INTEGRATION OF WASTE HEAT STREAMS INTO INDUSTRIAL CHPS OR DISTRICT HEATING UNITS

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ABSTRACT: The European Horizon 2020 project [1] FLEXCHX aims to develop a flexible and integrated hybrid process combining electrolysis of water with gasification of biomass and catalytic liquefaction. This hybrid concept might allow more flexible and fast response to changes in consumer heat demand and might capable of managing the energy system fluctuations on an hourly and daily basis. In addition, the gasification and FT process concept has many designs and operation alternatives, therefore in order to develop a flexible hybrid process combining electrolysis, there was evaluated different operating modes and conditions at which some amount of by-product heat is generated. In this purpose, there was performed an analysis of the selected energy object integrated into the district heating system presenting the structure and regulation of the Lithuanian energy market. The basic aim of this work is to assess qualitatively the various potential district heating and industrial CHP applications where the waste streams may be integrated according to the heat and power markets. This work provides data for the surrounding conditions of FLEXCHX process in the present CHP system and possibilities of integration variations.
Keywords: gasification, combined heat and power generation (CHP), waste, steam, demand.

1 INTRODUCTION

According to Renewable Heating and Cooling Platform, almost 50 % of the total energy consumed in Europe is used for heat generation. The heating and cooling sector [2] is expected to play a key role in achieving targets set for renewable energy (Renewable Energy Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II)) [3]. In addition to these challenges, Europe also has to decarbonize the transport sector to meet its CO_2 reduction targets by 2050 [4]. While electric vehicles are becoming a viable solution for light-duty and city transport, there is still a huge demand for renewable fuels in the heavy road, maritime and commercial aviation sectors.

The current gasoline demand in Europe is 85.8 Mt/a [5], which is the second largest demand for all crude oil-based products. This figure includes the renewable alternative demand as well as a small percentage of gasoline used in other sectors than transport, i.e. petrochemical feedstock, residential, commercial, agricultural and industrial uses. The Fuel Quality Directive [5] also sets limits for biofuels that can be added to conventional fuels. These limits were increased in 2009 to allow more biofuel blending into fossil fuels while maintaining safe operation limits in the engine. From above it seen that EU still supports first generation biofuel production, however promotes the contribution of advanced biofuels and biogas and have an ambition to reach a share of final consumption of energy in the transport sector to be at least 3,5 % beyond 2030 [5].

The work idea is focused on the development of flexible technology (FLEXCHX) [1] in order to design combined production of Fisher-Tropsh (FT) reaction products [6], [7] and heat/power for a different type of CHP systems having different requirements set by the district heat network or industrial steam consumption. Combined Heat and Power production technologies using various wood residues and agro biomass are widely distributed at different sizes ranging from very small engine plants to large-scale fluidized bed boiler plants. Power generation efficiencies in CHP units are usually below 30 %, while the overall efficiency of power and heat production can exceed 85 %. It is known that CHP plants based on direct combustion and conventional steam cycle are not highly flexible and their operation is usually limited to the heating season. The state-of-the-art CHP technologies have become under severe financial stress in a number of European markets characterised by a rapid addition of VRE (variable renewable energy) capacity and stagnating electricity demand [8]. Consequently, many new thermal generators are currently designed to produce only hot water for heating purposes instead of CHP. As a result, there is a clear need for new flexible district heating and power production solutions in Europe that can maintain economic feasibility under increasing VRE penetration. In order to increase the share of renewable energy in heat and power production, Energy companies have an interest in new possibilities. In this purpose, the FLEXCHX concept, which is based on the development of highly innovative new technology, might allow a more flexible response to changes in consumer heat demand producing the main product – FT wax. Therefore, this double integration principle makes it possible to combine the interest of local energy production and large-scale refining or chemical industries. However, one of the main aspects is that the end price of the product should be competitive against fossil equivalents, as well as the heat price must be competitive in the heat market. Renewable diesel is thus an interesting market opportunity, as is renewable jet fuel, which is expected to have a rising demand.

2 CONCEPT OF HIGHLY FLEXIBLE COMBINED TECHNOLOGY (FLEXCHX)

2.1 FLEXCHX concept

The FLEXCHX concept offers creation a flexible combined heat, power and fuel production concept for managing the seasonal mismatch between solar energy supply and demand for heat and power that is highly pronounced particularly in Northern and Central Europe. Plenty of solutions already exists for managing short-term variation in the energy system, but there is a clear need for new technology that can reconcile the seasonal mismatch of abundant solar supply with peak heat demand during the dark winter months.

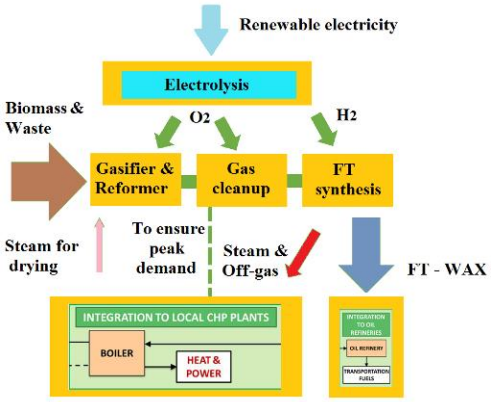

Figure 1: Combined hybrid process (FLEXCHX)

One of the main advantages is that this concept can be used for management of power fluctuations depending on the changing demand for heat consumers during shorter periods as it can shift flexibly between operation modes. For example, during periods of peak power and heat demand, the synthesis unit can even be bypassed and the syngas fed directly to the CHP plant for quickly maximizing the heat and power production

The core of the plant is the FLEXCHX conversion unit, where solid biomass residues are converted to FT wax and by-product (off-gas and steam). Whereas within the FT synthesis step the intermediate product as waste steam and off-gases are generated, therefore might be delivered to the local CHP plant for heat and power generation increasing energy efficiency. Depending on consumer demand, these various streams would be used for heat and power production. In the case when demand would reduce, the surplus of waste streams might be supplied to the gasification process for biomass drying or could ensure the operation of the gasifier thus creating an efficient waste streams utilization cycle. The seasonal flexibility is achieved by changing the operation modes between "Summer" and "Winter" mode. Therefore, it can assert that, compared to a typical biofuel boiler, the FLEXCHX concept might allow more fast response to changes in consumer heat demand.

Studies on the integration of waste streams to local heat and power production systems are essential in designing a coherent production concept for cost-effective tri-generation of FT wax, heat, and power. In this purpose, there was carried out the analysis of integration possibilities considering market of the district heating system.

2.2 Feedstock requirements for gasification technology

According to RED II directive, advanced biofuels for transportation can be produced mostly from non-food feedstocks such as waste biomass, forest residues, straw, animal manure, sewage sludge, etc. Therefore, the main focus of these requirements adopts for advanced gasification systems which has to achieve a desired product syngas quality and process efficiency.

There are a large number of different types of biomass with a specific physical and thermochemical characteristics such as moisture content, particle size and shape, ash content ash fusion characteristics, volatile compounds, reactivity, chemical composition, energy content, bulk density and homogeneity of all these properties [9], [10], which have influence on gasification process. The choice of biomass feedstock for different kinds of gasification technology is based on these characteristics. Furthermore, each gasification technology has its own unique optimal working regime, tolerance limits of feedstock parameters, the quality of produced syngas and efficiency of gasification. While there are many of these characteristic, moisture content, particle size and ash content play main role in gasification process.

Taking into account these features and tolerance limits and also characteristics of feedstock, the most suitable types of biomass feedstock for gasification remains various wood residues, agro-biomasses and biogenic waste fractions.

3 INTEGRATION POSSIBILITIES OF WASTE STREAMS INTO THE CHP PLANT

3.1 An overview of the general situation in the Lithuanian energy sector and district heating market

There are three types of heat producers in Lithuania:

- Heat suppliers are responsible for heat supply in the area. Usually they also have heat production facilities. Eligible production costs are regulated;
- Regulated independent heat producers. Independent heat producer is regulated if either: receives state aid for electricity production in CHP; support has been received to the investment of a heat generation unit;
- Non-regulated independent heat producers.

Price regulation is based on following aspects:

- National Commission for Energy Control calculates eligible costs based on the properties of production facilities and comparative analysis;
- To become eligible, the investment must be approved by the Commission;
- If there is at least one independent heat producer in the district heating system, heat must be purchased through Baltpool [12] auction system.

The auctions evolved as a more flexible system to determine the price to purchase heat from independent heat producers. The main principles:

- The auctions are performed 2 months in advance to allow market participants in getting a better position to purchase fuel;
- All market heat producers, including heat supplier, participate at the auction;
- Auctions are performed in Baltpool electronic platform.

3.2 District heating system in selected area

For the analysis of FLEXCHX integration in existing district heating system, the second big city Kaunas of Lithuania was selected. Kaunas has a relatively large district heating system, which covers the main part of the city. The required heat demand is ensured by independent heat producers (IHP) and heat supplier according to the market price of heat The heat supplier of Kaunas city distributes and transmit heat, as well as it has heat generation sources ("Šilkas", "Inkaras", "Pergalė", "A. Juozapavičiaus av. 23" boiler-houses and "Petrašiūnai" power-plant) integrated into the DH

network. In Kaunas city IHP have nine additional boiler houses and CHP plant: UAB „Kauno termofikacijos elektrinė“, UAB „Danpower Baltic Taika“, UAB „Lorizon Energy“, UAB „Danpower Baltic Biruliškių“, UAB „Aldec General“, UAB „Ekopartneris“, UAB „Pramonės energija“, UAB „Petrašiūnų energija“, UAB „Foksita“ ir UAB „Danpower Baltic Taika elektrinė“. All heat generation sources are shown in Figure 2.

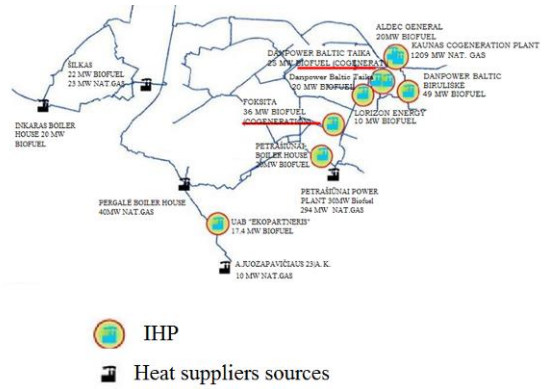

Figure 2: Heat producers in Kaunas city

The National Energy Strategy of Lithuania [13] defines the objectives oriented towards a stable and predictable regulatory framework and a non-discriminatory competitive environment for all participants of the district heating market.

The analysis of the market shows that the market's competitiveness criteria have a significant impact on the market. If the dominant participant is a high-price leader then there is a favorable situation for other participants (potential and existing) to enter the market and offer the lower price. Both potential and existing market participants need to rationally assess their capabilities and be able to compete in the market by offering the lowest price. Therefore, the integration of the new FLEXCHX concept must be based on techno-economic solutions. For this stage, only a technical evaluation was carried out on the basis of the project (FLEXCHX), that allows to determine the initial conditions and possibilities of the concept integration.

3.3 Selection of the integration case

In order to evaluate the integration possibilities of waste streams, their demand, there was performed detail analysis of market taking into account location, heat capacity, responsibility, and operating modes of integration cases.

From the Soviet time there left a huge total installed thermal capacity in Kaunas city, which is over than 2 GW. Although nowadays the maximum required heat is only 0.5 GW. The current situation in Lithuania with increased competition between heat producers leads to lower heat price for final consumers. Considering the situation on the heat market it can be seen that the heat price correlates with the number of IHP. Therefore, the integration of new technologies that reduce the price is desirable.

In order to highlight the applicability of the FLEXCHX concept a well-developed including biofuel supply system and industrial location with DH system and other conditions the CHP plant No. 5 (Figure 3) was selected.

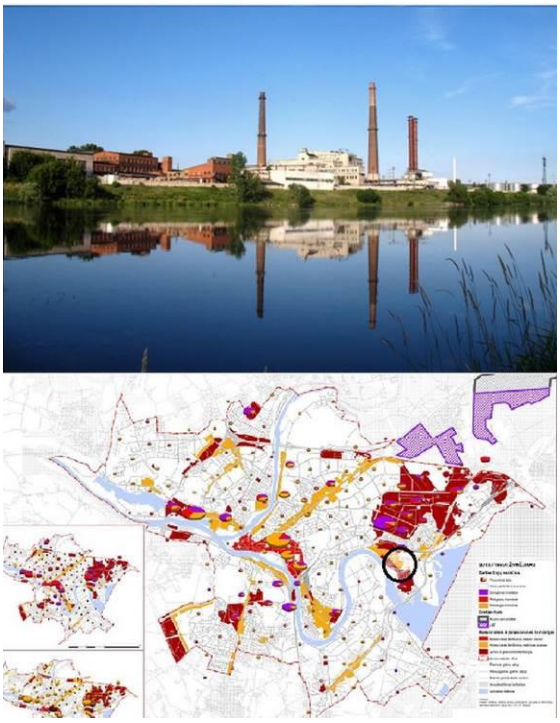

Figure 3: Selected CHP plant

Selected larger-scale CHP plant is integrated into the DH network of Kaunas city. Whereas it works as an operator by providing the reserve of thermal power. Annual required heat production curve (Fig. 3, actual data) represents the working mode of the selected CHP plant. Based on this curve, the operation of the facilities can be divided into different operating modes:

- the basic operating mode provides 30 MW of thermal power in dark season;
- the reserve capacity is ~ 40 MW;
- during the summer period, power plant works if required.

By operating in the basic operating mode, the power plant constantly ensures about 30 MW of heat capacity during the winter season. This power plant also has operator status, where it is necessary to ensure the capacity of the reserve up to 100 MW in case of the unexpected demand for thermal power. In this power plant, the natural gas boilers are used to respond quickly to any changes in heat demand, thus ensuring rapid load change capability. During the year 2017, the maximum fluctuation of thermal capacity was 40 MW (Fig. 4) and that was only 6.7% (11515 MWh) of the total amount of heat demand. The 18 MW natural gas boiler is used to provide slight fluctuations. The load of this boiler is not significant; the approximate amount of the produced heat is only 1.2% of annual heat production. The average heat capacity is about 6.6 MW (load varies from 0.9 to 18 MW). During the summer period, the CHP plant works if there is a lack of heat power using biofuel boilers.

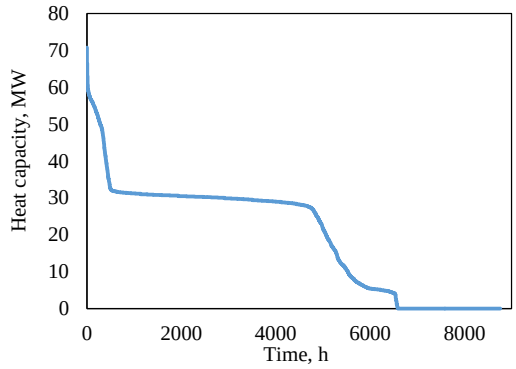

Figure 4: Required heat capacity of CHP plant No. 5

Total capacity at CHP plant is almost 295 MW of which about 30 MW is produced with biofuel boilers, while 265 MW is ensured using natural gas. During the heating season required capacity of thermal power is in the range of 58.05- 30.45 MW, in the summer season -15.97 - 4.71 MW.

3.4 Study on the integration of the FLEXCHX process to potential CHP applications

Considering the initial hybrid process concept (FLEXCHX) the possibilities of integration of waste streams and syngas into the power plant were being evaluated. It was assumed that the capacity of gasifier should be oriented to the fluctuation zone in order to optimize the use of waste streams because it is necessary to ensure a very flexible working mode in the selected power plant. The nominal capacity of the FLEXCHX plant was selected to be 10, 20, 30 and 40 MW evaluating the working mode (annual load duration curves) and surrounding conditions. As well as there has been established that at all operating conditions of gasifier certain amount of by-product heat is generated (Table I) considering the wax production. Preliminary balance of hybrid process is shown in Figure 5.

Table I: Total net heat and power production

Gasifier capacity	Total net heat production	Net power production
MW	MW	MW el.
Case "Winter"		
10	2.36	-1.00
20	4.73	-2.00
30	7.09	-2.99
40	9.46	-3.99
Case "Summer"		
10	5.20	-11.78
20	10.40	-23.57
30	15.60	-35.35
40	20.79	-47.13

These secondary products formed after the technological process are still usable and can be utilized for energy production by integration into heat and power plants. According to the actual data (operation mode, annual load duration curve) for selected integration case, the utilization efficiency coefficient of waste streams was determined (Table II). That coefficient represents the ratio between the output of the generated waste stream and its integrated quantity.

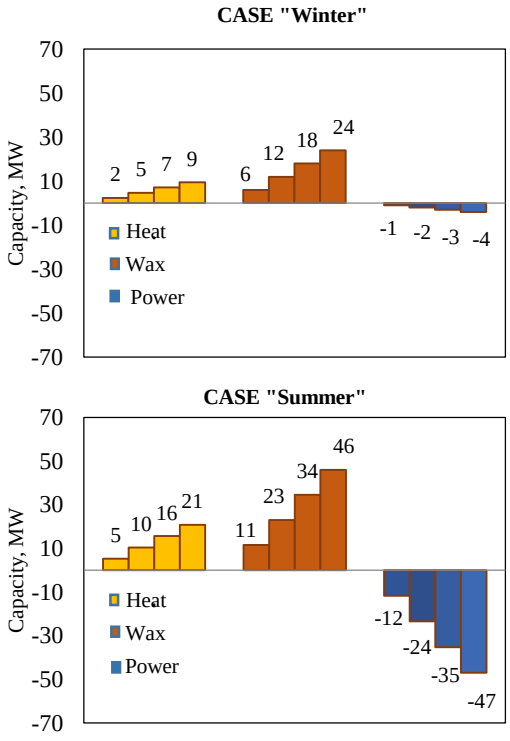

Figure 5: Preliminary energy balance scenarios of hybrid process

Table II: Consumed heat content from waste streams

Gasifier capacity	Potential waste heat content	Heat content	Heat production from waste streams	Utilization coeff.
MW	MWh	MWh	%	-
Actual data				
CHP plant	-	172.672	-	-
Case „Winter"				
10	20716	15535	9	0.750
20	41432	30949	18	0.747
30	62148	45018	26	0.724
40	82865	58330	34	0.704
Case „Summer"				
10	45541	33885	20	0.744
20	91081	63516	37	0.697
30	136622	91409	53	0.669
40	182162	118145	68	0.649

During summer season, heat demand is significantly reduced because most of the boiler houses are often shut off. Therefore, the use of waste heat streams may be ineffective if the initial capacity of the gasifier is too high. Analysis of CHP plant No. 5 was performed for few scenarios depending on the gasifier capacity from 10 to 40 MW. The heat utilization efficiency (Figure 6) of waste streams was calculated and for this particular case was between 0.74-0.85. If the price of the integrated heat would be competitive in the heat market, the efficiency might reach 1 and heat production can be increased by 35% of total heat. The competition, which dictates market conditions, is one of the advantages of a large

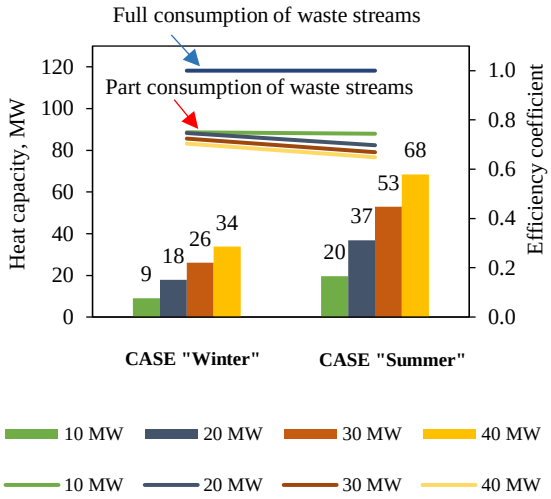

Figure 6: Waste streams consumption depending on different capacities of gasifier

number of small heat producers in the DH network. Therefore, the possibility to use waste streams at CHP plant would be most dependent on the heat price in the market.

The following conditions were accepted during the technical assessment:

- The flexible working mode of the gasifier is adapted to ensure the fluctuations of the heat capacity when the required load is over 30 MW. In order to cover the fluctuations of the heat demand, the syngas might be supplied directly to the CHP plant for quickly maximizing the heat and power production by-passing the synthesis unit.
- Low-calorie gas (as the off-gas) can be burned in the natural gas boilers though burners should be reconstructed by applying of these gases. If the required capacity is less than < 30 MW, the off-gas can be directly supplied to the biofuel furnace. It can partly substitute biofuel used for heat production in existing biomass boilers.
- If the economic assessment reveals that the use of syngas for ensuring power fluctuations wouldn't be economically viable, then a syngas supply option for unexpected heat demand would be considered as ineffective. In this case, the output of FT-wax and the by-products would be generated evenly throughout the year.
- In summer, the CHP plant doesn't supply heat to the DH system as the prime cost of heat production is higher than the offered price of other producers.

Variation of integration depending on operating modes and installed capacity of the gasifier is presented in Figure 7.

The data analysis of selected potential site and the FLEXCHX concept integration study are based on actual capabilities, i.e., limited by real parameters: capacities, flows, heat and power production and etc. Based on the calculations, it can be concluded that the alternative of the FLEXCHX concept promotes the use of waste heat streams, although it depends on the capacity of the gasifier.

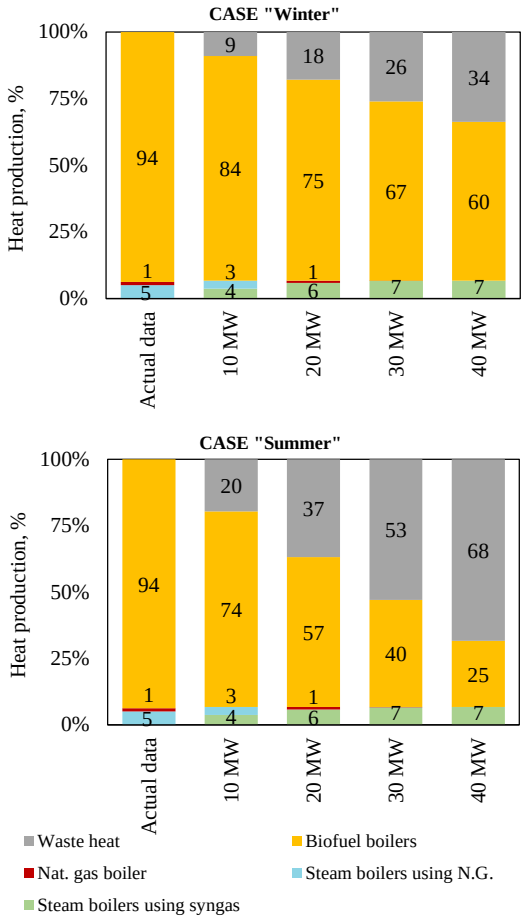

Figure 7: Waste Heat Consumption Depending on Different Capacities of Gasifier

4 CONCLUSIONS

Lithuanian market was evaluated on selected applications which could be potential sites for industrial as well as demo plants. The size and locations of the biomass-fired district heating plants are considered very promising for the initial markets of FLEXCHX technology. Based on preliminary studies of the target hybrid process, there was established that:

- The new FLEXCHX process concept allows to increase the revenue obtained from locally available biomass residues; and the use of electricity excess in the process enables to increase share of renewable energy in both, CHP and transport fuel market.
- Focusing on the heat fluctuations, the capacity of the gasifier was selected to be in the range of 10-40 MW; and therefore it was determined that at all operating conditions, the amount of by-product can generated from 2.36 to 20.79 MW of heat. Waste streams can be used all year-round, which gives the possibility of a flexible response to minor power fluctuations.
- The FLEXCHX concept allows more flexible and fast response to changes in consumer heat demand comparing with biofuel boilers. There was evaluated that the gasifier might ensure peak

demand of thermal power directly utilizing syngas in the boilers for heat production. Peaks takes just 6% of the total demand, therefore FT-wax production would not be significantly affected.

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