the waste). Another common base (or medium) load in Sweden is biomass fuelled combined heat and power plants (bio-CHP) which can have running costs close to zero with the existing support schemes for renewable electricity (the revenues of electricity production cover for the running costs). In a European perspective, waste incineration and bio-CHP is not as common for base load production, but exists and are expected to grow considering the EU sustainability goals. [1]

If the running costs of base load generation are negative or close to zero, the value of excess heat from a biorefinery is low. Certainly, the value per unit of utilized excess heat is higher if the biorefinery instead can deliver heat higher up in the merit order, and compete with middle and top load production units, which gives a considerably higher price of the excess heat. On the other hand, the utilization time is then reduced since there is no need for middle and top load all year round, which reduces the total amount of heat that can be delivered, see Figure 8.1. As also shown in the figure, the amount of heat that can be delivered depends on the size of the district heating system compared to the heat available in the biorefinery; with a comparably large amount of excess heat, the amount delivered compared to the delivery capacity decreases.

If the biorefinery is ready to take on a delivery responsibility, the biorefinery can be compared to any other boiler alternative from the district heating suppliers´ point of view. This means that in a case where the district heating system is in need of new capacity (preferably base load

1 Johnsson F. (editor) (2010), European Energy Pathway, Alliance for Global Sustainability (AGS), Mölndal.

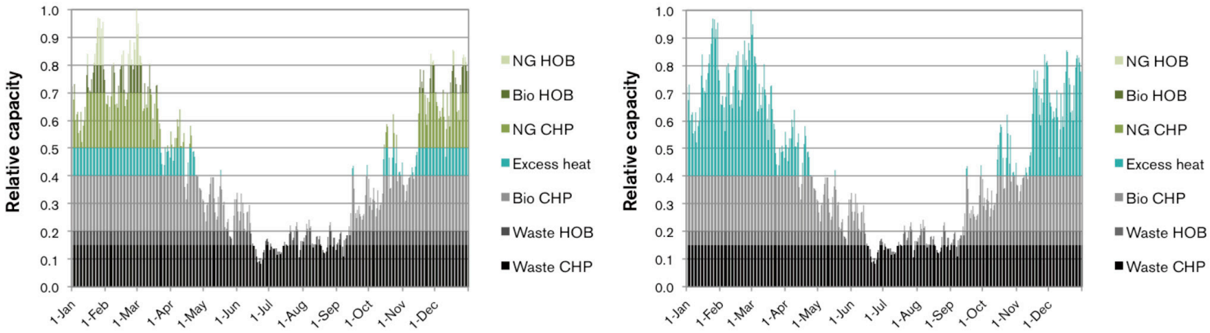


**Figure 8.1** In a district heating system with low running cost of base load units it is more favourable to deliver excess heat higher up in the merit order, implying reduced utilization time due to deliveries only a limited part of the year. If the excess heat delivery capacity is large compared to the heat demand of the district heating system, the actual deliveries compared to delivery capacity decrease (compare right with left in figure). CHP = combined heat and power, HOB = heat only boiler

capacity), the value of excess heat can be derived from the total heat production cost, including not only running costs but also investment costs. In this case, excess heat can be a very competitive option at relatively high prices for excess heat, thus facilitating good profitability for the biorefinery heat deliveries. On the other hand, delivery responsibility might imply that the biorefinery has to make additional investments in order to be able to deliver top load heat when the main process for some reason is not operating.

## THE ECONOMIC CONTRIBUTION OF SELLING EXCESS HEAT

One central question regarding the use of excess heat is the importance of the economic contribution from excess heat revenues. To illustrate the value of excess heat revenues, an example is constructed, see Figure 8.2. In this simplified example we consider a gasification process where 50% of the input energy is converted to biofuels and 10% to usable excess heat (the remaining 40% are losses), according to the approach used in.[2] Representative energy prices for the energy flows are also assumed in order to illustrate cash flows. Two heat price levels are used to analyse the impact of excess heat revenues. To get a more complete picture also the investment cost as well as the operating and maintenance cost can be included, here taken from Boding H. et al. 2003[3] where a DME plant (Dimethyl ether) is described.

With these assumptions for energy flows and energy prices, the excess heat revenues are relatively small compared to the cost of input resources in the form of wood and the revenues from sales of biofuel, see Figure 8.3. Hence, in this example, with a rather small amount of heat being utilized, the excess heat revenues are of minor importance in the overall economic picture. However, if investment cost as well as operation and maintenance cost are included, the profit margin decreases and the importance of excess heat revenues grow. In fact, with the figures used in this example, a high price on excess heat is needed to get the in-payments higher than the out-payments in this cash flow analysis.

Another way of turning the issue of heat utilisation and its profitability is to start from a long-term sustainability perspective since it might be argued that in the long term no useful heat should be wasted and, thus, when constructing new plants, all useful waste heat should be absorbed by a heat sink, e.g. a district heating system. This would introduce rather strict constraints on the design of a biorefinery and its system settings, and the operation of a biorefinery could

2 Egeskog A. et al (2009). Co-generation of biofuels for transportation and heat for district heating systems–an assessment of the national possibilities in the EU. Energy Policy 37: 5260–5272.

3 Boding H. et al (2003). BioMeeT II – Stakeholders for biomass based Methanol/DME/Power/Heat energy combine. Eco-traffic and Nykomb Synergetics.

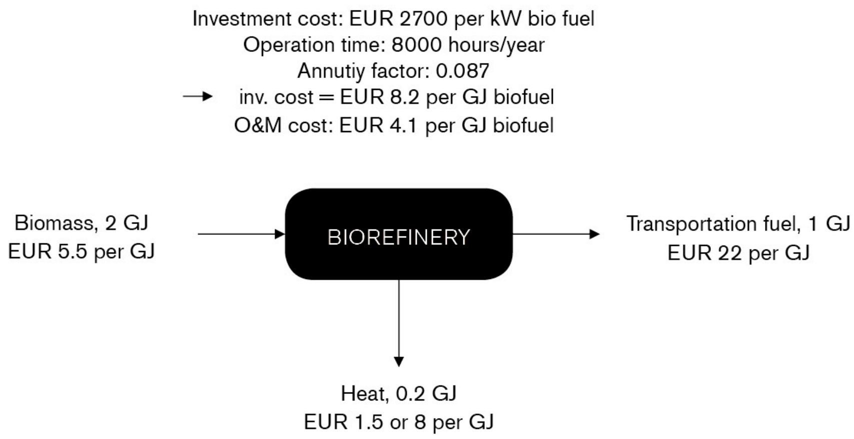


**Figure 8.2** Simplification of a biorefinery, with energy flows, related energy prices as well as capital and operation costs.

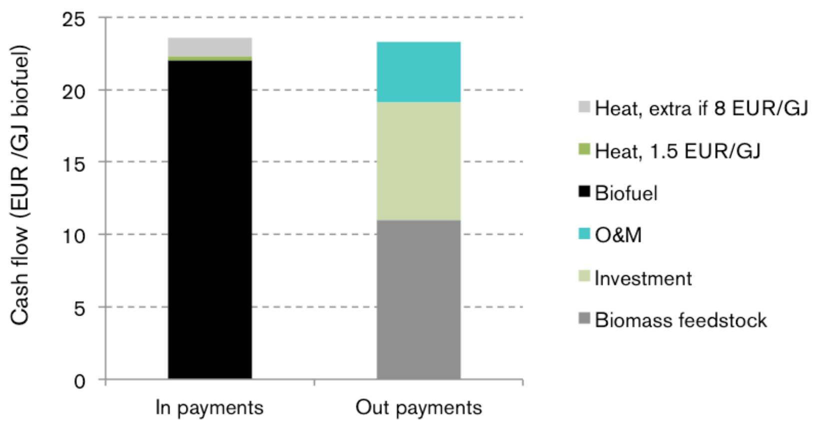


**Figure 8.3** Cash flow analysis based on data in Figure 8.2

be optimised as an integrated part of a district heating system.[4]

To sum up, the profitability of selling excess heat from a biorefinery depends on the price of heat and the amounts that can be sold. As described above, these two factors in turn depend on the size of the nearby district heating system, its heat production technologies and its need for new capacity. It also depends on if the biorefinery has delivery responsibility or not and how various policy instruments affect relative prices.

Clearly, the prerequisites at the nearby district heating system are very important for the value of excess heat. Hence, localization of the biorefinery can be decisive for the profitability of heat sales. As also shown in the examples above, the income from selling heat can be an important contribution to the profitability of the whole biorefinery.

## CO2 MITIGATION POTENTIAL OF EXCESS HEAT UTILIZATION

Besides profitability of selling excess heat, the $CO_2$ emission consequences of using the excess heat for district heating are of interest. The use of excess heat affects emissions not only at the biorefinery but also in the district heating system and in the power generation system.[5]

At the biorefinery, the consequences on $CO_2$

4 See e.g. Fahlén E och Ahlgren EO (2009). Assessment of integration of different biomass gasification alternatives in a district-heating system. Energy, 34: 2184-2195.

5 See e.g. Fahlén E och Ahlgren EO (2009). Assessment of integration of different biomass gasification alternatives in a district-heating system. Energy, 34: 2184-2195.

emission of utilizing excess heat can be close to zero if the heat is true excess with no other use. If, on the other hand, the economic optimization of the refinery implies that some heat delivery is favoured before other use, heat deliveries imply increased resource use in other parts of the plant. One example of this could be that low pressure steam is used for district heating with very high efficiency instead of electricity production with relatively low efficiency. In this case, the $CO_2$ emission consequence of using steam for heat can be quantified by comparison to emissions from electricity production in the surrounding energy system (e.g. in a reference or background system), considering the amount of electricity that could have been produced from the steam (see also discussion on system efficiency in Chapter 6 and reference systems in Chapter 7).

The $CO_2$ emission consequences at the district heating system of utilizing the excess heat depends on the district heating system and how the heat is used. In principal, external heat deliveries replace some kind of alternative heat production in the district heating system. Hence, the $CO_2$ emission consequence of heat delivery can be quantified by analyzing the heat production before and after heat deliveries from the biorefinery. This approach is exemplified in Figures 8.4 and 8.5 below. Since the $CO_2$ emission consequences can be very different with different configurations of the district heating system, two examples are given.

In the first example we consider a typical Swedish district heating system with waste incineration as base load, heat from bio fuelled combined heat

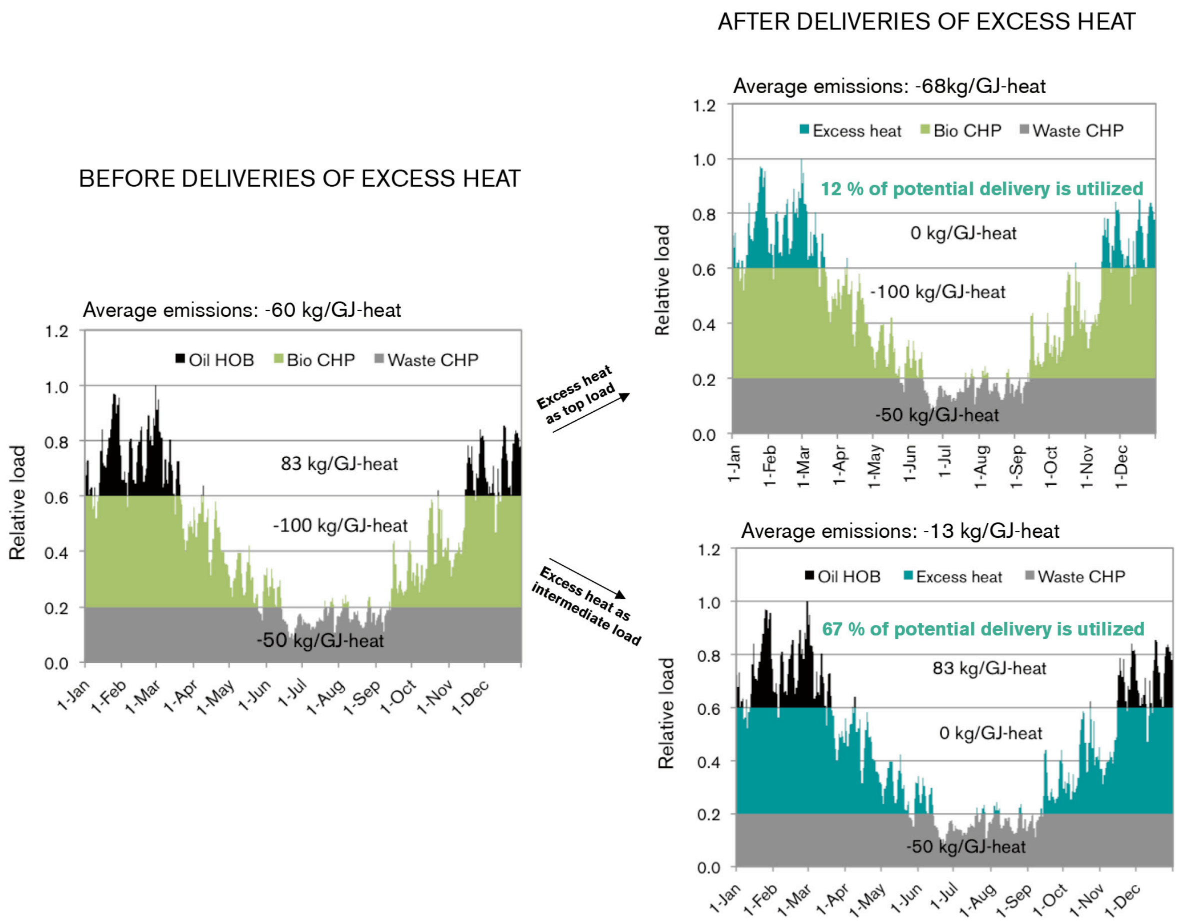


**Figure 8.4** $CO_2$ consequences of excess heat deliveries to a typical Swedish district heating system. Emissions if excess heat is used as top load (right, above) and as intermediate load (right, below) can be compared to the case without excess heat (left).

and power plants (bio CHP) as intermediate load, and fuel oil as top load, see Figure 8.4. As can be seen in the figure, base and intermediate load production are assumed to have negative $CO_2$ emissions from a system perspective. In the case of waste incineration, the negative emissions can be explained by the assumption that the alternative treatment of waste is landfill dumping causing methane emissions. For a waste CHP there is also the effect of decreased marginal electricity generation (assuming 400 kg/MWh emissions from marginal electricity). Decrease of marginal electricity generation is also the reason for negative emissions from a bio CHP. (See Chapters 1 and 7 for more discussions about when and how different kinds of marginal effects can and should be taken into account.)

If excess heat is used to replace top load production, the $CO_2$ emissions decrease. As discussed in the section above, using excess heat as top load can be a relevant consideration in a case where the biorefinery cannot take delivery responsibility. As also discussed in the same section, using excess heat as top load imply that only a part of the total possible heat deliveries can be utilized, in this case 12 %.

If a longer utilization time is desired, the biorefinery can take on delivery responsibility and, as discussed above, compete with intermediate production units in a situation where a new production unit is needed. In the example in Figure 8.4, this would lead to that 53 % of the potential heat deliveries are utilized. On the other hand, the $CO_2$ emissions increase when a unit with negative emission is replaced with excess heat having zero emissions. This arguing is correct if biomass is considered $CO_2$ neutral. The $CO_2$ neutrality of biomass can be discussed from a wider system perspective. If wood fuel is considered as a limited resource, there is always an alternative use of biomass that sets the $CO_2$ emissions related to the marginal use of biomass (see the concluding section below for some further considerations that put the numbers in figure 8.4 into perspective).

In the second example we instead consider a fossil fuel based district heating system with a coal fired combined heat and power plant as base load and natural gas heat only boiler as top load. This kind of district heating production is more common in a European perspective. Again, the principle with top load utilization for no delivery responsibility and base load utilization with delivery responsibility can be applied, since heat production cost in existing coal plants can be very low. In contrast to the first example, excess heat deliveries imply $CO_2$ emission reduction in both cases, and even larger reductions in the case when excess heat replaces base load.

From the above examples it is clear that the $CO_2$ emission consequences of heat deliveries depend on the configuration of the district heating system and how the heat is utilized. As discussed in the previous section, the profitability of excess heat deliveries can potentially be higher if the biorefinery can take on delivery responsibility. Generally, delivery responsibility means that excess heat can compete with production units lower in the merit order, generally having lower or even negative, $CO_2$ emissions.

With this reasoning, there would be a trade-off between profitability and $CO_2$ emission reductions of excess heat deliveries from a biorefinery. The above discussion also clearly shows that the design and operation in terms of how much effort that should be devoted to the optimisation of output of primary products (electricity and fuels) strongly depend on local heat system characteristics. Further, there is also a time aspect to this since also in a European context a development towards lower emission base load is necessary in order to meet the sustainability goals of the EU, which in turn would decrease the value of excess heat deliveries from a $CO_2$ reduction perspective.[6]

6 e.g. Johnsson F. (editor) (2010). European Energy Pathway, Alliance for Global Sustainability (AGS), Mölndal.

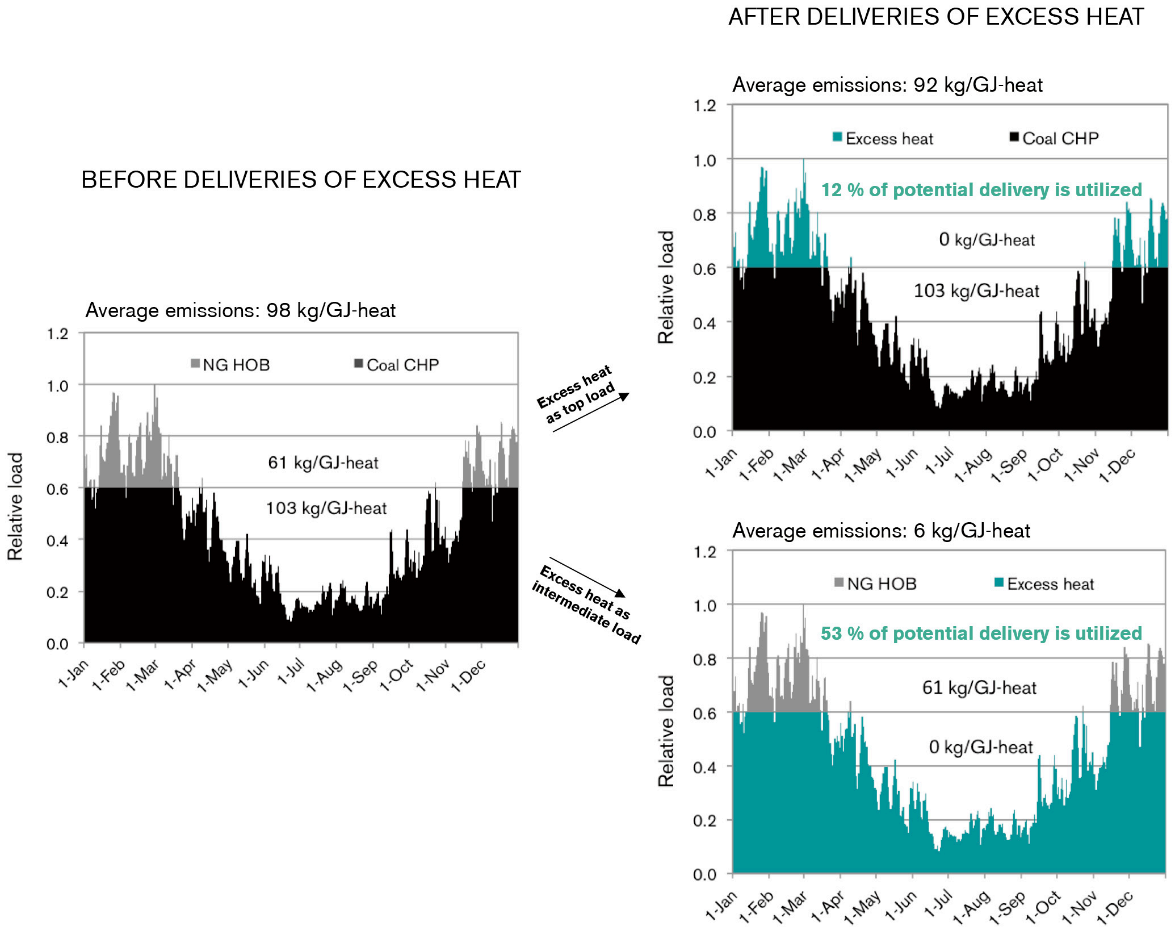


**Figure 8.5** $CO_2$ consequences of excess heat deliveries to a fossil fuel based district heating system.

## HEAT UTILIZATION AND THE OPTIMAL SCALE OF BIOREFINERIES

There are a number of factors governing the optimal size and distribution of biorefineries and bio CHP plants. In a plant perspective, most factors improve with increased plant scale, while in a wider system perspective there are a number of factors showing opposite behaviour.

At the level of the individual plant, conversion efficiencies normally increase and costs per output decrease with size while in the surrounding energy and materials systems costs typically increase with scale. This applies to both distribution of the biomass feedstock to the plant and distribution of the plant outputs, i.e. heat and electricity, to the consumers (compare system levels in Figure 1.2). While power can be distributed over long distances many biomass fractions are local in their character either due to transportation difficulties or due to non-mature biomass markets. These system scale factors influence the optimal plant size. Heat is an even more local product, and the market for heat is limited to the local heat demand (e.g. a city nearby the biorefinery). The heat output from a biorefinery can be enough to cover the entire heat demand of a smaller city. Hence, the local heat market can be an important factor when optimizing the size of the biorefinery.

Other energy infrastructures are also influencing the optimal scale of plants. Regarding the power grid, decentralized options might require costly grid extensions while on the other hand this more dispersed power generation might reduce the risk of power failures in areas with weaker grids. Natural gas infrastructures may also play a role for plant scaling and localisation, not only through heat market competition between natural gas and biomass but also for market access for products from gasification-based biorefineries. If synthetic natural gas (SNG), i.e. bio methane, is an output, the market access through natural gas grids may improve the possibility to maximize revenues.

## PROFITABILITY AND CO2 MITIGATION POTENTIAL IN THE RECENT LITERATURE

The issue of biorefinery and waste heat utilization has been covered in a small number of recent publications. The point of departure is often the investigation of an optimal utilization of available biomass resources; how are available biomass resources being best utilized from a carbon mitigation point of view (tonnes of $CO_2$ mitigated), or how the resources best are utilized from a carbon cost perspective (EUR/tonnes of $CO_2$ mitigated).

The profitability of biorefineries has been in focus in a few recent investigations assessing various designs connected to district heating. Major issues in the analysis have been whether the biorefinery from a system economic point of view preferably should produce transport biofuels or combined heat and power, how sensitive the technologies are to variations in electricity price and policy support such as certificates for green electricity and transport biofuels and the importance of the heat sales for the overall economics of the plants (see also Chapter 9 for a discussion of the effectiveness of different policy instruments). Generally, the time perspective has been a mid-term future, typically 2020-2025, and it has been assumed that at that time the technology is already mature and commercially available. These studies have all been assuming a Swedish setting but some conclusions could be applicable also to a more general European setting.

In a study comparing the profitability and $CO_2$ emissions of different biorefinery concepts including integration of a biorefinery with an existing NGCC CHP, it was found that the results are highly sensitive to assumptions regarding the production mix in the DH system and energy market developments but generally the most cost-optimal solution is a stand-alone SNG plant with DH delivery.[7]

In a techno-economic optimization of biomass utilization in the Västra Götaland region of Sweden, different bio CHP and biorefinery options connected to district heating were contrasted[8]. Policies for $CO_2$ reduction and "green" power promotion were assumed, and the required subsidy levels for large-scale production of transport biofuels were estimated. Results indicate a trade-off between biomass CHP generation with high electrical output and transport biofuel production. The trade-off is a consequence of constraints on local, lower cost, biomass supply. Thus, large transport biofuel production might be linked to a lower bio power generation which in a short-term perspective, assuming $CO_2$ intensive marginal power generation, implies minor climate benefits of transport biofuels (see also discussion on different reference systems in Chapter 7 and the example in Figure 7.2).

In two studies using the DH system of Linköping as a case, it was found that it is profitable to apply a small amount of cooling of the DH supply when a biomass gasification plant is integrated into the DH system.[9,10] Both studies further conclude that the introduction of a biomass gasification plant into a DH system is profitable but whether transport biofuel production or combined heat and power generation is most profitable depends on energy market conditions and economic policy support levels. It is also concluded that with the applied assumptions the obtained results are relatively robust with regards to biorefinery capital cost variations.

7 Fahlén E och Ahlgren EO (2009). Assessment of integration of different biomass gasification alternatives in a district-heating system. Energy, 34: 2184-2195.
8 Börjesson M och Ahlgren EO (2010). Biomass gasification in cost-optimized district heating systems – a regional modelling analysis. Energy Policy, 38: 168-180.
9 Difs, K. et al (2010). Biomass gasification opportunities in a district heating system. Biomass and Bioenergy 34: 637-651.
10 Wetterlund E & Söderström M (2010). Biomass gasification in district heating systems – The effect of economic energy policies. Applied Energy 87: 2914-2922.

## CONCLUDING REMARKS

To sum up, the profitability and, especially, the $CO_2$ consequences of excess heat deliveries are complex and highly site specific. Hence, the economic and environmental impacts of heat deliveries should be evaluated for every specific case. If the targeted district heating system has low production costs and low $CO_2$ emissions, it can be difficult to justify utilization of excess heat.

A general conclusion could be that the profitability of heat deliveries from a biorefinery can potentially be substantially higher in a situation where the biorefinery can compete with a new base or intermediate load production unit. However, as shown above, replacement of a biomass based production unit can have adverse $CO_2$ emission consequences when biomass is considered as $CO_2$ neutral and in abundant supply.

The conclusion that utilizing excess heat can have negative $CO_2$ consequences might seem contra intuitive and, in fact, this conclusion might be a product of too narrow system boundaries. In a wider perspective it is probably correct to utilize heat with no cost and no emissions as long as there are costs related to heat production and emissions in our energy system. If excess heat from biorefineries and other industrial processes can cover the heat demand, saved biomass in alternative heat production can be utilized in other parts of the energy system, for instance for electricity or biofuel production (e.g. in a biorefinery).

Looking at a mature district heating market as Sweden, the situation is not always favourable for added excess heat deliveries since there will be a competition with existing base load production units as waste incineration and bio CHP. Waste incineration has a negative cost since alternative waste handling is expensive (land fill is not allowed and has to be phased out) and bio CHP has a low or negative production cost since there are policy instruments promoting this technology. This leads to the conclusion that policy instruments are decisive for how excess heat will be used. Hence, it is important that policy makers consider the system consequences when designing policy instruments to avoid any secondary, maybe unwanted, side effects.