Recommendations and challenges for BTC integration

D4.5

Authors: Yelena Vardanyan (RISE), José Pablo Chaves Ávila (Comillas), Jens Pålsson (PHOENIX)

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Summary

This deliverable aims at identifying barriers while integrating novel BTC CHP technology in local heat systems as well as in the electricity system. The work has been based on the review of the Bio-FlexGen work, relevant EU/national regulation and on the feedback from industry partners. These barriers are identified and assessed in three different dimensions; technical, economic and administrative/regulatory.

First, the review of Bio-FlexGen work has been conducted to highlight the technical and economic challenges while integrating BTC in both business use case level and system level. Then, gap analysis has been carried out based on the feedback received from the industry partners. Finally, recommendations, how to tackle the identified barriers, have been provided.

Table 1 provides the skeleton of the work.

Table 1: Summary of the work.

	Review of Bio-FlexGen work	Review of relevant regulation	Feedback from industry partners
Economic	√		√
Administrative/regulatory	√	√	√
Technical	√		√

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Abbreviations

BTC	Biomass-fired Top Cycle
CAPEX	Capital expenditures
CHP	Combined Heat and Power
DA	Day-Ahead (market)
DH	District Heating
mFRR	Manual Frequency Restoration Reserve (market)
TvAB	Tekniska Verken AB, Linköping, Sweden (utility)
ATEX	Atmospheres Explosible
FCR	Frequency Containment Reserve
FFR	Frequency Following Response

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1 Introduction

The Bio-FlexGen project aims at developing a renewable energy-based combined heat and power (CHP) system characterized by increased efficiency, cost-effectiveness, flexibility, and robustness in response to the challenging requirements of an energy system with a high share of variable renewable energy. This is realized by means of the flexible Biomass-fired Top Cycle (BTC) plant technology developed in the project on basis of Phoenix Biopower technology.

In this regard, it is essential to identify and analyse regulatory and administrative barriers while integrating this novel technology at both the local business use case level and the system level. In addition, the deliverable will provide recommendations how to tackle the identified barriers.

The structure of the deliverable follows:

- Section 2 provides the background and identifies the challenges by reviewing the work done in Bio-FlexGen project and the existing EU/national relevant regulations.
- Section 3 maps a list of identified barriers to the use cases and provides gap analyses
- Recommendations to tackle identified barriers are presented in section 4.
- Finally, section 5 provides conclusions.

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2 Identified challenges for BTC integration

This section provides the background and identifies barriers through reviewing the existing relevant regulation, the Bio-FlexGen work and feed-back from industry partners.

2.1 Review of Bio-FlexGen work

2.1.1 Technical

As in the development of all new technologies there are various requirements to consider, both economic in terms of CAPEX and OPEX, performance and capacity, complying with safety, environmental and other regulations and meeting grid service, fuel flexibility and other market requirements. As a new technology, there is also a challenge with availability (planned outage) and reliability (unplanned outage), which will directly impact OPEX and revenues if operation time is reduced.

Bio-FlexGen has provided a platform to further develop and test BTC technology in many areas such as combustion, gasification and overall plant performance. In the development roadmap, there is a milestone to reach a full-scale demonstration plant by year 2030. Design and selection of components and systems are done to find the most reliable and cost-efficient solution. Validation by tests is a necessary and adjustments and design iterations normally follow.

An example how the availability and reliability issue as well as CAPEX are addressed is to use standard and well proven technology for balance of plant components such as heat recovery steam generator. The gas turbine combustor and expander can be steam-cooled for high performance but will utilise conventional air-cooling in the short-term for lower cost, risk and shorter development times. Another example to address CAPEX is the patented hybrid gasifier technology that, by combining circulating and bubbling fluidised bed features, achieves a high cold gas efficiency at high pressure with a more compact (and cost effective) design. A way to decrease the risk related to availability and reliability is to use more robust technology (less advanced operation parameters) in the first plants built, as well as biomass feedstocks that are easier to handle and pressurise, such as pellets.

One aspect that was discussed in D3.1 [1] was start-up time for BTC CHP plant ranging from 3 h in hot mode to around 21 h from cold start. To be able to participate in as many grid service markets as possible it is desirable to have as short start up time as possible. Shortening the startup times might enable to capture market price volatility and increase the profit. Nevertheless, other conventional CHP technologies do roughly have the same start up times as BTC. For this reason, it is not identified as a barrier [2].

2.1.2 Economic

Economic aspects have been studied on both use case level and system level. Several use cases from Sweden (TvAB - utility of the city of Linköping) and Spain (Sulquisa - a leading producer of Sodium Sulphate and CEMEX-cement production company) have been modelled and simulated. For the system level analyses Swedish and Spanish energy systems have been modelled and simulated for the reference years: years 2030 and 2050 for Spain and 2035 and 2045 for Sweden.

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2.1.2.1 Use case level analyses

Swedish use cases investigated whether using efficient cogeneration of BTC technology enables optimal participation in energy markets and generates extra profit. The investigation was carried out in two steps: 1) studying whether TvAB power system will benefit from the utilization of BTC technology on one hand to meet the heat demand and on the other hand to generate electricity during high price hours and increase the profit and 2) investigating the potential of BTC technology to provide balancing power, while being introduced in the Linköping power system. These studies provide useful insights of the BTC technology in the district heating sector identifying the main gains and barriers for commercial exploitation of the technology.

The district heating supply temperature from a BTC is limited to approximately 75-80 °C by available heat in flue gas condenser and thus, it is insufficient for the Linköping district heating grid, where the supply temperature varies between 95 – 120 °C. Thus, it introduces a technical barrier in the Swedish use case. The FLEX plant analysed for TvAB use case could provide roughly 21 MWth from the flue gas condenser of which 8 MWth goes to the fuel dryer. The temperature rise of the BTC hot water stream from 75-80 C to the actual required supply water temperature was assumed to be covered by a topping boiler in the range of 9.5 to 11 MWth depending on month corresponding to 40 to 50 % of the total available heat production. This unit runs on a cheaper fuel than the BTC, like recycled wood.

Results show that when one unit of existing CHP in TvAB portfolio is replaced with BTC units, the generated profit is higher in all simulation runs, disregarding the investment cost. This outcome is consistent while also analyzing the business use case 2, where we assume that TvAB is providing balancing power while trading in both day-ahead and mFRR markets. Moreover, a sensitivity analysis showed that the portfolio’s total profit highly depends on the biomass prices, and if the biomass prices are low, the total profit is the highest. However, with the inclusion of investment expenses for BTC units, we see that annual periodized investment cost is at least 2.5 times higher than the annual profit. BTC dispatch is limited to about 2000 hours, despite high prices and volatility, due to the very low marginal cost of production from waste incineration plant and the lack of any cost-effective cooling capacity, besides the district heating grid. To increase the viability of investing in BTC in a system dominated by waste-incineration, the case may need to consider investing in cooling capacity and / or consider larger heat storage.

Spanish use cases follow. The Sulquisa use case focuses primarily on the economics of continuous electricity production and steam generation when three conventional natural gas-fired CHP units are replaced with BTC technology. This use case was dimensioned by the heat demand which required a smaller plant type (nominal 10 MW electricity) than all other use cases that used a capacity of 25 MW nominal power output. Further, three use cases explored with cement producer CEMEX aim to contrast various operational modes for the BTC CHP technology for two different plant locations, Alcanar and Alicante: use case ‘CEMEX Power-Gen’ investigates the potential of BTC technology to cover both plants’ electricity demand while providing balancing power when no heat demand is considered; use case ‘CEMEX CHP’ adds a heat demand for drying two different fuel lines in Alcanar plant; and finally, use case ‘CEMEX Hydrogen’, which studies, first, BTC operation with renewable hydrogen for the start-up sequences, and second, the use of renewable hydrogen as partial fuel replacement in the kiln.

The main technical barrier encountered during the execution of the Sulquisa use case was the limitation of the BTC to provide heat at the required temperature (water vapour at 190°C). For this reason, a high-temperature heat pump downstream of the BTC was included to reach the required conditions. Modelling the integrated operation of the BTC and the heat pump, which consumes part of the electricity generated by the BTC, resulted in a reduction of the net power output. Additionally, the replacement of three conventional CHP units with a BTC-heat pump coupling could also mean

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restricted operational flexibility in future scenarios, in case Sulquisa's demand exceeds the coupling capacity.

Results show the potential of BTC technology in different industrial applications such as 2021 scenario where BTC technology could achieve higher profits and lower costs in all cases to cover the demands of electricity and heat industries. Even considering investment expenses, the total profitability increases in all cases compared to the benchmark cases. However, on-site hydrogen production for heating purposes proved more costly than fossil fuels in 2021 and 2023 scenarios.

The 2023 sensitivity analysis reflected the impact of lower electricity prices and fuel costs on BTC performance, showing lower profitability for BTC. Further studies should consider future scenarios and analyse BTC competitiveness under higher CO_2 emission and fossil fuel costs, and lower electricity prices. Moreover, renewable hydrogen could be extended to new purposes, such as a way to achieve electricity storage.

2.1.2.2 System-level analyses

The Swedish TSO (Svenska Kraftnät) has developed different scenarios/economic pathways to analyse long-term market behaviour toward green transition. Sweden is divided into four bidding zones to ensure secure operation of the electricity system. When the transmission lines are getting congested, electricity market clearing is resulting in different prices for each bidding zone to improve the local balance between supply and demand. Therefore, Swedish system level cases for 2035 and 2045 are created and simulated as four bidding zones coupling electricity and heat sector. The cases are created by adopting a long-term market scenario and a set of modelling assumptions.

The accurate assessment of the BTC integration at the system level highly depends on how accurately the future power-heat sectors can be resembled. The long-term market analyses report generated by Svenska Kraftnät provides an overview of the estimated future electricity sector [3]; for example how the electricity demand will look like in 2035 or 2045, how it will be distributed among the price zones, how the generation mix will look like and where the planed generation sources (wind, nuclear, solar and so on) will be located. However, we faced a big technical challenge to find heat sector-related data for each bidding zone in Sweden. For example, it required an extensive literature review to extract heat demand data for the reference years and to adopt reasonable assumptions to distribute among the four bidding zones.

Another barrier was related to the lack of industry relevant information, both heat demand and technology potential in the industry sector, and their distribution among price zones. These data were extracted gathering information from the industrial sector (current and planned in 2035 and 2045) and adopting a set of reasonable assumptions.

The results obtained from all cases for the reference year of 2035 show that to satisfy the system electric demand, the model prioritizes BTC investment over nuclear technology. However, for a situation where the need for investment in heat-generating technologies is higher to meet the system heat demand than that of electricity, the model prefers to invest in conventional CHP biomass rather than in BTC technology. This behaviour is consistent even if we decrease BTC CAPEX by 25 %. Such a decrease in BTC CAPEX results in 2.44 MEUR/MWe, while CHP biomass has CAPEX of 2.94 MEUR/MWe. In a system where there is a bigger need to invest in heat-generating technology than that of electricity, the model prefers to invest in CHP biomass technology as every MW of electric power installed for CHP, the system gets 3 MW of heat installed.

Integrating BTC technology in the generation mix of the 2045 energy system, the opposite effect was observed compared to the 2035 scenario. In the 2045 reference case, where the need for investment in electricity-generating technologies is higher to meet the system electric demand than heat, the model always finds BTC technology more competitive than other technologies. All simulations for the 2045 Swedish energy system highlighted that BTC is a competitive technology that can participate in electricity and heat mix and satisfy both system electricity and heat demand.

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A single-node-system was assumed for the **Spanish** reference years, considering an infinite capacity of interconnection of all lines. The system did not consider international exchanges, following the reasoning of establishing a worst-case-scenario, in which the system cannot benefit from imports or exports. Spain's 2023 draft update version of its Integrated National Energy and Climate Plan (INECP 2023-2030) [4] was used as the main data source for modelling 2030's electric system. For 2050, the Ten-Year Network Development Plans (TYNDP 2024) [5], by the European Networks of Transmission System Operators for Electricity and Gas (ENTSO-E and ENTSO-G), was used.

A problem encountered at the system level analysis was the lack of data on the Spanish industrial heat sector, both demand- and technology-related. As no precise or reliable demand data was available disaggregated by hours, it was necessary to make a series of realistic assumptions to obtain an hourly profile for low-temperature industrial heat demand. The technical characterization of heat and CHP technologies, such as CAPEX (investment and fixed operation and maintenance costs), and electric and thermal efficiencies, was done with an extended literature review.

Results for the 2030 scenarios indicate that BTC is a competitive technology that can be integrated into both the electricity and heat sectors, even when competing with conventional biomass CHP technology. Including BTC reduces electricity marginal costs and increases the share of renewable generation in both sectors. Additionally, cogeneration and electric heat technologies (electric boilers and heat pumps) are preferred over carbon-emitting boilers, despite their lower investment costs. On the other hand, hydrogen boilers, while able to decarbonize heat production using renewable fuel, are non-competitive due to their high CAPEX. Sensitivities were studied when increasing biomass prices, CO_2 emission ETS prices, and the efficiency of conventional CHP. BTC investment remained unchanged in all cases, with only marginal changes in heat and electricity generation.

For 2050, initial assumptions show that BTC technology is less competitive, with no investments in the main scenarios due to its high CAPEX compared to conventional biomass CHP technology. However, the model invests in BTC with a 10% reduction in investment cost. Electrification of heat production surpasses 80%, with biomass boilers and CHPs complementing the mix. Additionally, higher biomass prices make CHP and biomass boiler generation less attractive and BTC more competitive due to its higher efficiency.

According to the Spanish Integrated National Energy and Climate Plan, the Spanish electricity system is projected to achieve 81% renewable electricity generation by 2030 and 100% by 2050. According to the results from Deliverable 4.2 [6], BTC technology enables renewable generation to exceed the 81% threshold.

2.1.3 Regulatory

In the electricity market, CHP units have historically participated primarily in the day-ahead and intraday market segments, often influenced by support schemes. The greatest potential for new market revenues lies in the short-term timeframe, including balancing and flexibility markets which are becoming widespread in the European Union. CHP plants have the technical potential to participate in FFR, aFRR, and mFRR markets. Comprehensive explanation, definition and summary of those markets in both Sweden and Spain are provided in D3.2 [7]. Participation in FCR depends on the plant type. Major obstacles to this participation include minimum bid sizes, the technical ability to meet response time, and the challenge of decoupling electricity from thermal energy production in CHP units.

CHP units are also (mainly) active in the heat market, typically within district heating and cooling networks. There is a wide regulation of heating networks across Europe, from minimally regulated sectors to strictly regulated publicly owned networks. Regulations mainly focus on tariff design and third-party access. Additionally, CHP units can participate in other markets beyond electricity and heat, accessing various remuneration sources. The report examines CHP participation in the EU CO2 Emission Trading Scheme (ETS), guarantees of origin for electricity, and the hydrogen market, where CHP can act as both a consumer and producer of low-carbon or renewable hydrogen. It also classifies different European support schemes to incentivize cogeneration, highlighting diverse trends. For

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instance, the UK may phase out incentives for non-renewable CHP due to its carbon footprint compared to renewable sources.

Four cases have been studied on the regulatory environment for CHP in Sweden, Spain, Germany, and Italy. Each study assesses the current state of the CHP industry, the main regulations driving cogeneration deployment, CHP participation in the electricity market, heating network regulations, and future prospects. The heterogeneity is evident in these case studies, with none showing a clear growth trend. In some countries, investors face significant uncertainties and await further regulatory frameworks, while in others, like Spain, the traditional CHP industry is expected to decline, with minimal new capacity anticipated in the coming years.

2.2 Review of regulations in EU/National

2.2.1 Regulations on biomass use

2.2.1.1 Sweden

Swedish regions have relatively high biomass availability. Biomass has become an increasingly important energy source accounting nearly 38 % of the final energy use in Swedish economy [8]. Biomass is used in several sectors, but the development of bioenergy has been particularly strong in the district heating sector. Currently, nearly half the heat demand in Swedish district heating system is met with forestry-based biomass and 7% with demolition wood waste.

The regulatory environment in connection to biomass is enormous [9]. On October 2023, the European Parliament enforced the Renewable Energy Directive (RED III) to promote energy from renewable sources [10]. The article 10 in the directive [10] sets the principle of the cascading use of biomass. Accordingly, there are restrictions on the use of primary woody biomass (PWB) in RED III [10]. A definition for primary woody biomass (PWB), meaning biomass sourced directly from forests, was added for the first time to the RED. The definition however includes exemptions for forests affected by fires, pests and disease, carving out significant potential loopholes for the use of PWB. The primary woody biomass used in Sweden is tops and branches, thinnings and damaged wood. According to RED III, Member States should design support schemes to ensuring that woody biomass is used according to its highest economic and environmental added value in the following order of priorities: 1) wood-based products, 2) extending the service life of wood-based products, 3) re-use, 4) recycling, 5) bioenergy and finally 6) disposal. In addition, there are targets on annual total efficiency of biomass use. The reference [11] assesses the impact of such restrictions on the Swedish strategy of meeting climate targets defined in Swedish climate law. The law aims at contributing to the Paris agreement's target and includes a national target for net-zero emissions in 2045. The report summarizes impacts of such restrictions on the Swedish energy use and on Swedish climate policies and targets. It concluded that the proposed restrictions by the EU parliament on primary woody biomass will have a non-positive impact on the energy use, GHG emissions, and future bioenergy development in Sweden; thus, threatening Swedish targets on being 100% fossil free by 2045.

The development of a strategy to promote a sustainable, competitive and growing bioeconomy has been initiated by the previous government. An interim report entitled 'Renewable in the idea' was presented in March 2023, which proposed measures to promote the efficient production of biofuels based on domestic feedstocks in Sweden. Sweden's updated National Energy and Climate Plan (NECP) 2021-2030 came into force in June 2024 [12]. The document has been updated in relation to the draft that the government reported to the European Commission in summer 2023. Updates have been made to address some of the new requirements of modified EU directives and regulations. NECP includes the plan for the use of bioenergy in the heating and cooling, electricity and transport sectors by type of biomass from 2005-2040 based on the assessment in the Swedish Energy Agency's 2040 scenario and several other studies.

A study by the University of Lund in 2021 [12] estimates that biomass availability could increase by 27-37 TWh per year by 2030. The study made the estimations accounting for the sustainability

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requirements of stumps harvesting stated in Article 29 of RED III [10]. Still, there are several uncertainties in the longer term (related to regulations, climate change, adaptability of forest owners), which may affect the availability of biomass for energy purposes. Thus, the availability of biomass fuels in Sweden is estimated to be relatively stable, with some increases and declines from year to year. Swedish authorities, the Swedish Forest Agency, as well as the Swedish Energy Agency ensure that the use of biomass fuels is carried out in accordance with the requirements of RED III.

According to Swedish Energy Agency's baseline scenario, the total use of bioenergy decreases by 22.5 TWh between 2022 and 2025 and is estimated to be just over 133 TWh in 2025. The use of bioenergy is estimated to remain relatively stable in 2030 and afterwords until the year of 2040.

2.2.1.2 Spain

In Spain, forest residues represent the primary potential biomass source across most regions. Cereal straw ranks as the second-largest source, with substantial availability in areas like Castilla-La Mancha and Castilla y León. Olive grove prunings and pits are particularly important in Andalusia and Extremadura, where they surpass cereal straw in significance. Citrus residues hold relevance in the Valencia region, while vineyards are prevalent in La Rioja and Castilla-La Mancha. Maize stover plays a key role in northern regions such as Castilla y León and Galicia. Additionally, rice straw is a notable biomass source in Extremadura, Valencia, and Andalusia.

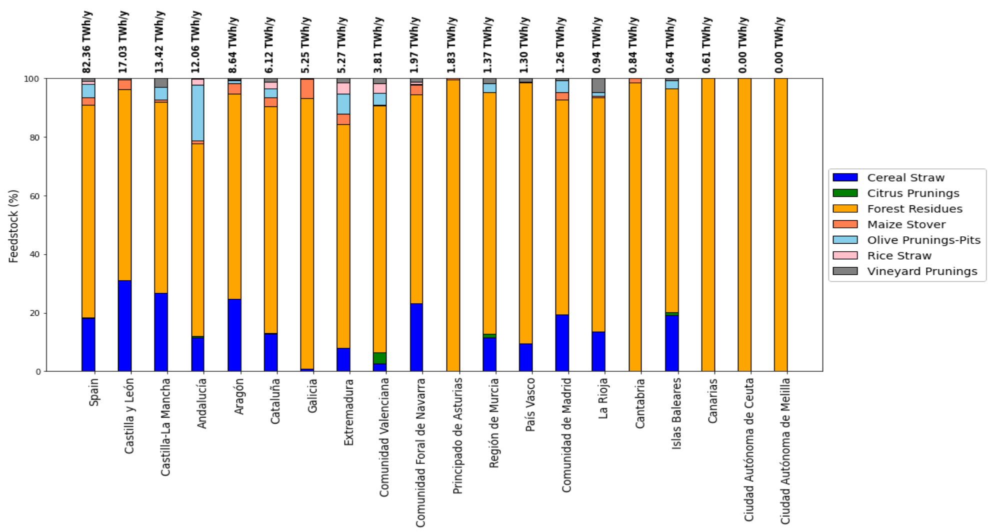

Figure 1. Biomass feedstock in energy volume in volume at NUTS-2 level in Spain. No energy conversion was applied. Source: BioFlexGen Deliverable 4.3 [13].

In Spain, regions such as Asturias, País Vasco, Cataluña, Comunidad Valenciana, and Murcia may face biomass constraints, while central regions like Aragón, Castilla-La Mancha, and Castilla y León have higher biomass potential than demand, allowing them to supply biomass to other constrained regions.

Following the regional analysis, a high-resolution analysis evaluated potential biomass feedstocks' chemical and physical properties for their compatibility with BTC technology [13]. This analysis showed that biomass feedstocks from forest residues or certain agricultural wastes, such as prunings or pits, are highly compatible with BTC. The analysis [13] indicated that regions with high demand for BTC cannot always access high-quality, local biomass feedstock, thus limiting the replication of this technology. The demand for the various BTC products also affects the solution's replicability. More sites are viable for replication if the CHP application with only low-temperature heat delivery is considered. However, including hydrogen production reduces the number of potential locations,

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though many regions still have good conditions for both products. A hydrogen pipeline infrastructure would help alleviate constraints. If CO_2 capture and storage is considered, the number of suitable locations significantly reduces. Prioritizing locations with demand for all products and good local biomass availability maximizes the benefits of BTC and likelihood of early implementation. Regions with higher compatibility are for example Castellón and Tarragona in Spain.

2.2.2 Regulation related to environmental permit for the plants

2.2.2.1 EU-regulation

A high level of protection of human health and the environment by reducing harmful industrial emissions across the EU is addressed in the Industrial Emissions Directive 2010/75/EU (IED) [14]. The Directive regulates the EU's largest industrial installations, including energy industries, production and processing of metals, minerals and chemicals and waste management (Annex I). A permit must be granted for every installation to ensure operation aligned with the principles and provisions of the Directive.

Several pillars constituting the core of the Directive are 1) **the integrated approach** to take into account the holistic environmental performance over the lifetime of a plant in the permitting process, 2) **emission limit values** , which should be based on the **Best Available Techniques (BAT)** defined at the EU level 3) frequently compulsory **environmental inspections** every 1 to 3 years, and finally 4) the **public has a right to participate** in the permitting related decision-making processes and to be informed about the results of emissions monitoring.

The Directive has been reviewed in 2022 as part of the European Green Deal. The revision aims at focusing to promoting the use of safer, less toxic or non-toxic chemicals in industrial processes. The revised, new directive came into force in April 2024 [15], and it is Directive (EU) 2024 /1785 of the European Parliament and of the Council amending directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC on the landfill of waste.

2.2.2.2 Sweden

The Confederation of Swedish Enterprise (Svenskt Näringsliv), Swedish Forest Industries Federation (SFIF), Jernkontoret (the Swedish Iron and Steel Producers' Association), the Swedish Association of Mines, Mineral and Metal Producers (Svemin) and Innovation and Chemical Industries in Sweden (IKEM) welcome the European Parliament's approval of a balanced set of revisions to the Industrial Emissions Directive (IED) and look forward to continuing to work in trialogue negotiations regarding the IED, and in due course when the new rules are adopted into Swedish law [16].

2.2.2.3 Spain

In Spain, the Royal Decree 376/2022 [17] of May 17, regulates the sustainability criteria and the reduction of greenhouse gas emissions for biofuels, bioliquids, and biomass fuels, as well as the system of guarantees of origin for renewable gases. It also establishes that, for biofuels to be considered in the fulfillment of the objectives set out in the previous directives, they must comply with the sustainability criteria described in the aforementioned royal decree, relating to:

- Land use and land-use change associated with the production of raw materials,
- Sustainable production of biofuels, and
- Reduction of greenhouse gas emissions resulting from the use of biofuels.

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3 Mapping barriers to use cases

This section lists barriers identified both in previous section and while communicated with the industry/technology provider partners. The list of the potential barriers has been created with the corresponding descriptions, as it is shown below, and communicated with the industry partners. It has been requested to rank the barriers' significance from 1 (less significant) to 10 (most significant) considering which headlines in the table are relevant for the underlying business use case. The feedback from the industry partners is summarised in Table 2.

Description of the listed barriers

- **Biomass availability -** refers to availability of biomass now or in the future connected to Swedish/Spanish regulations.
- **Biomass cost -** refers to the price the company is facing to obtain the biomass.
- **Grid connection permit –** access to electricity networks is becoming a challenge due to increasing congestions in some locations. Time or requirements could be a barrier to connecting BTC with the electric network.
- **Required temperature level –** If BTC is able to meet the required temperature level in all DH grids or in process industry.
- **mFRR market access** – fulfilling the market access requirements such as min. bid size, ramp rate and so on.
- **Hydrogen infrastructure & safety –** H2 needs to be transported through pipelines or trucks considering safety regulations as the H2 is flammable and prone to leakage.
- **Investment cost for BTC** refers to BTC CAPEX.
- **Biomass infrastructure, logistics and administration –** shifting from current use of natural gas, fuel-oil or other fuel to biomass has some costs related to the fuel procurement, storage, transportation, etc.
- **Site limitations –** BTC installation can be prevented due to limited space at the company premises, limitations on emissions due to proximity to towns, among others.
- **Environmental permitting processes –**Environmental Permits would need to be granted on harmful emissions such as NOx, SOx, particles etc.
- **Safety measures-** The fuel side of the BTC such as the gasifier where the syngas is produced is pressurized and needs to fulfil pressure vessels regulation and related explosive gases considerations (ATEX).
- **Availability/reliability –** as a new technology, BTC lacks operational data and therefore has no track record on availability, reliability, and performance, but validation by tests, simulation and others can be used as prediction.

Table 2: Use case specific barriers.

	Biomass availability	Biomass cost	Grid connection permits	Required temperature Level	mFRR market access	Hydrogen infrastructure & safety

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TvAB	4	9	3	1	1	N/A
CEMEX	7	10	8	1	1	9
Sulquisa	8	9	9	2	1	N/A
	Investment cost for BTC	Biomass infrastructure, logistics and administration	Site limitations	Permitting processes	Safety measures	Availability/ reliability
TvAB	7	1	1	2	5	7
CEMEX	9	6	5	5	5	7
Sulquisa	8	5	1	8	5	7

3.1 Gap analysis

Gap analysis follows based on the feedback gathered from industry partners in previous section.

3.1.1 Economic barriers

Biomass cost as well as ***investment cost for BTC*** are the most important economic barriers for all industry partners. All three industry partners consider the biomass quite expensive fuel. The biomass prices are high to substitute other fuels. Different factors affect this, such as the availability of biomass, competition with other uses, the transportation costs from where biomass grows to where the demand is located, processing of the raw biomass, and storage costs, among others.

3.1.2 Administrative/ Regulatory barriers

Other important administrative/regulatory barriers for Spanish industry partners are ***Biomass availability***, ***Grid connections permit***, ***Fuel shifting cost*** and Environmental ***Permitting processes***. For CEMEX ***biomass availability*** is very challenging, while Sulquisa finds the availability of biomass at medium to long distances (more than 300 km) to be very challenging. For CEMEX ***Grid connections permit*** is a very challenging barrier, as it is very difficult to contract the necessary power because there is limited capacity in the network. For the Alicante plant, it is easier than that of Alcanar, but for both: it is necessary to have an availability study by the distributor (previously paid a guarantee: 40k€ per MW). The same holds for Sulquisa as in the area; the process is strained due to the surge in photovoltaic projects. Thus, it is necessary to assess the feasibility of the administrative processing of a grid connection point.

CEMEX finds ***Fuel shifting cost*** barrier essential and still needs to be evaluated. Sulquisa thinks they need to assess the implications of fuel switching from all perspectives; work-related, environmental, occupational hazards, quality, availability, etc.
Both CEMEX and Sulquisa assume very long administrative processes for environment permitting such as NOx and particle emissions.
TvAB finds all these barriers challenging (might delay the process) but solvable, thus, not significant.

Safety measures is medium- important barrier for all industry partners; according to CEMEX and Sulquisa it is necessary to assess the risks generated while integrating BTC, while TvAB thinks there is also potential behavioural barrier related to the employees' reluctance to face new risks.

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3.1.3 Technical barrier

Availability/reliability is a significant barrier for all industry partners. It is a new technology; thus, long-term durability and availability are unknown.

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4 Recommendations to tackle identified barriers

4.1 Use-case specific barriers communicated with industry partners

Biomass cost

Biomass management has many benefits for society and the environment beyond the direct energy uses (heat and electricity generation). These benefits include (not limited to): waste reduction from landfills, fire prevention, job creation in rural areas when harvesting, processing and biodiversity preservation by helping to prevent deforestation or land degradation.

Public policies should account for all these externalities that biomass management generates and are not currently priced. Public support for the biomass value chain could account for such benefits and reduce fuel costs.

BTC investment cost

As with all process-technologies, the first-of-a-kind BTC plant will have high investment costs and risks. Even the following installations, e.g. the next five plants, will have elevated risks. Private companies cannot absorb this risk alone and government support schemes, e.g. European Innovation Fund, are required to offset this risk and promote the introduction of new technology and secure their follow-on benefits in society.

Over time, learning curves and larger volumes can reduce manufacturing and installation costs, which can make the technology more attractive and competitive in comparison with other competitors. As the BTC concept fundamentally moves from today's boiler and steam cycle technology to high pressure and high-performance gasification and gas turbine technology, it is reasonable to expect as yet unforeseen cost-saving opportunities to arise beyond the cost estimates utilised in this project. A measure to facilitate this cost-reduction process, is to develop the BTC with standardised sizes, based on a limited number of gas turbine models, e.g. 10, 25, 60 MWe. This approach can drive design solutions that minimise manufacturing, assembly and installation costs of each component and system. Further, using high volume and well-proven components and systems where possible is another way to reduce development cost and risk in the investment.

Biomass availability

Some actions can be performed to increase biomass availability such as conducting a comprehensive biomass resource assessment in the region, identifying local sources of agricultural waste, forest residues, and energy crops. Low-grade biogenic feedstock and even waste (especially for hydrogen production) can be used to address the disturbances caused by biomass feedstock shortage.

Collaborating with local forestry and agricultural stakeholders might ensure a sustainable and reliable supply chain. Establishing long-term contracts with suppliers may secure future availability. In addition, biomass availability is strongly related to regulations and market design. Establishing a stable regulatory environment is important, where a price signal can be effective.

Grid connections permit

Flexible connection agreements can be a temporary solution to get faster grid access [18].

Developing hybrid systems (e.g., combining biomass with solar PV) might improve the chances of being permitted to connect. Investigate the option of flexible connection agreements, where generation can be curtailed during periods of congestion, while still allowing for grid access under specific conditions.

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Biomass infrastructure, logistics and administration

Different measures can be taken to reduce barriers to fuel shifting, such as investing in efficient storage and transportation systems for biomass.

- Design the supply chain to minimize transportation distances and sourcing locally if possible.
- Industrial co-location using same infrastructure for heat and electricity can contribute to lower those costs. These industrial clusters can reduce storage costs and profit from economies of scale for the different biomass processes.

Permitting processes

Begin consultations with local environmental authorities early in the planning process to identify specific emission standards and requirements (e.g., NOx, particulates) and environmental impact assessments required for biomass CHP installations.

Safety measures

Organize safety-related training for personnel, prepare instructions/manuals, increase knowledge and awareness of the potential risks in other ways, keep work and health regulations up to date.

Availability/reliability

The risks for low availability and reliability of new technology are usually a hinder to replication. Such risks can impact plant revenues and the business case severely. The staged development of the BTC technology, i.e. to test at well-weighted steps in scale and performance, is a key measure to improve the reliability of the first generation of BTC plants. In more detail, the following steps are envisioned

- TRL5 validation of the 1/10 geometrically scaled gasification system and full-scale combustion system
- TRL7 demonstration at geometrically full-scale gasification system and combustion system, however with a rebuilt gas turbine operating at low pressures and therefore capacity.
- TRL8 demonstration using same gasification system as TRL7, but at full pressure, operating parameters and capacity, and with the full-scale gas turbine and all associated systems.

In this way, the geometric scaling of the gasifier takes place early in the process, i.e. from TRL5 to TRL7 in gasification system, and TRL3 to TRL5 for the combustor. Therefore, more operating hours are obtained at full-scale prior to final demonstration and risks are decreased for the follow-on plants.

To further decrease risk, the first plants will utilise pre-treated fuel to ensure reliable fuel handling and feeding to the gasifier.

4.2 Other barriers not specified in use cases

Regulations on biomass annual total efficiency

Operating BTC in summer low-heat demand hours and providing electricity to the grid will lead to waste a lot of heat, thus decreasing yearly biomass efficiency. This will lead to violating the regulations on biomass annual total efficiency. However, seasonal storage in any portfolio would solve the problem. Instead of wasting generated heat during the summer times, it would be possible to store and use it during winter high heat demand hours. Therefore, the inclusion of seasonal storage instead of a heat sink will make great use of the flexible operation of BTC technology while fulfilling the biomass annual efficiency target.

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CO_2 markets and infrastructure for BECCS

Biogenic CO_2 is a new product that can be utilized as a feedstock in utilization cases, e.g. materials or e-fuels, or sequestered, creating a so-called negative emission. Both these cases require new market frameworks, regulations and infrastructure to be realized along with risk sharing amongst market actors to establish a critical volume for profitable operations. Examples of infrastructure are for transport, e.g. from plant to harbour and from harbour to sequestration site, or to an intermediate storage before a pipeline to the sequestration site. Co-ordinated efforts throughout the value chain are needed to realise economies of scale and to share risks. The foremost example of this emerging market is the North Sea, where multiple large corporations are establishing new value chains and associated infrastructure to sequester CO_2 captured in Northern Europe, e.g. Northern Lights. These can be tied to both fossil CO_2 and biogenic CO_2 capture and sequestration projects.

A price signal is needed to mobilize these efforts, and voluntary markets have bought the largest volumes. However, legislation is progressing in several countries, with Denmark, Norway and Sweden introducing mechanisms, e.g. with Denmark issuing fixed-price contracts and with reverse auctions soon to be held in Sweden. Importantly, discussions at the EU level are advancing to include biogenic CO_2 in the ETS.

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5 Conclusions

This deliverable provides a comprehensive review of the Bio-FlexGen work, relevant regulations, and feedback from industry partners to identify and assess technical, administrative/regulatory, and economic barriers while integrating novel BTC CHP technology in local heat systems and the electricity system.

First, the review of Bio-FlexGen work has been conducted to highlight the technical and economic challenges while integrating BTC at both the business use case level and system level. Then, gap analysis has been carried out based on the feedback received from the industry partners. Finally, strategies for mitigation and recommendations on how to tackle the identified barriers have been provided.

According to the carried-out analysis, the most significant barriers are **Biomass cost** and **investment cost for BTC** from economic dimension and **Availability/reliability** barrier from technical dimension. It is suggested that the public policies should quantify the biomass management benefits for the society and support to the biomass value chain to reduce the fuel cost to address the barrier related to **biomass cost**. As mitigation strategy for the **investment cost for BTC** it is pointed that government support schemes or European Innovation Fund are required to offset high CAPEX risk and promote the introduction of new technology and secure their follow-on benefits in society. Furthermore, the staged development of the BTC technology, i.e. to test at well-weighted steps in scale and performance, is a key measure to improve the reliability of the first generation of BTC plants and thus, to mitigate the **Availability/reliability** barrier.

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