Bio-FlexGen

Bio-FlexGen in a nutshell

The European Bioenergy Future 21 November 2024 at BluePoints Brussels

Susanne Paulrud, RISE Research Institutes of Sweden

2024-11-21, Brussels

Bio-FlexGen

Purpose:

- Increase the efficiency and flexibility of biomass-fired CHP plants
  - Compliment fluctuating renewable energy
  - Security of supply

Concept:

- Novel BTC technology with increased flexibility
  - Products: electricity and heat or H_2 and CO_2
  - Feedstocks: wood residues
  - Quickly start using hydrogen when additional electricity is needed.

Biomass-Fired Top Cycle or BTC in the future

Fluctuating supply of renewable energy from solar and wind power plants.

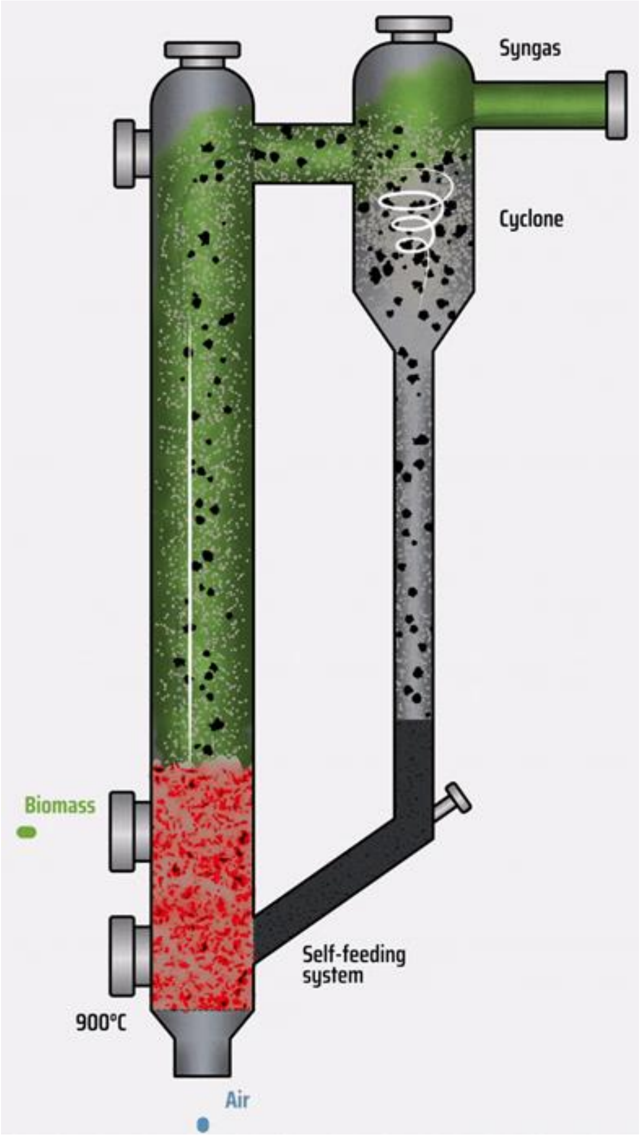
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Bio-FlexGen

Goal:

- Develop the central technologies
  - Oxygen- or air-blown biomass gasification in a Hybrid Fluidised Bed reactor
  - Combustion of syngas or H2 in a high-steam environment in the Top Cycle gas turbine

- Integration of the BTC technology to the energy system and the economic viability for different user cases



Hybrid Fluidised Bed (HFB) gasifier

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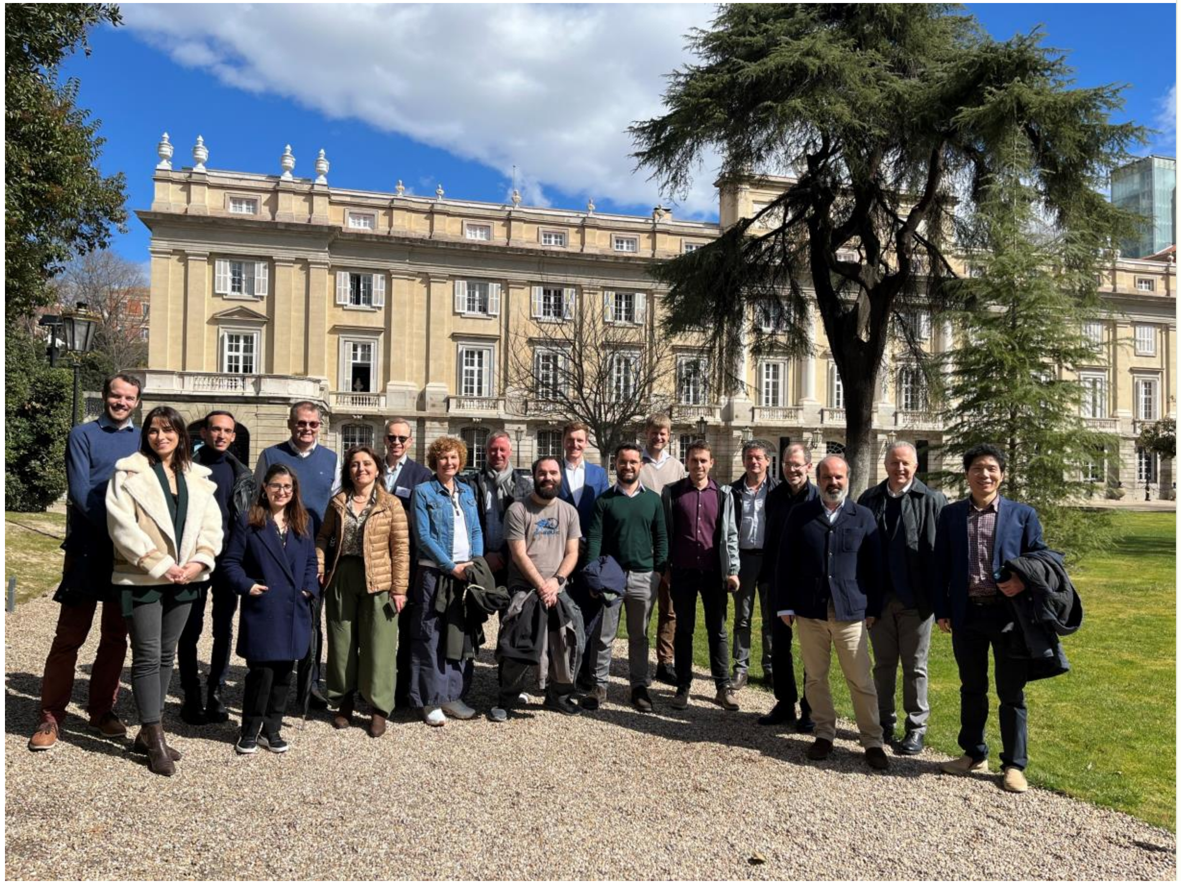

- The Swedish company Phoenix BioPower is the developer of the BTC technology.
- Since September 2021, the project has connected 14 partners from five countries

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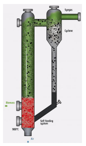
Technology Readiness Levels

- Bio-flexgen advances the **technologies to TRL4**

2 — Technology concept formulated

3 — Experimental proof of concept

4 — Technology validated in lab



Flexible oxygen/air blown HFB Gasifier

Flexible gas turbine combustion system

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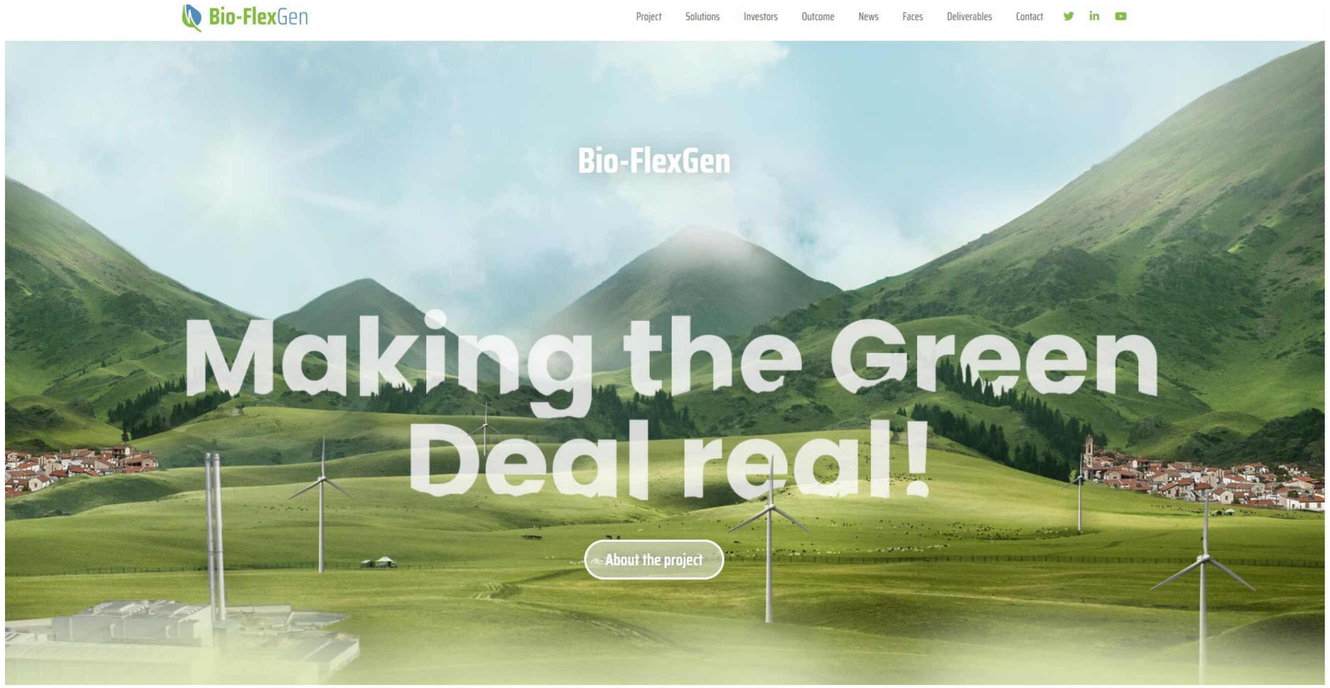
Follow our journey!

Bio-FlexGen
598 följare
8 mån •

Meet Humphrey, our world first test rig!

Humphrey is at the forefront of innovation, validating our revolutionary Hybrid ... mer

Visa översättning



www.bioflexgen.eu

Contact: susanne.paulrud@ri.se

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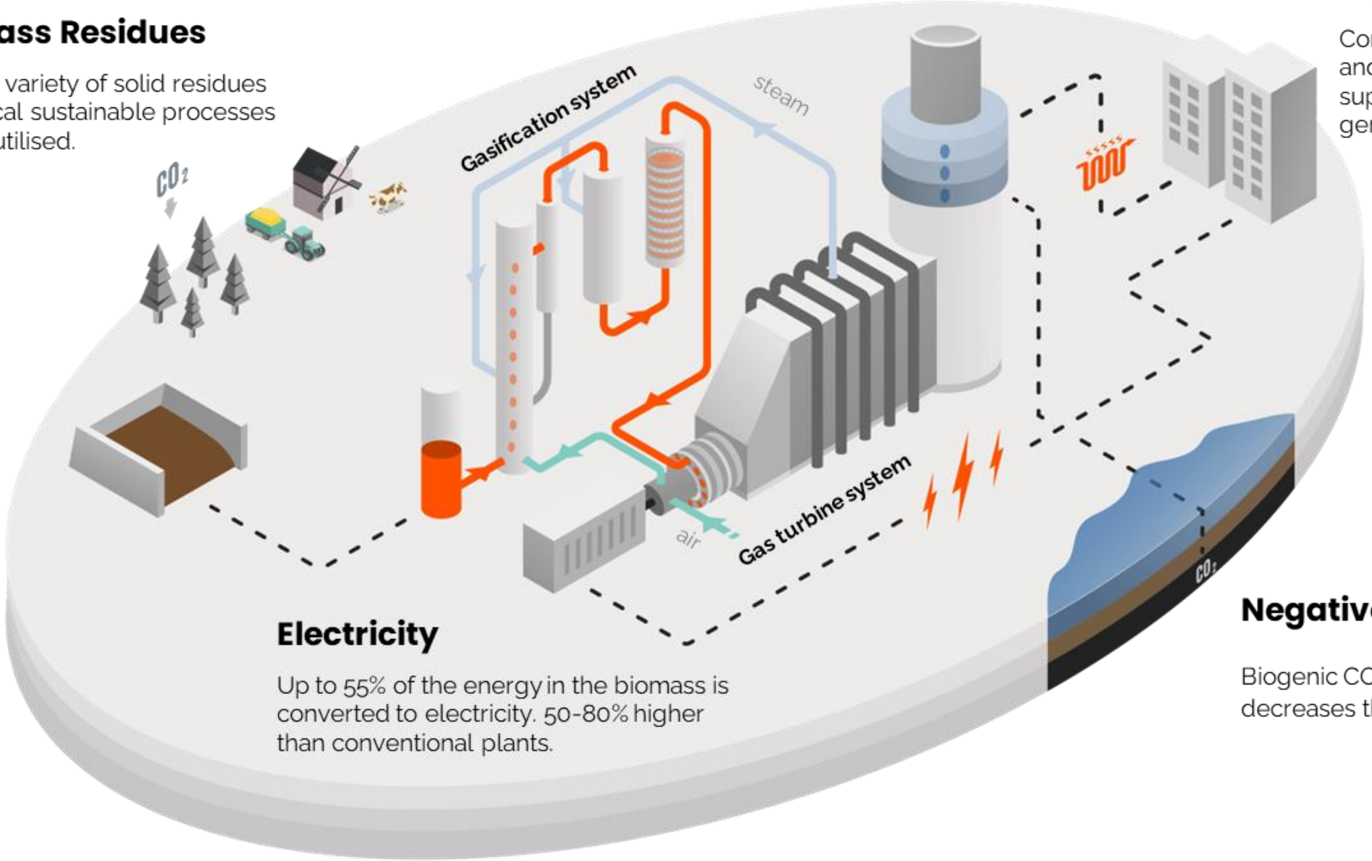
Introducing the novel BTC concept and the required gasification and combustion technologies

Michael Bartlett, Phoenix Biopower

Introducing the BTC: Biomass-Fired Top Cycle

A unique combination of gasification and gas turbine technology



Biomass Residues

A broad variety of solid residues from local sustainable processes can be utilised.

Heating

Combined production of district heating and power (CHP). For a given heat supply, 3 times more electricity is generated.

Electricity

Up to 55% of the energy in the biomass is converted to electricity. 50-80% higher than conventional plants.

Negative emissions

Biogenic CO_2 capture and sequestration decreases the CO_2 level in our atmosphere.

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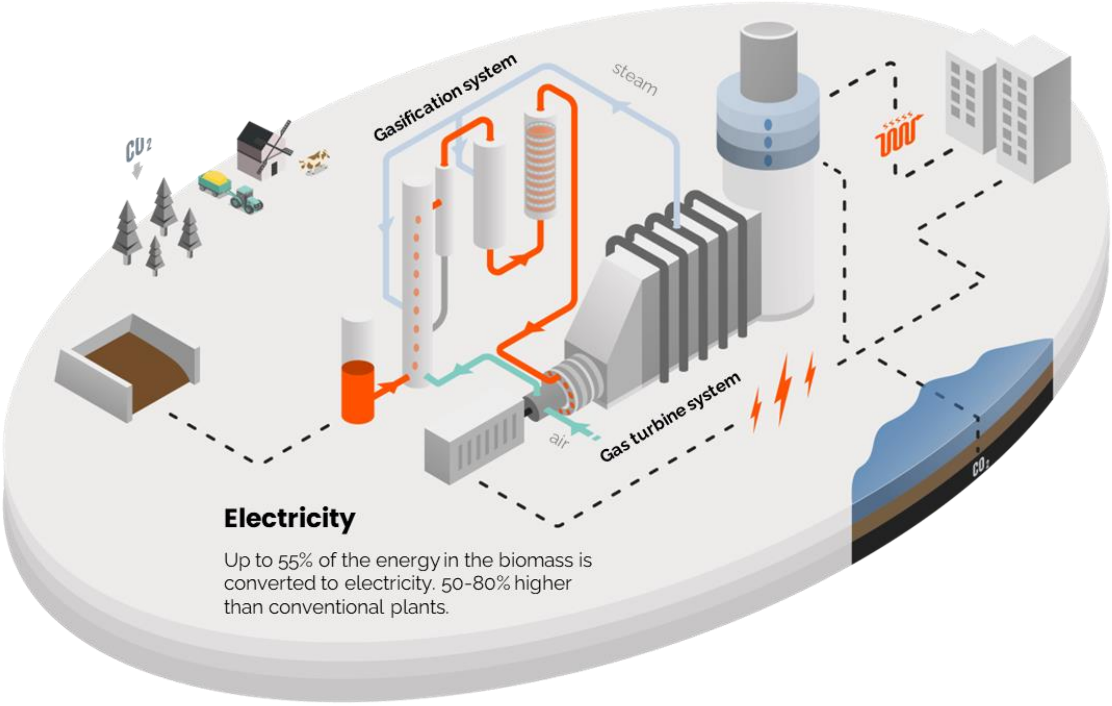
Introducing the BTC: Biomass-Fired Top Cycle

Technical features



Plant:

High-pressure biomass gasification with steam-injected gas turbine for high efficiency

Gasification system:

- High pressures (25+ bar) integration with steam-quenching of syngas and hot-gas filter
- Maximizes energy to the gas turbine

Gas turbine system:

- Gas turbine with 50% steam. Heat and water recovery
- Maximizes efficiency of the power cycle

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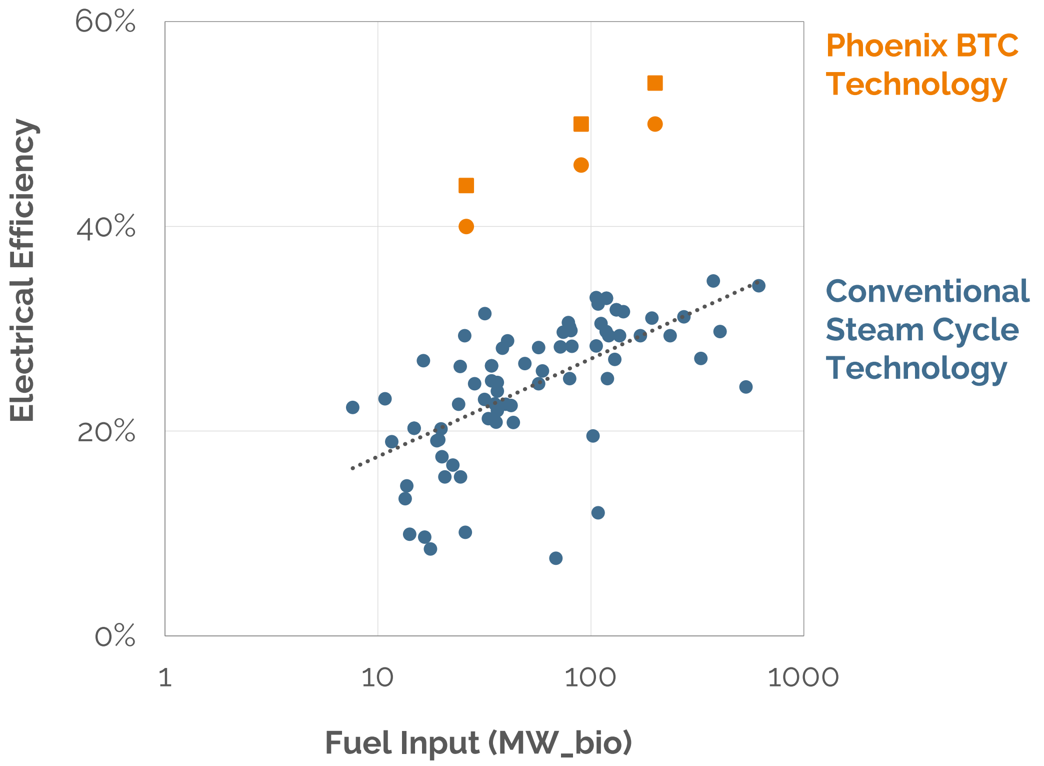
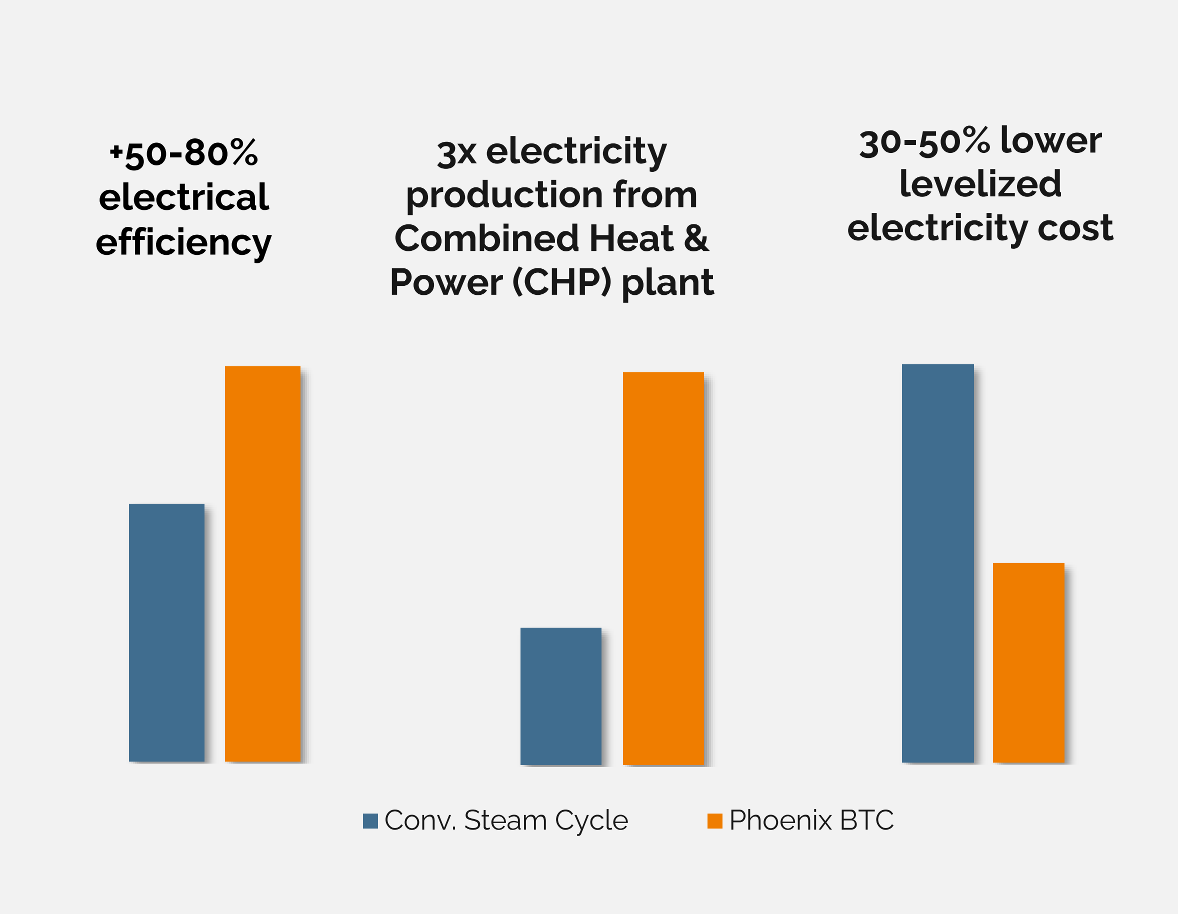
the BTC plant for high efficiency biopower
BTC – Biomass-fired Top Cycle

BTC: Highly Efficient Biopower





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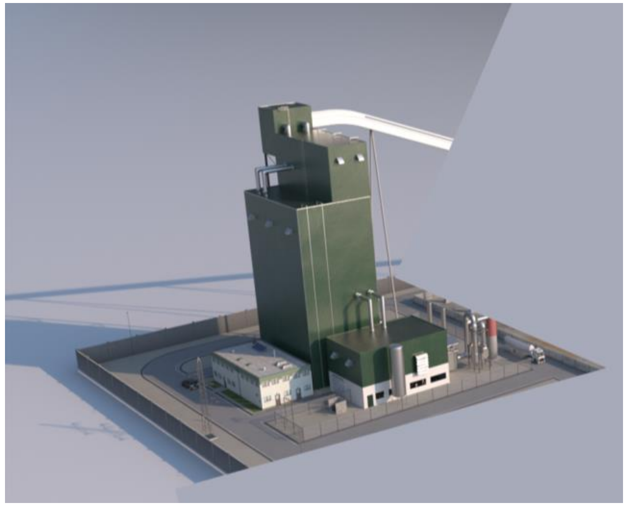
BTC Market Entry – 10 MW Demonstration Plant



Demo EPC
2025-2027

Phase 1 Operations: TRL6-7
2027-2030

Upgrade
2030 – 2031

Phase 2 Operations: TRL8
2032

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Project "Bio-FlexGen": 3 operating modes

#1 CHP Mode

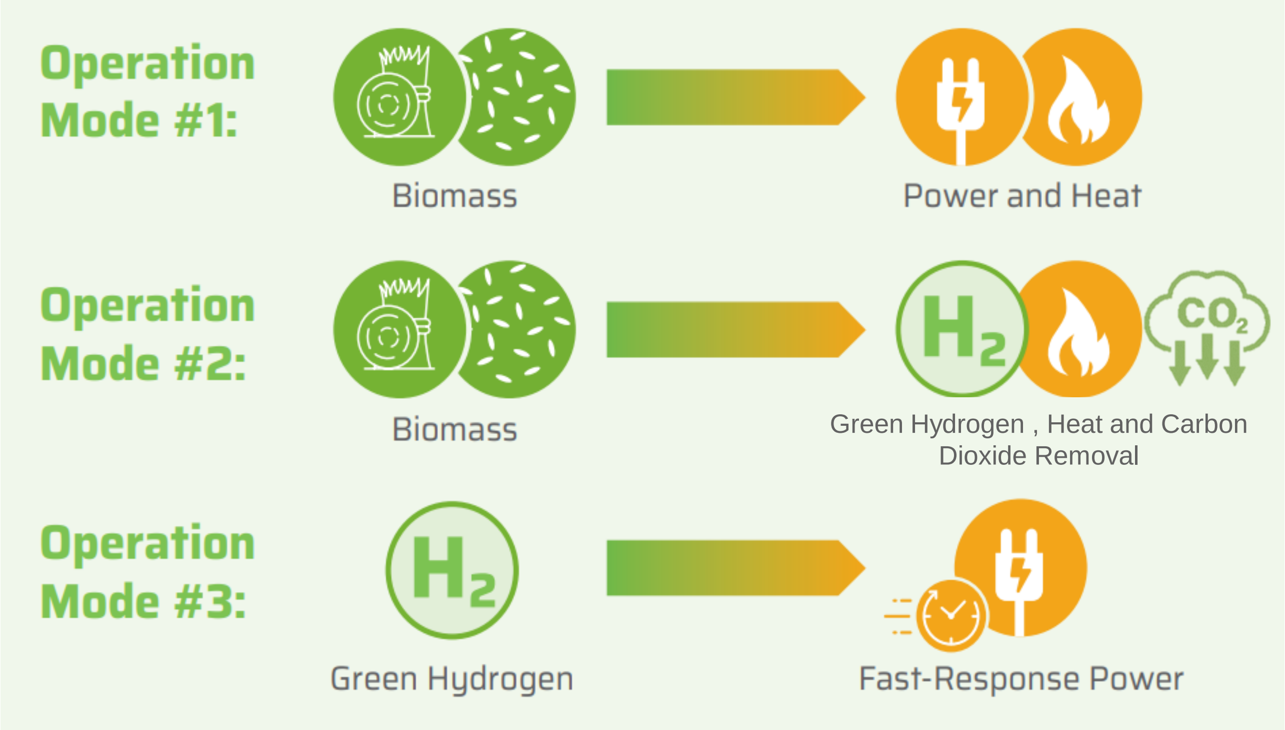
- Combined Heat & Power from biomass with high electricity yields (3x more local electricity)

#2 Bio-Hydrogen Export Mode

- Produce H2 and biogenic CO2 during the summer season, utilising same gasification system

#3 H2 Peaking Power Mode

- Produce power during summer season from stored hydrogen (switch to Mode#1 if needed)



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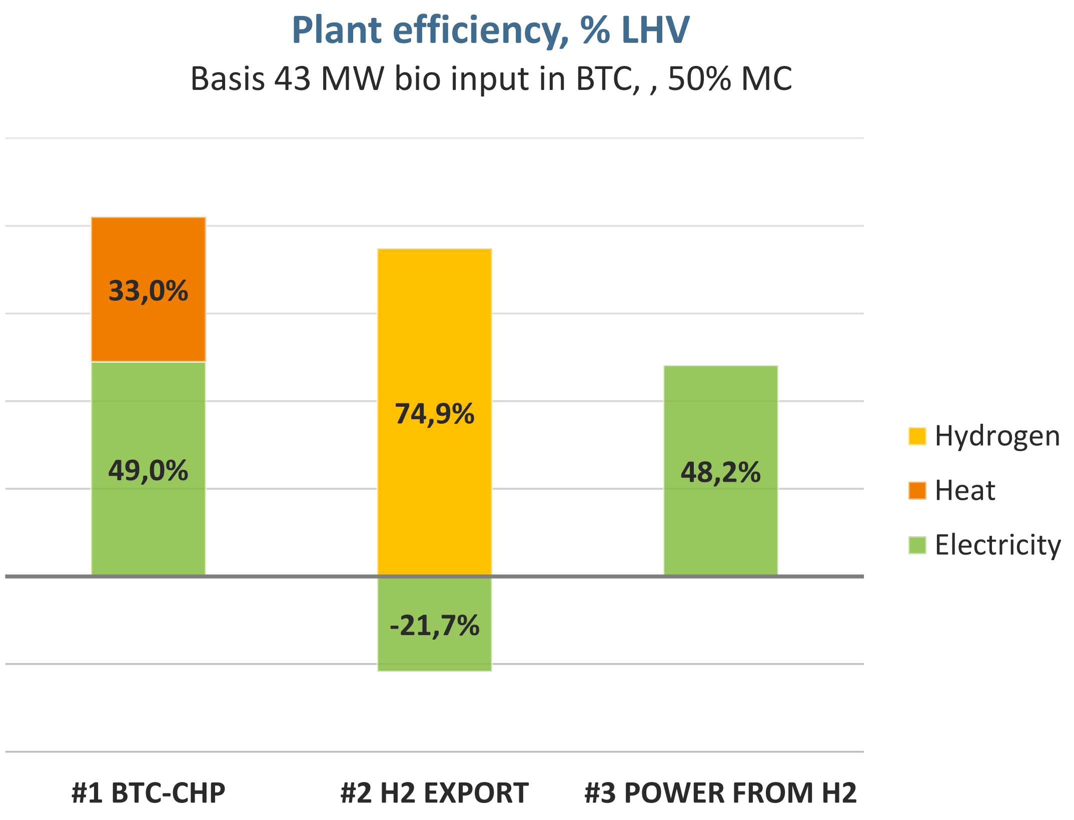
Performance of BTC Plant in Bio-FlexGen Modes

- Simulations showed the same architecture can be used for 3 modes.
- Significant additional equipment required for H2 production

- **CHP Mode**:
  - Electricity yield 3x conventional CHP plants
  - District heat at lower temperatures
- **H_2 Export Mode**:
  - Electricity consumption 1/5 or less of electrolysis
  - Co-generation of biogenic CO2
  - 200€/t CO2 gives same income as 3,4 €/kg H2
- **H_2 Peaking Mode**:
  - Superior efficiency to open cycle gas turbines



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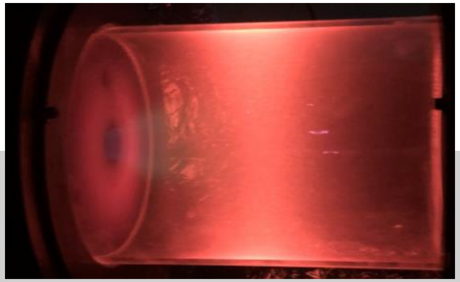
Bio-FlexGen development effort is the basis for scale-up...

Issues for bio-CHP

- High fuel prices
- Limited biomass availability

- Low plant utilisation of system outside heating season
- Low electricity prices in summer



- Volatility in prices
- Low plant utilisation outside heating season

Bio-FlexGen Scope

System & Plant

- Technoeconomics of BTC & Hyflex for H2 production
- System performance: industry site and regional district heating
- Replicability across energy system

Gasification

- Novel Hybrid Fluidised Bed (HFB) high pressure gasification system
- TRL4 for O2-blown operations
- Flexibility: low-cost feedstocks
- O2-or air-blown, 0-100% of GT load

Combustion

- Novel Combustion System (PACS)
- TRL4 for hydrogen operations and switch to syngas.
- Low NOx emissions and high stability with hydrogen
- Fuel flexibility syngas-H2

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Hybrid Fluidised Bed (HFB) Gasifier for pressurised operations in air-blown and oxygen-blown modes

Chunguang Zhou,
Chief engineer gasification
PhoenixBiopower

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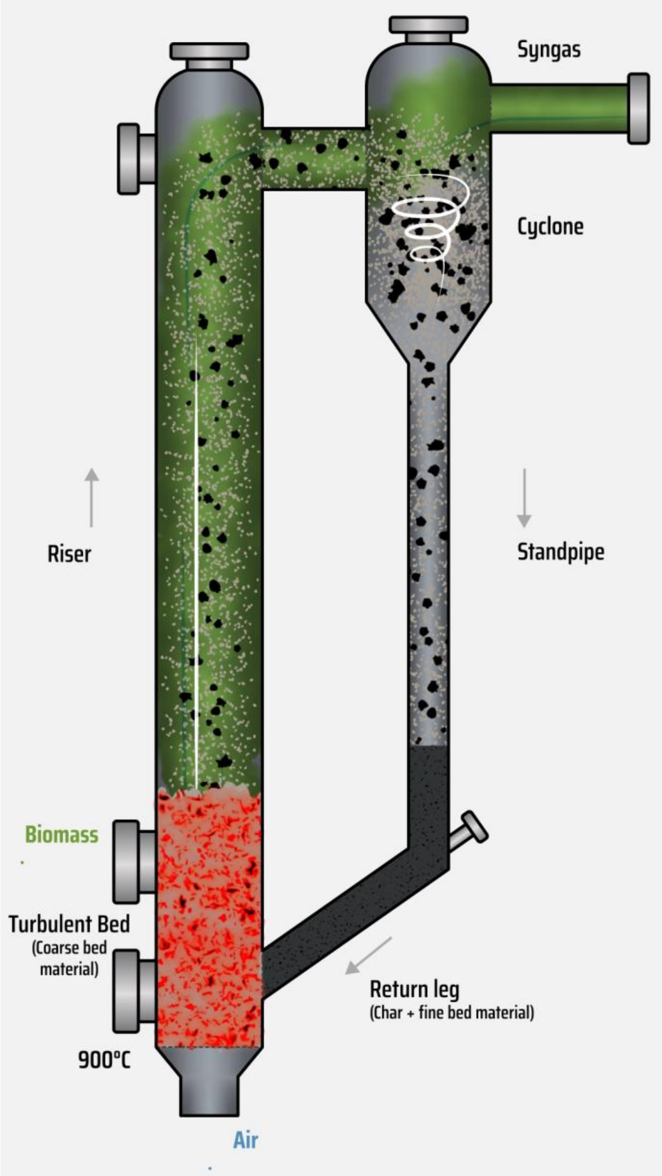
Bio-FlexGen

Introduction to HFB Technology

- The world's first Hybrid Fluidised Bed (HFB) gasification system
  - **Address challenges at high pressures, i.e. biomass conversion and reactor dimensions for relevant scales**
- The HFB gasifier consists of a riser, cyclone, a bed-return unit
- Uniquely, both a stationary, turbulent bed and a circulating bed are utilized,
  - Enabled by novel two component bed particle system.
  - Coarse bed component forms a stationary, turbulent bed
  - Fine particles form a circulating bed.
- It retains main features of fluidized bed technology,
  - Scalable
  - High reliability
  - Widely demonstrated at commercial scales.
  - Feedstock flexibility



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Key Advantages

Novel fluidized bed gasification technology for the integration with **high-pressure BTC** for power generation and **high-pressure synthesis** processes.

Air-blown gasification

- Application: integrated with gas turbine for power and heat production, broad turndown for 0-100% electricity output on biomass
- Operating pressure: ~30-50 bar

Oxygen-blown gasification

- Application: hydrogen, CH4, gasoline, jet fuel, methanol, etc.

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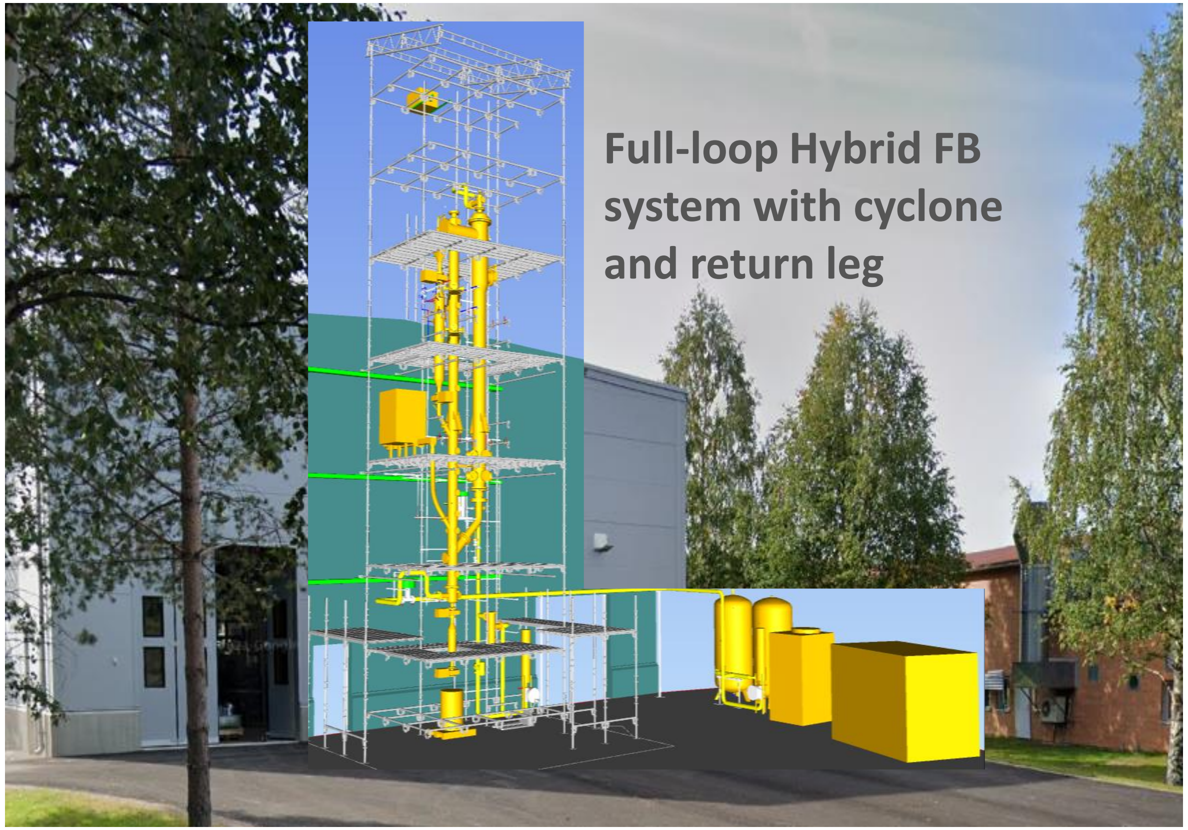
Unique

Verify and test hydrodynamics of Hybrid FB gasification



Design pressure 16 bar

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Objectives and Methodology

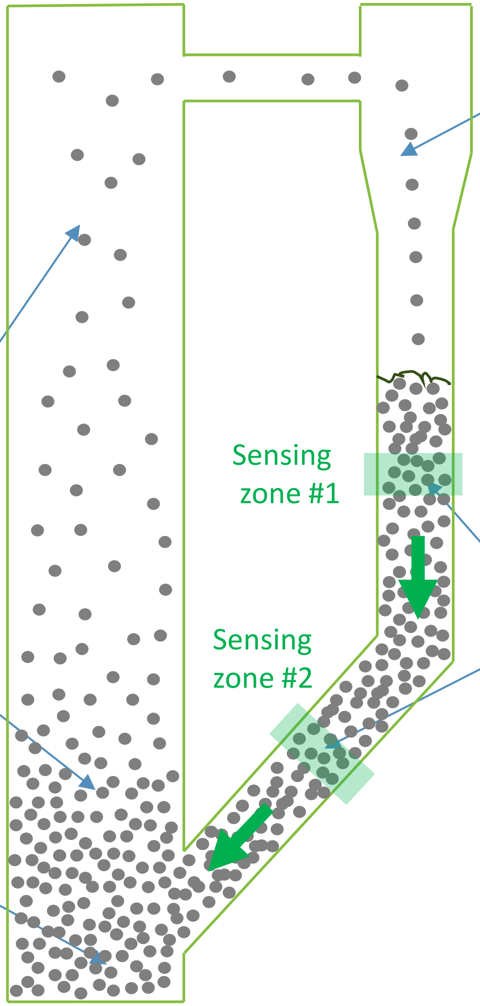
Objectives

- Validate the **Hybrid fluidization** concept;
- Optimize the **two-component bed particles** system;
- Develop and apply advanced measurement methods;
- **Key components** design and configuration.

Freeboard in the riser
- Particle moving velocity, cluster behaviors (**LDV**).
- Solids mass flux (**laser-extinction method**)
- Solid particles sampling

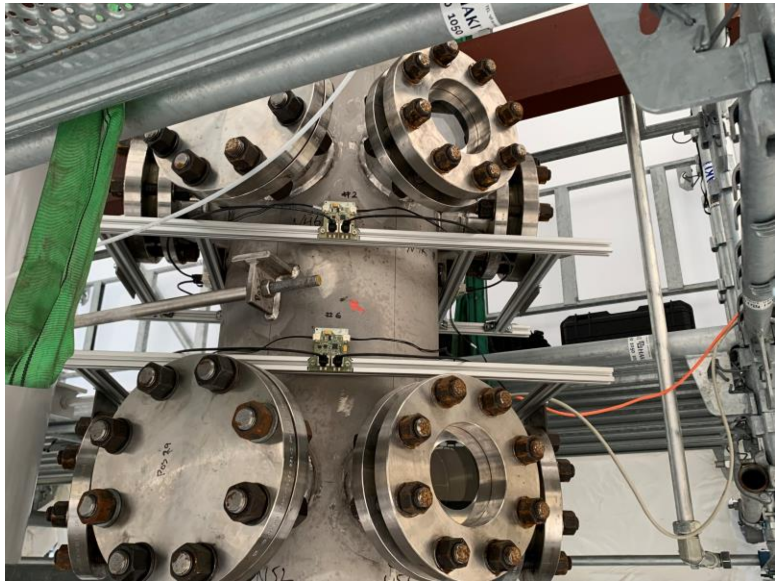
Dense bed in the riser
- Solids moving up velocity and mass flux in the dense bed (**capacitance probe**)
- High frequency differential pressure

Distributor design and optimization
- Configuration and dimensions
- Pressure drop



Cyclone design
- Configuration and dimensions
- Pressure drop, separation efficiency

Inclined pipe and Standpipe
- Configuration and dimensions
- Solids circulation rate (**magnetic tracer-tracking**)
- Gas leaking through the inclined pipe
- Solids particles sampling



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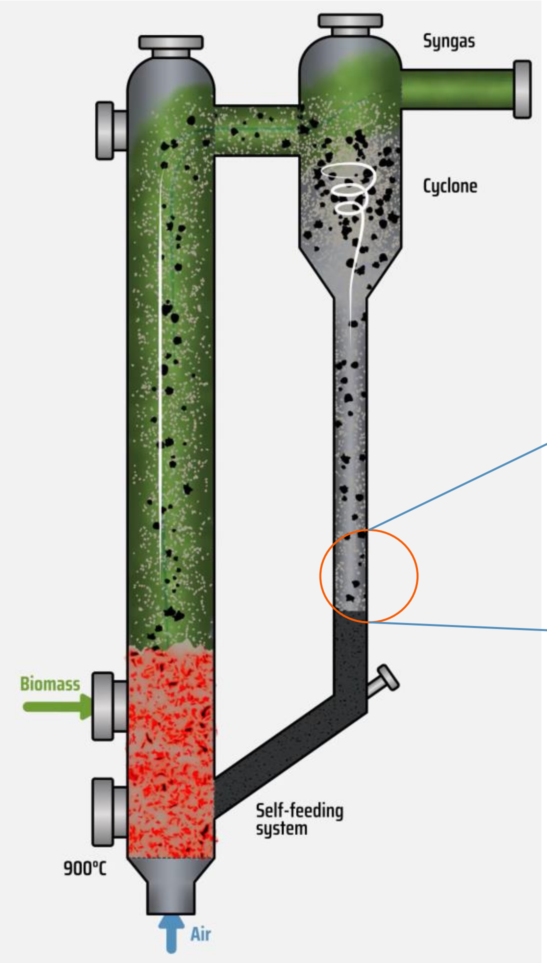
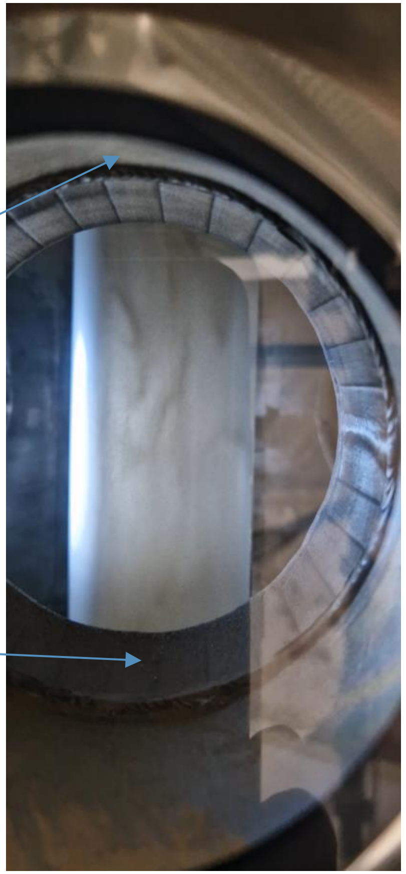
Hybrid Fluidization

Several months test campaign performed at Piteå

- Hybrid fluidization performance in the pilot-scale, pressurized FB rig





Bed and biomass particles circulated in the standpipe

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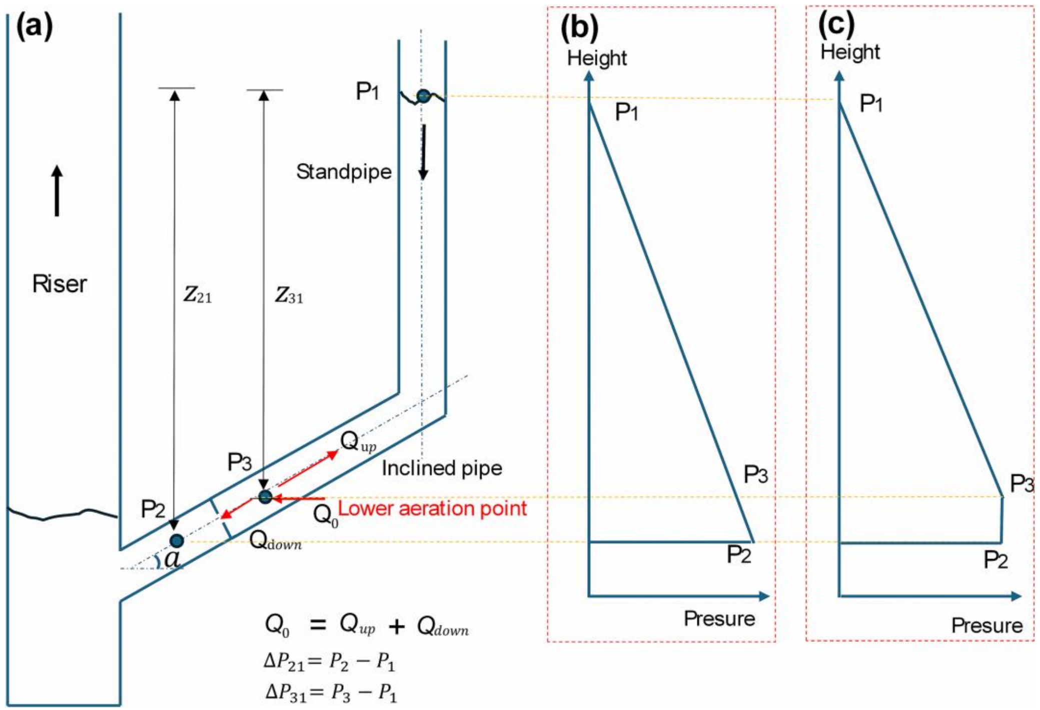
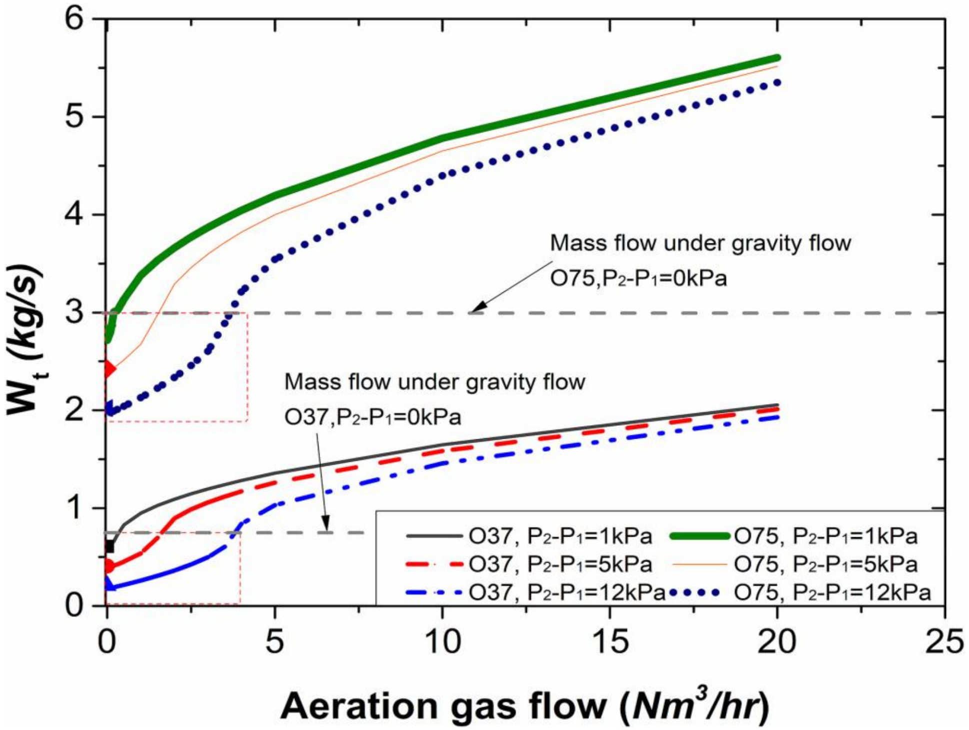
Modelling





Zhou, C., Jonasson, C., Gullberg, M., Ahrentorp, F., & Johansson, C. (2024). Application of the magnetic tracer-tracking system in solids circulation measurement in a fluidized bed standpipe. *Chemical Engineering Journal*, *498*, 155030.
Zhou, C., Jonasson, C., Gullberg, M., Ahrentorp, F., & Johansson, C. (2024). Measurement and Modeling of Solids Flow Behaviors in an Aerated Standpipe and Inclined Pipe of Circulating Fluidized Bed Full-Loop System. Powder Technology.2025.

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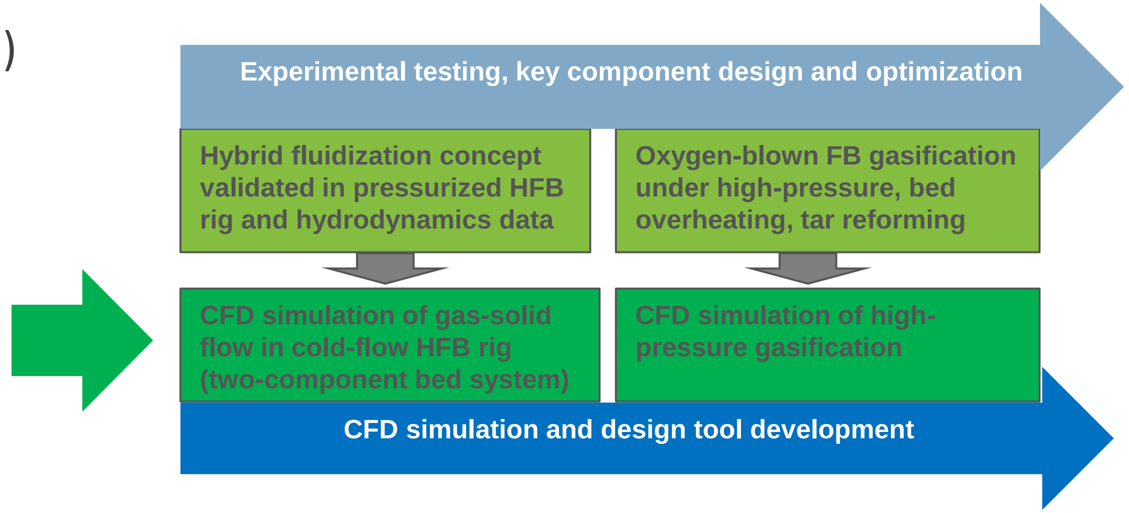
Summary and next step

Summary of cold-flow validation

- **Achieve stable operation** of turbulent and circulating beds in **the full-loop system** with very little gas leakage (**Hybrid fluidization concept and performance validated**)
- **Regulation inventories** of fine and coarse bed components is critical
- **2-3 dimensions and angles** of the inclined pipe and standpipe were tested
- Good performance of distributor and cyclone (**designs validated**)
- Mixture of sand and biomass particles also tested

Next-step for high-pressure oxygen-blown gasification and CFD modelling



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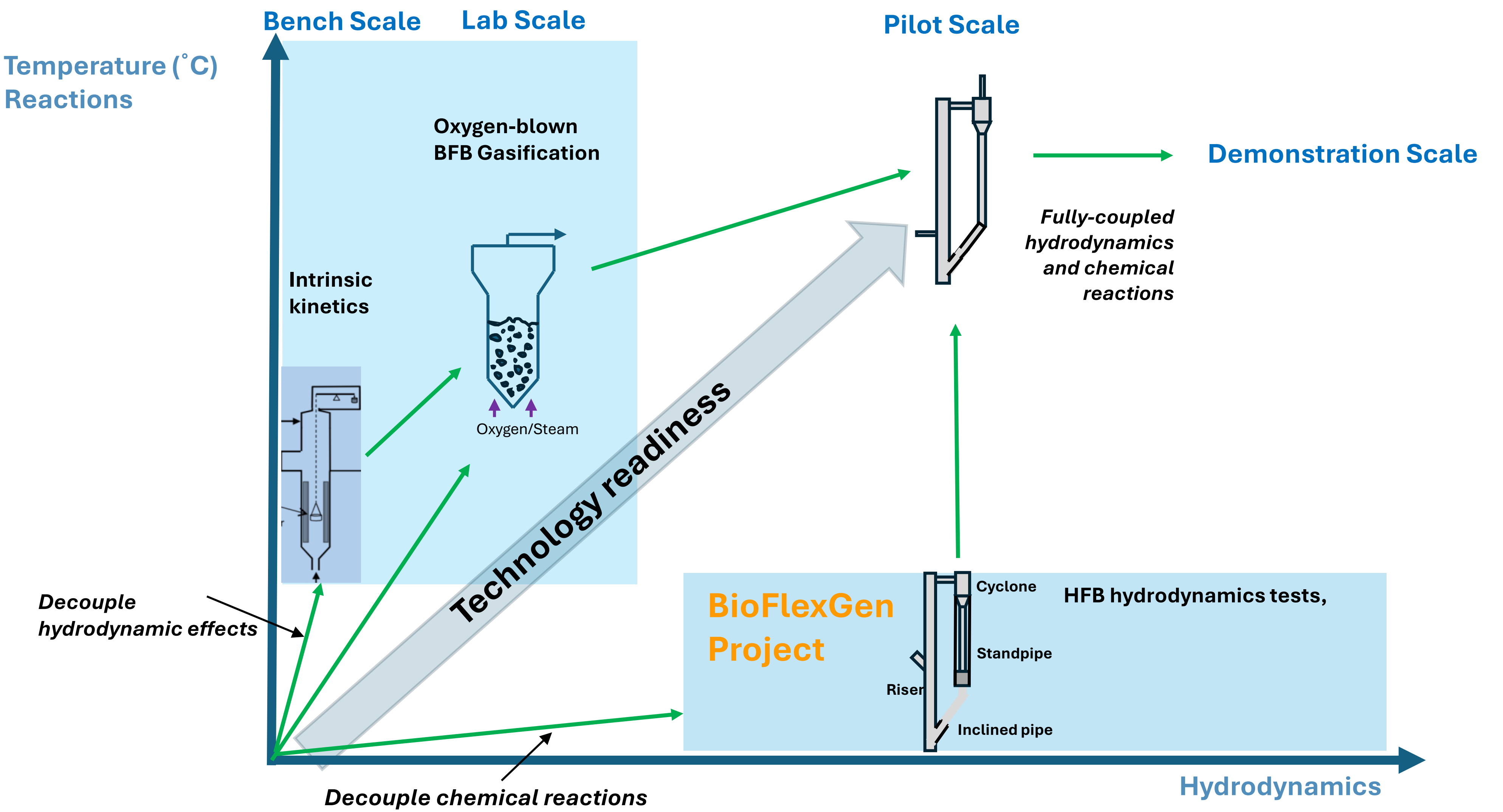
How shall we use the results: Scale HFB technology to TRL 5

- Strategies to scale up the Hybrid FB gasification technology



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PHOENIX BIOPOWER

Fuel switching capabilities of the combustion system

Felix Guethe,
Chief engineer Combustion
PhoenixBiopower

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Bio-FlexGen

Combustion concepts in the BTC

- Designed for very weak and diluted syngas – **differs** from **DLN**
  - → Combustion **MILD** (MILD -Moderate or Intense Low oxygen Dilution)
  - High temperature & dilution: using steam & long residence time in large volume

- Features:
  - High flexibilty for fuel and load: from weak gas to highly reactive hydrogen
  - Heat release near stoichiometric conditions
  - NO_x formation determined by fuel bound nitrogen – not «thermal» ~mixing

- Demonstrator Rig
  - «Fuel to flame « demonstration - atmospheric rig
    - Syngas from gasifier and high H2, switch over exercises

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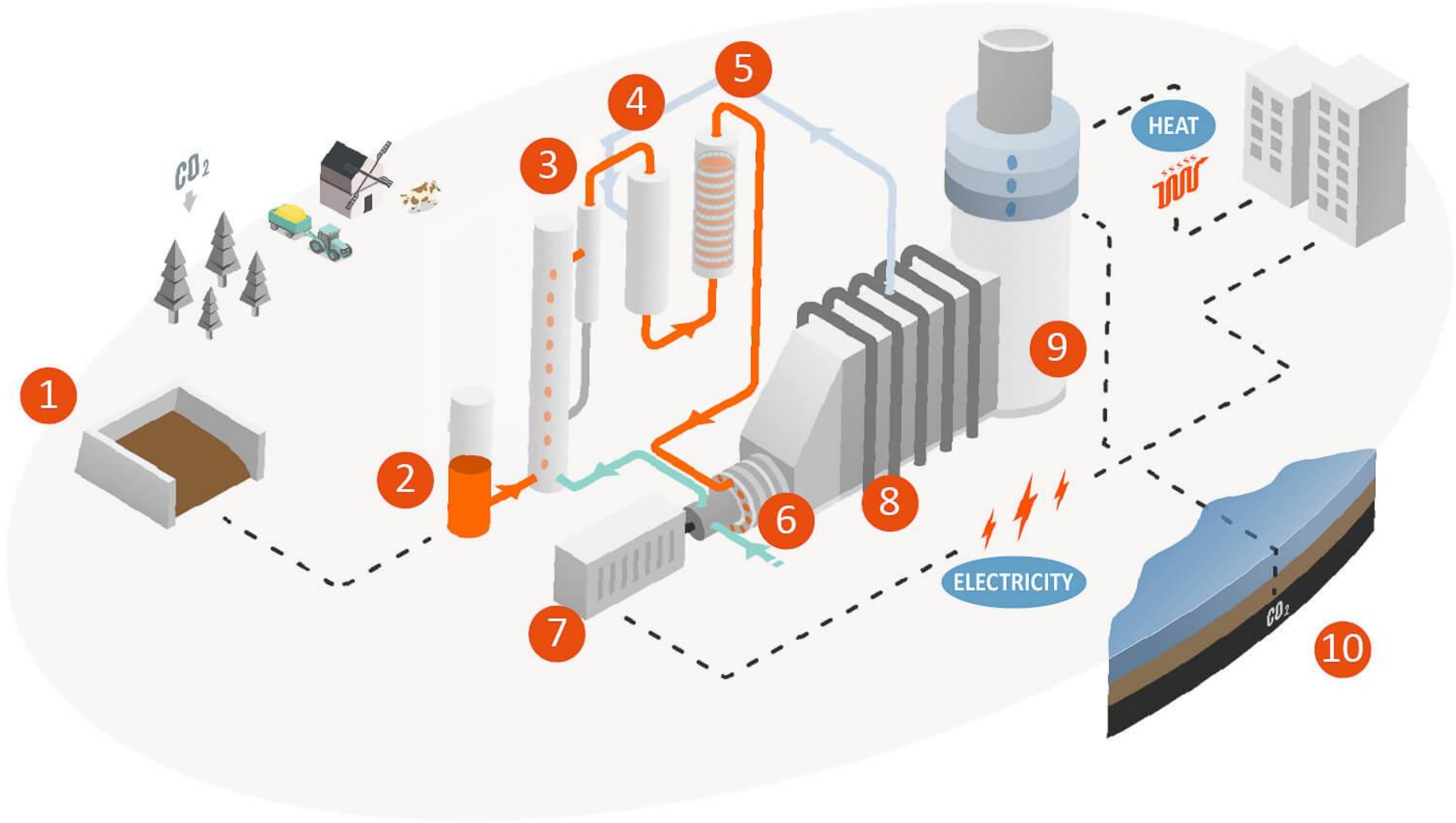
Atmospheric «Fuel to Flame» rig in Stockholm



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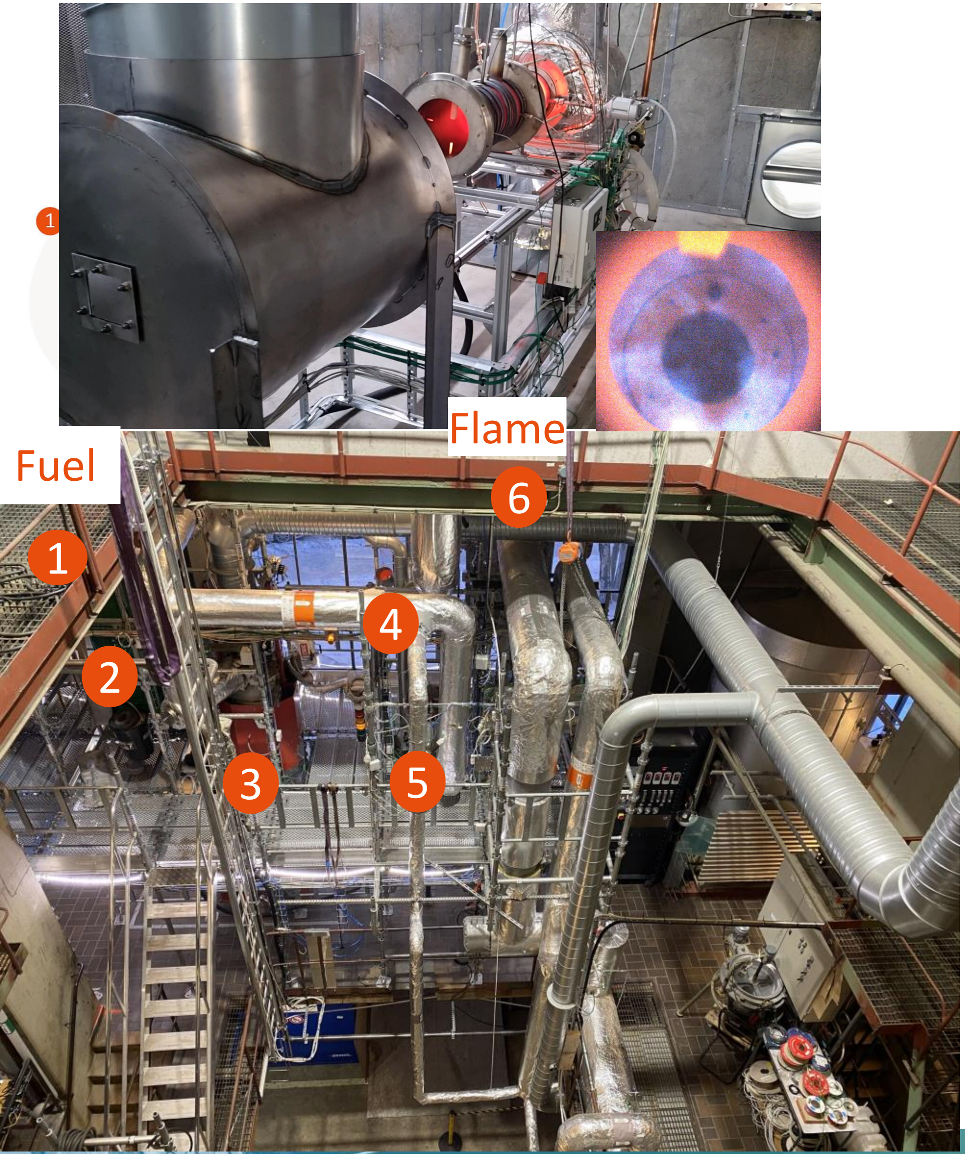
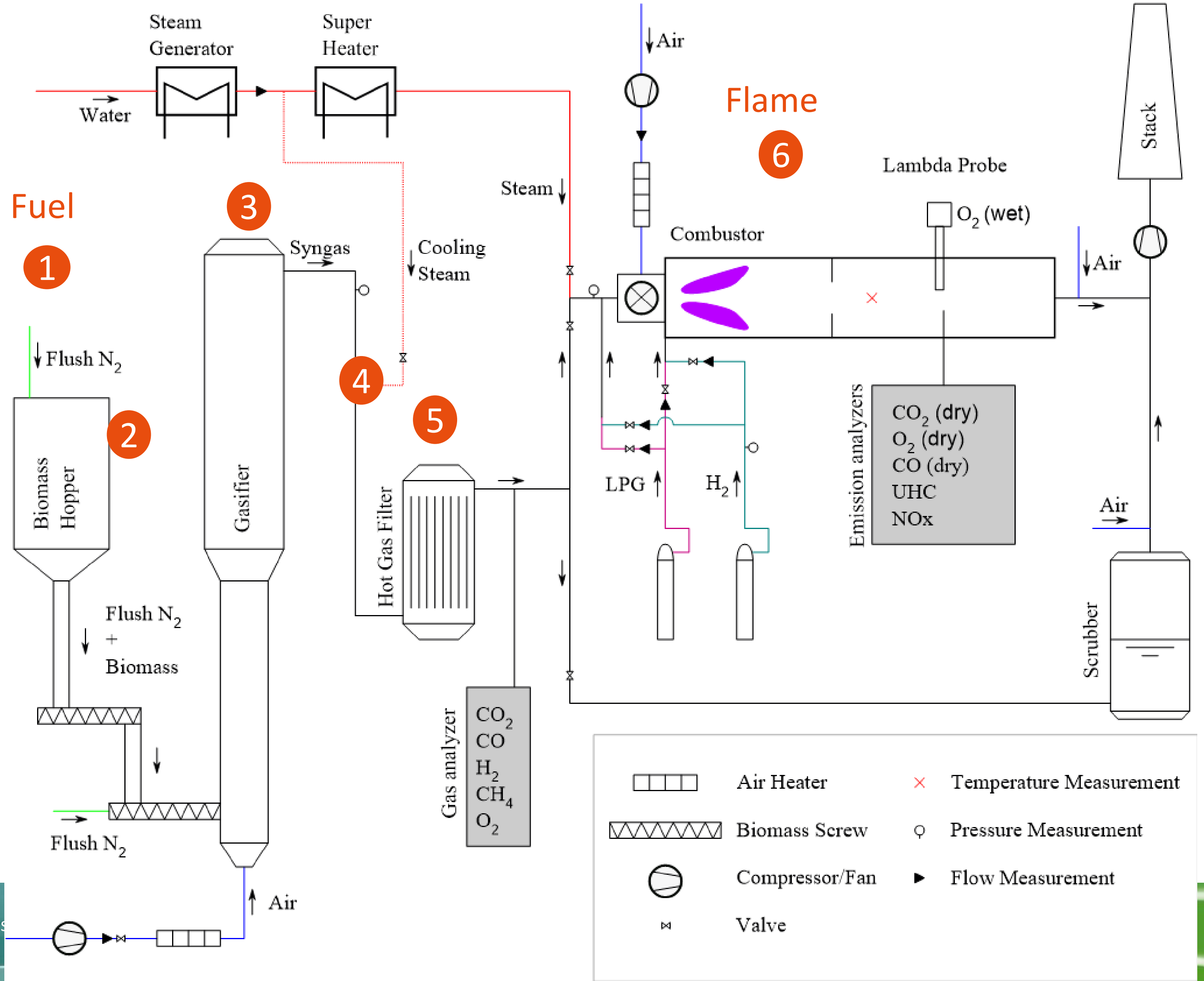
Atmospheric «Fuel to Flame» Integration rig





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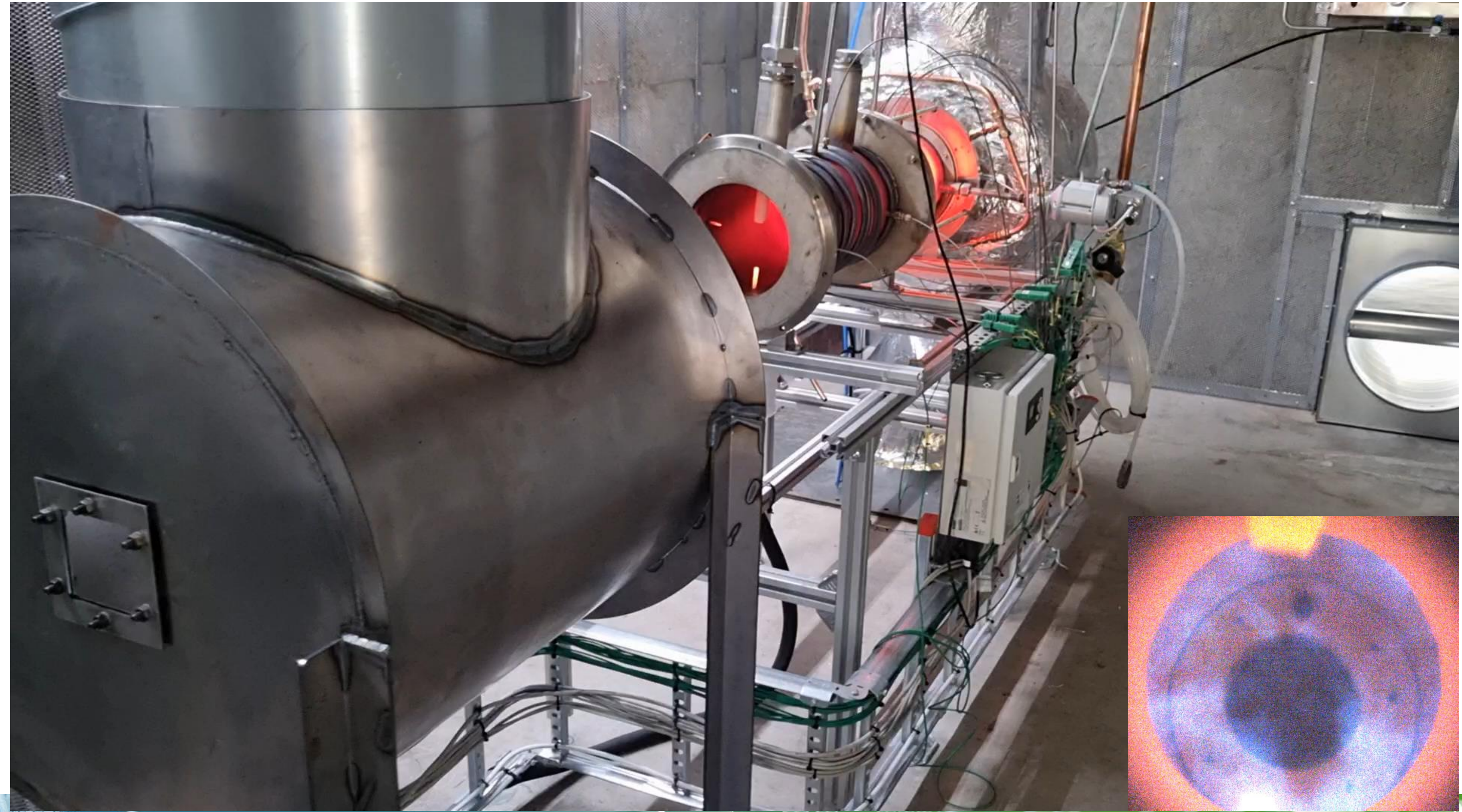

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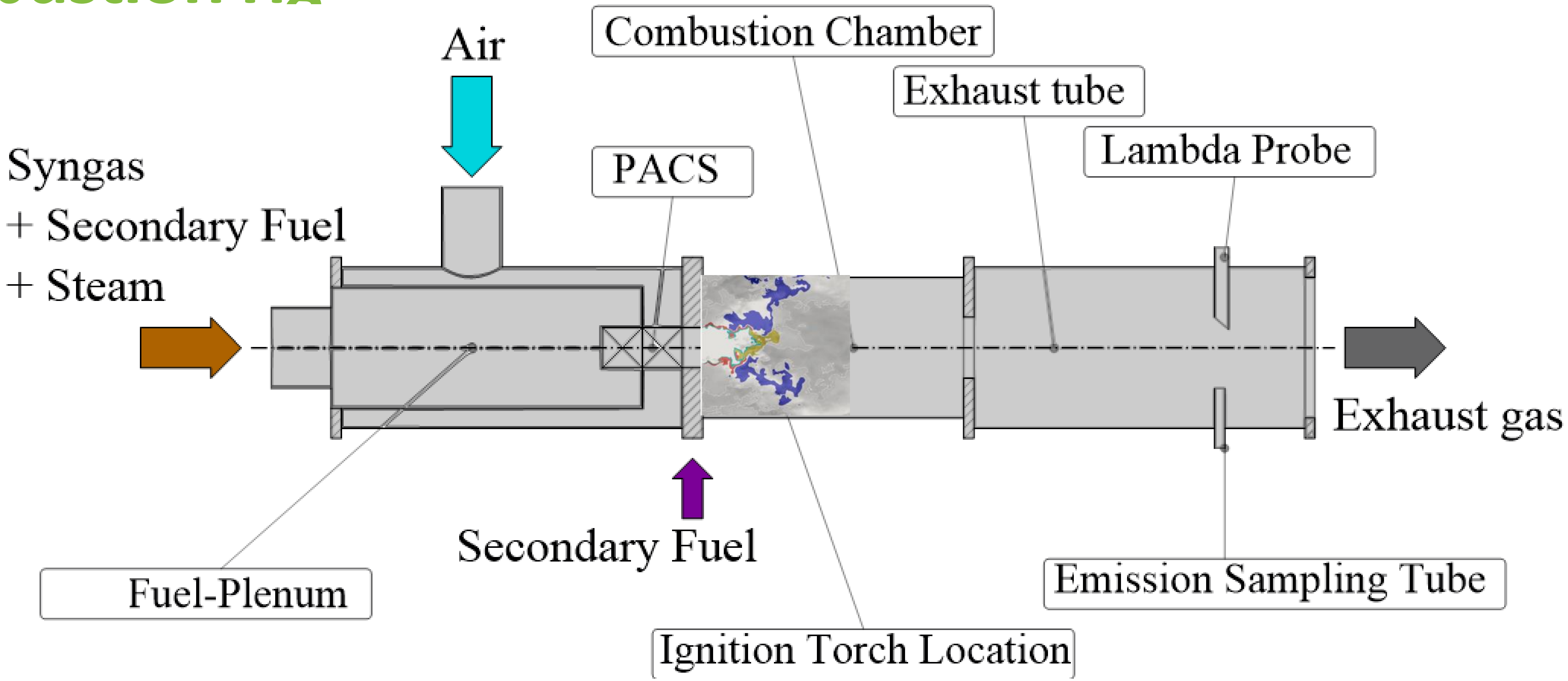
Combustion rig



- Combustion rig is hosting a MILD combustion chamber and a “Dual Swirl” burner (air / fuel)
  - Near stoichiometric (RQL), highly diluted, high recirculation, low O_2, high T_{in} & low T_{max}
  - Flexible for **weak syngas** , to hydrocarbons and up to **pure H_2**

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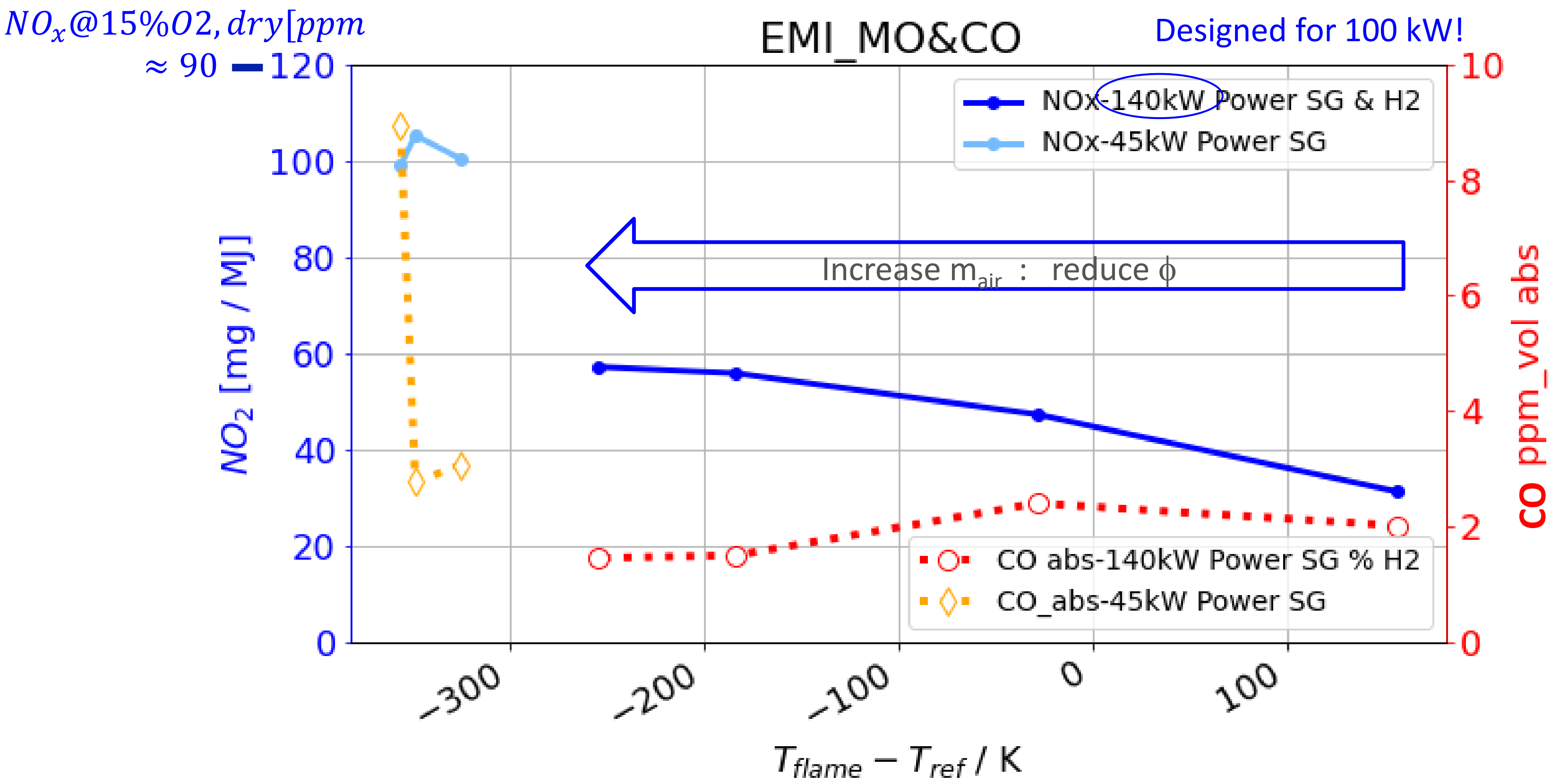
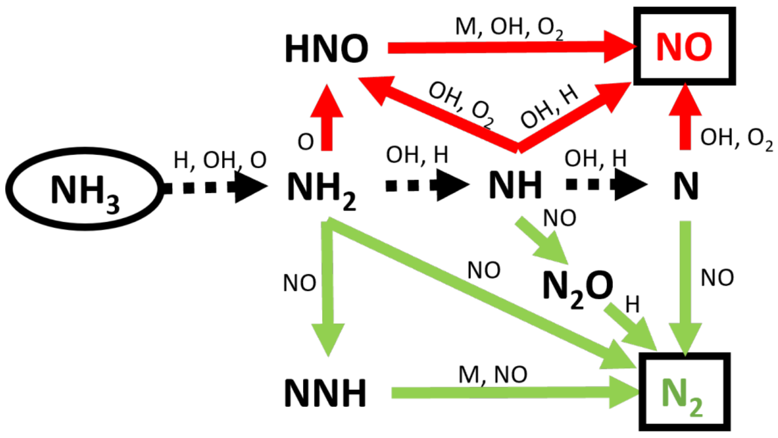
Nox Emissions from Syngas





- **Stable** operation no - CO!
- NO_x emission dominated by fuel bound nitrogen (**FBN**) from biomass
  - Product gas contains NH_3, HCN etc.

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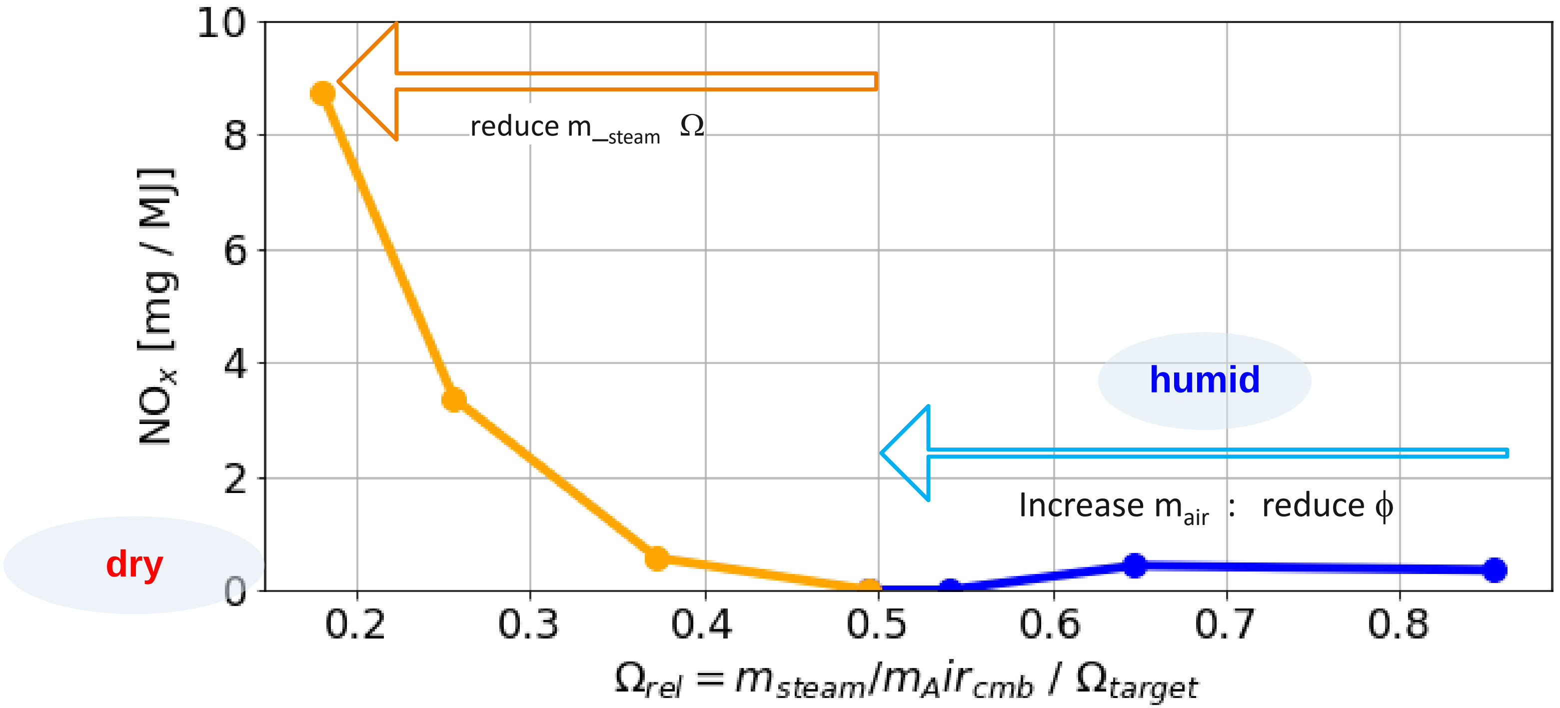
Pure Hydrogen: Humid→ dry



- **Thermal NO_x negligible** at humid conditions ~ high Ω
- Increasing air flow and decreasing steam decreases Ω and keeps **low NOx (single digit**)
- **Safe** operation without flashback in the Dual Swirler (PACS) burner until very low Ω and dry
- Further development **towards dry** operation emission compliant is in reach !

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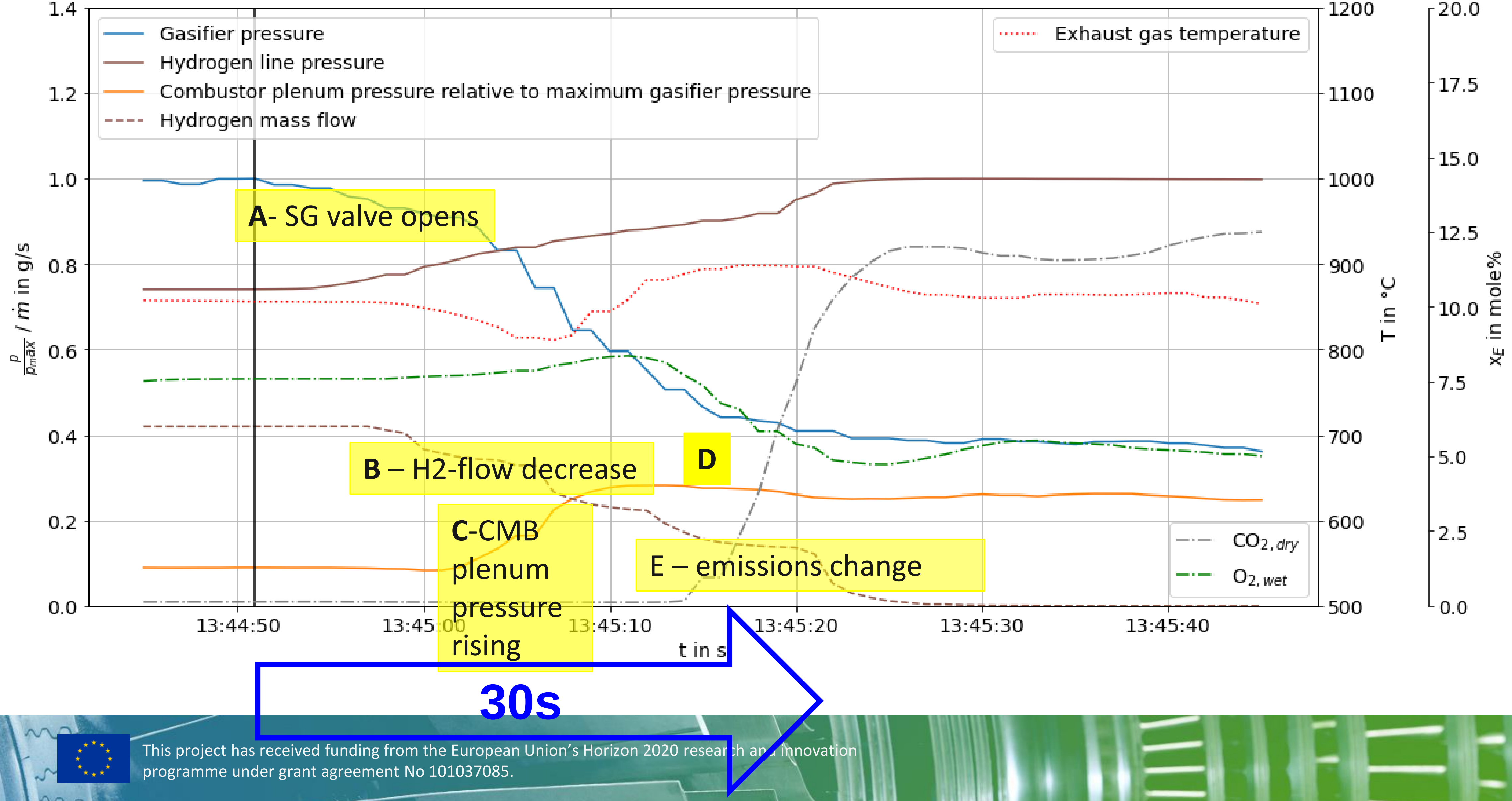
Transients

Online Switchover: Hydrogen → Syngas



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Summary and Next steps: Combustion

- Promising **burner technology** for wide range of fuels from weak to highly reactive (humid and dry) and even NH_3 !
- «Fuel To Flame Rig» demonstrator integrating gasifier and combustor
  - **Burner** development: operational range atmospheric
  - Continue **integration** of key technologies for BTC including **transients**
  - NOx formation from **FBN**: conversion in gasifier and combustor
    - Using NH_3 doping & **NH_3-measurements** of a gasifier product gas and conversion in the combustor performance - Horizon project - ACHIEVE starting
  - **Can combustor** prototype validation atmospheric and HP
  - TRL 3 at end of Phoenix testing at atmospheric -TRL 4 after TUB rig at high pressure
- **HP testing** of burner and combustor at different facilities
  - BTC-Demo plant and front runner plant at
  - Next steps: HP, can combustor, can validation in Demonstration plant

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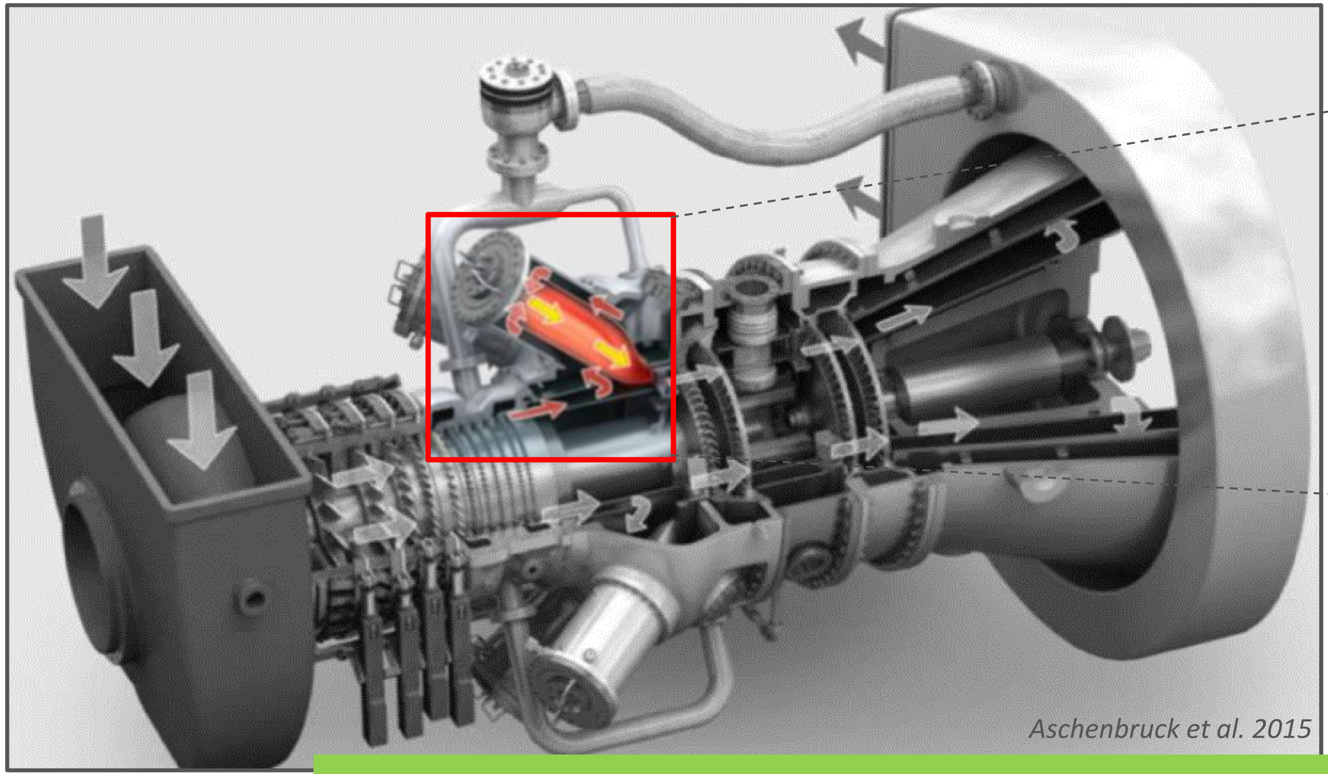
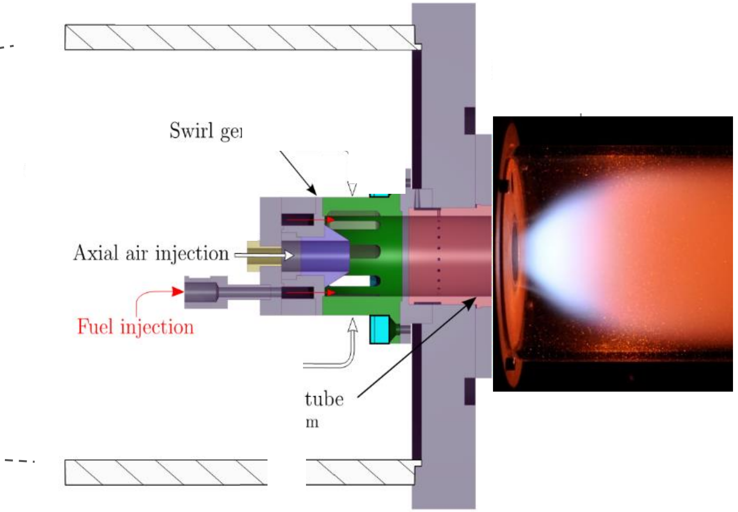
Validation at pressure





Elevated pressure affects:

- **physics of combustion process**
- **acoustic boundary conditions**

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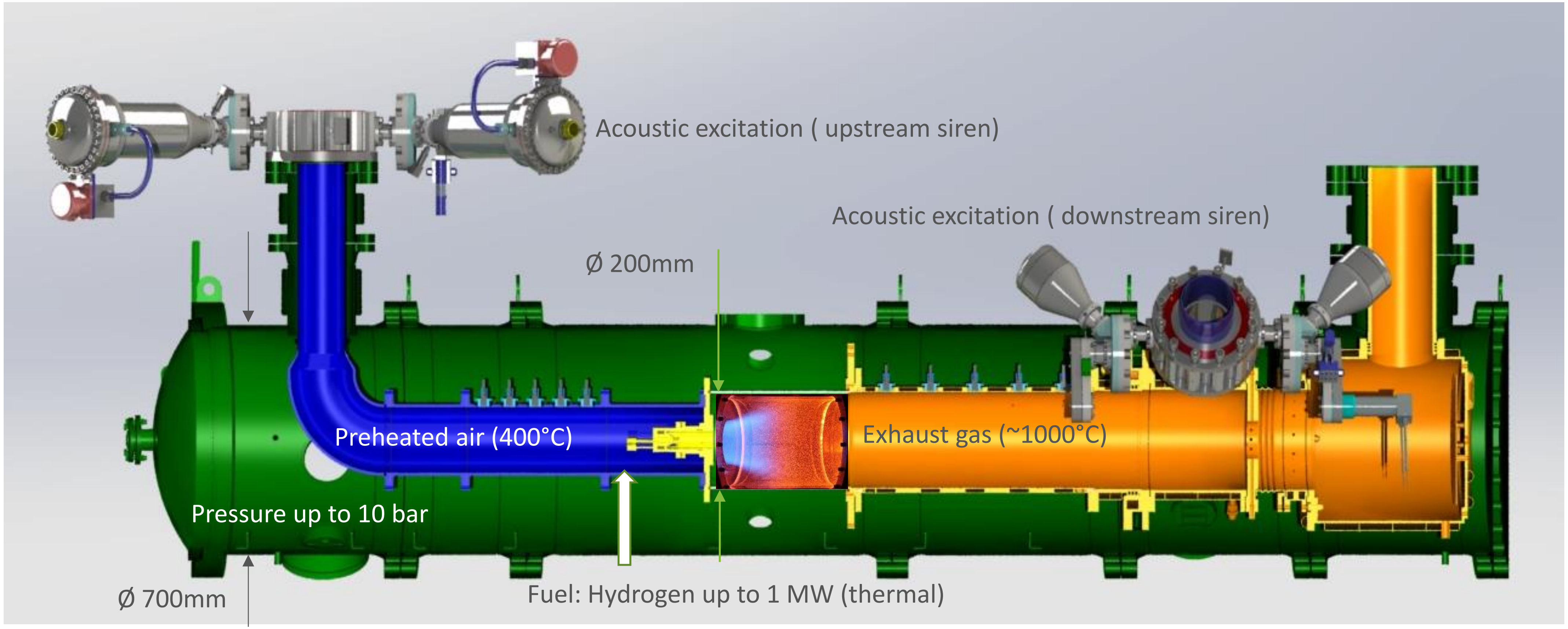
Medium pressure test rig (TU Berlin)



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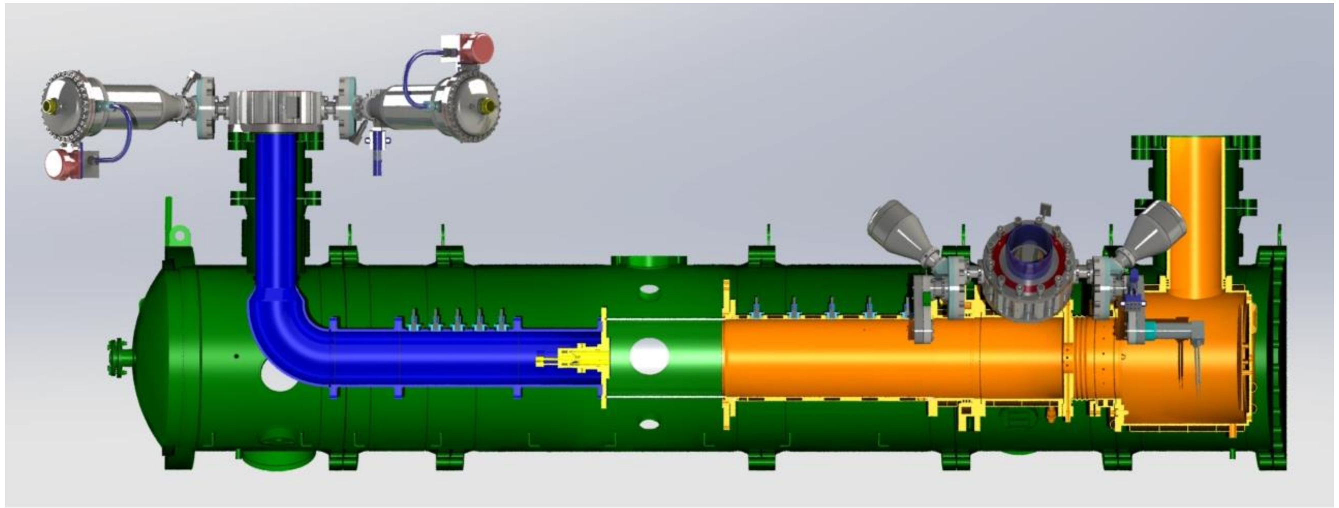
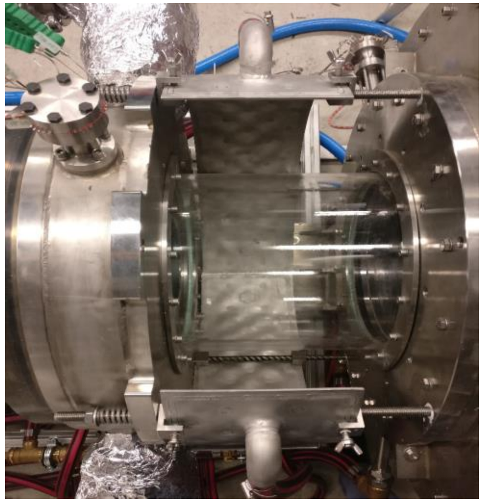
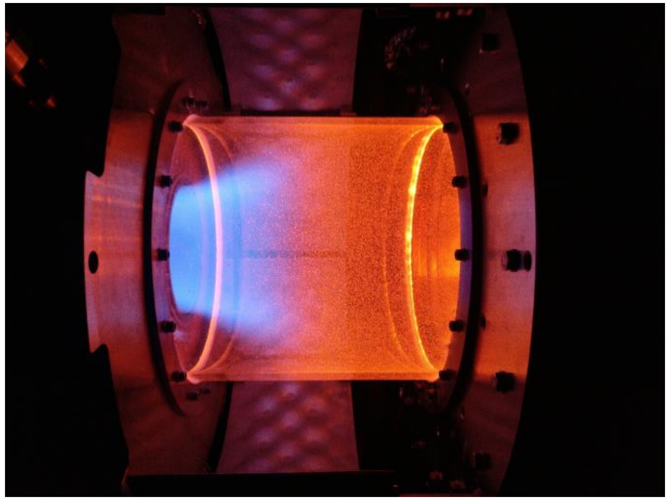
Medium pressure test rig (TU Berlin)







- Engine relevant operating conditions
  - Elevated pressure testing up to 10 bar (1 MW $_{th}$)
  - 400°C air inlet temperature
- Process specific inlet conditions:
  - superheated steam
  - hydrogen supply
  - Syngas characteristics achieved by inertisation of fuel
- Under commissioning
  - Phoenix Hardware tests Q2 2025

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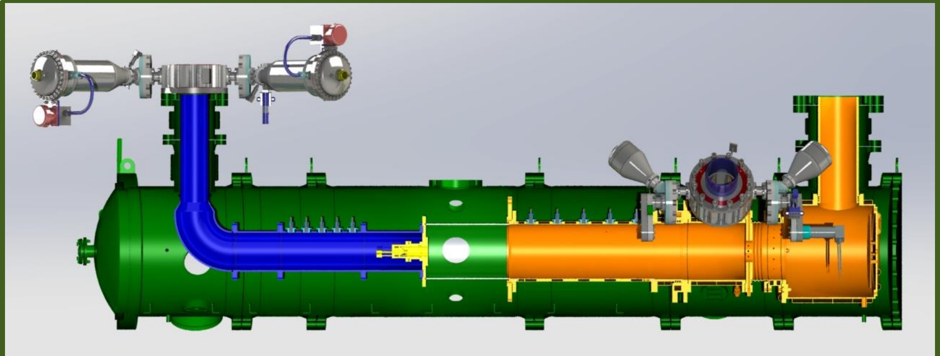
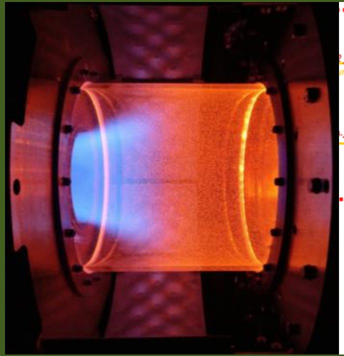
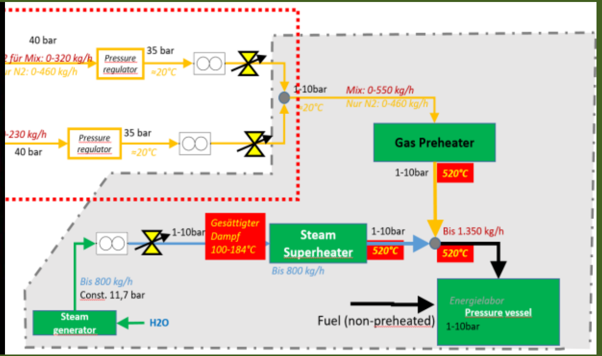
Progress beyond the state of the art

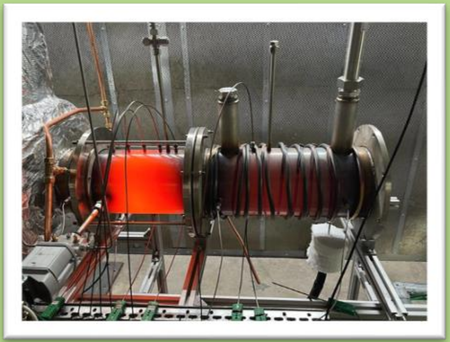
Demonstration of **fuel flexibility** and **emission compliance** at relevant engine conditions



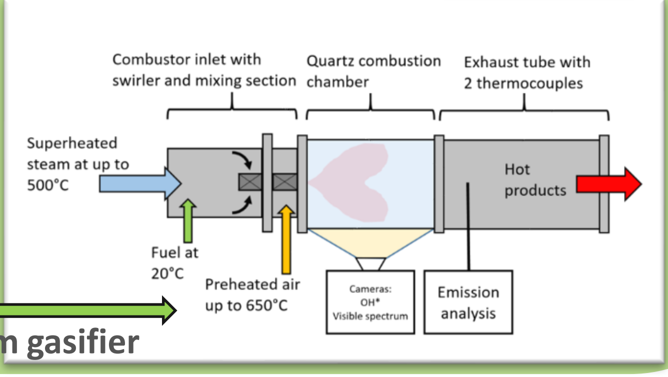
Katniss - pressurized combustion tests







Scarlett – integrated gasifier combustion tests



Syn gas from gasifier

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Bio-FlexGen

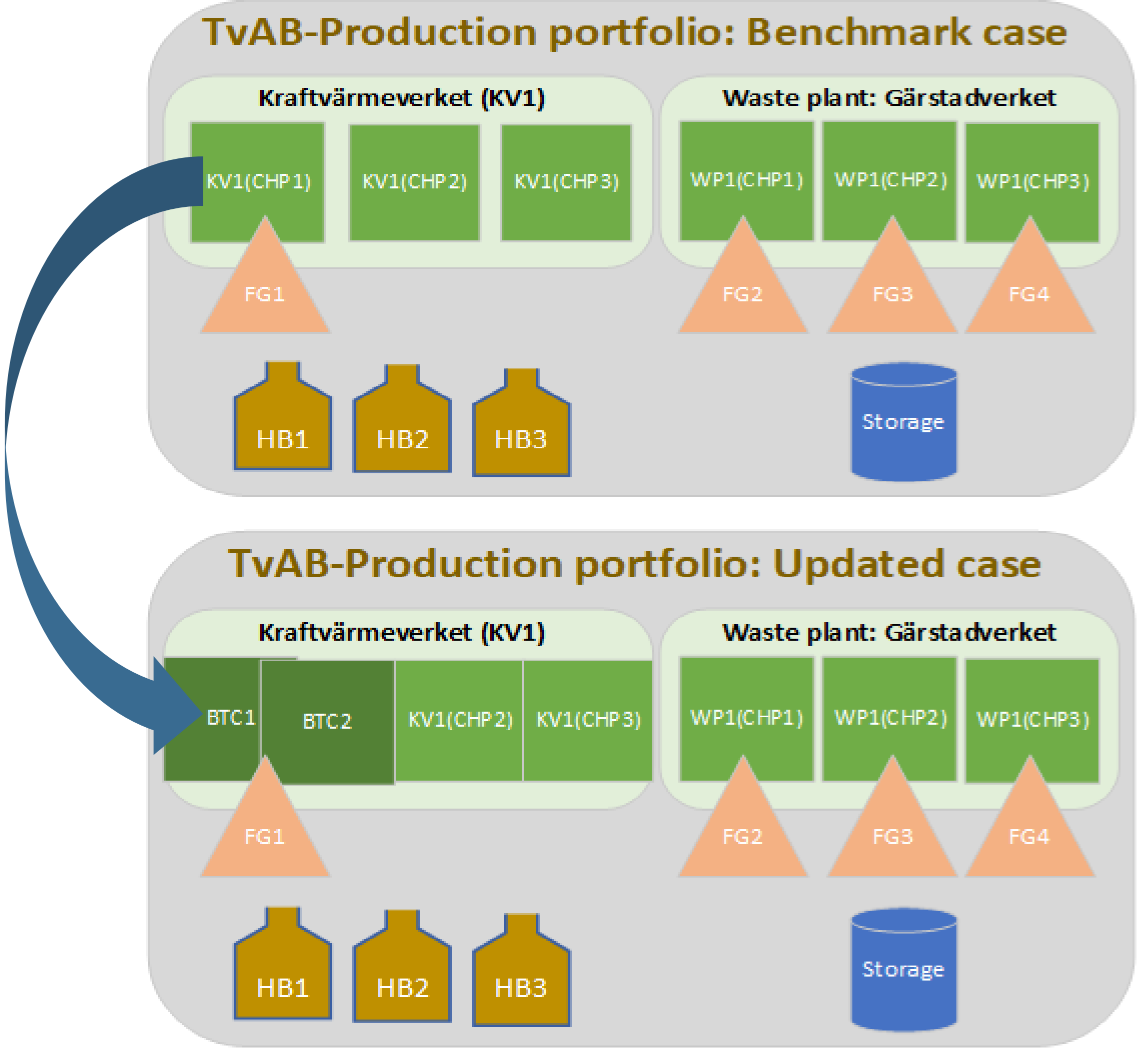
BTC integration in Swedish system

The European Bioenergy Future 21 November 2024 at BluePoints Brussels

Yelena Vardanyan, RISE Research Institutes of Sweden

2024-11-21, Brussels

Swedish Business Use cases: District Heating



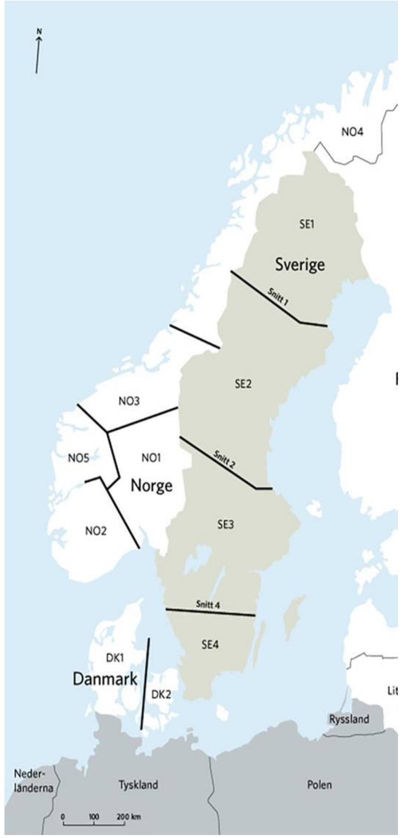
Use case 1 investigates whether using optimal cogeneration of BTC technology will present enough opportunity for TvAB, (Tekniska verken i Linköping AB) to meet the heat demand and to generate electricity during high price hours and increase the profit. ***Day-ahead market trading***

Use case 2 in Sweden investigates utilization of the new BTC CHP technology in the production portfolio of TvAB to provide balancing power. ***Day-ahead and mFRR market trading***

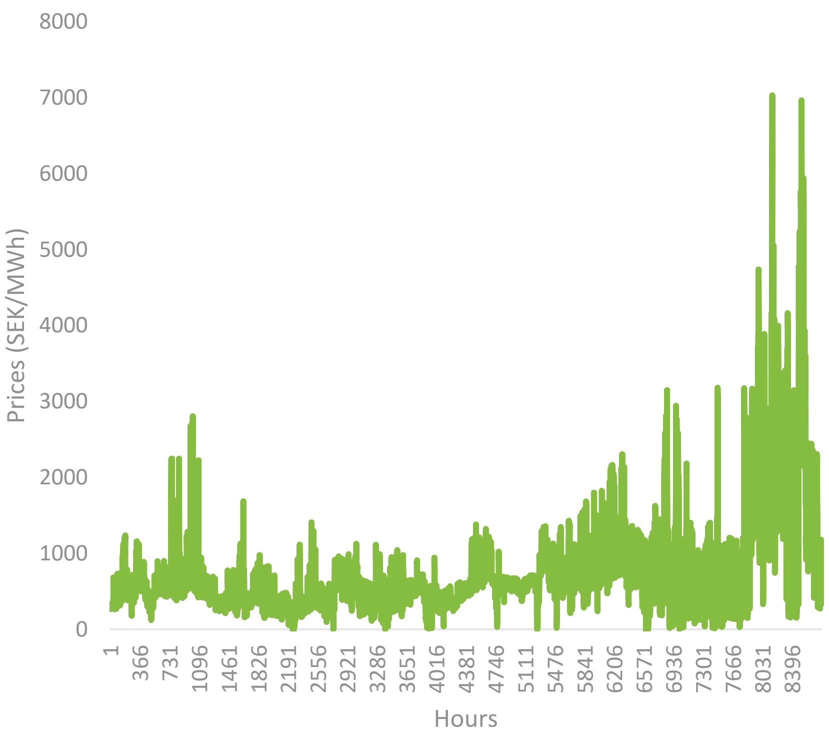
Reference year 2021

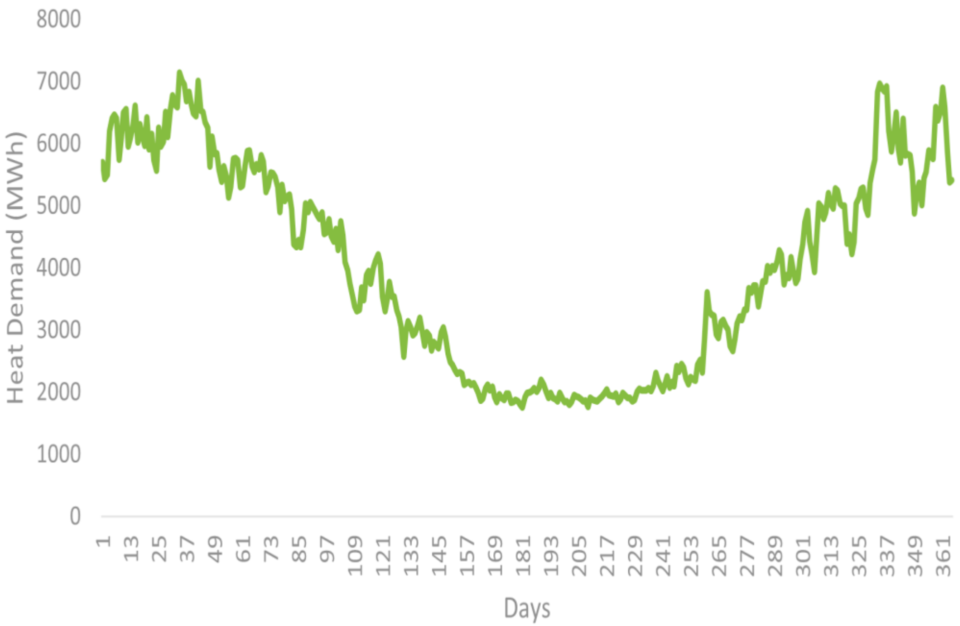
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Swedish Business use cases



Map of Nordic bidding zones, 2022.
Source: Svenska kraftnät.

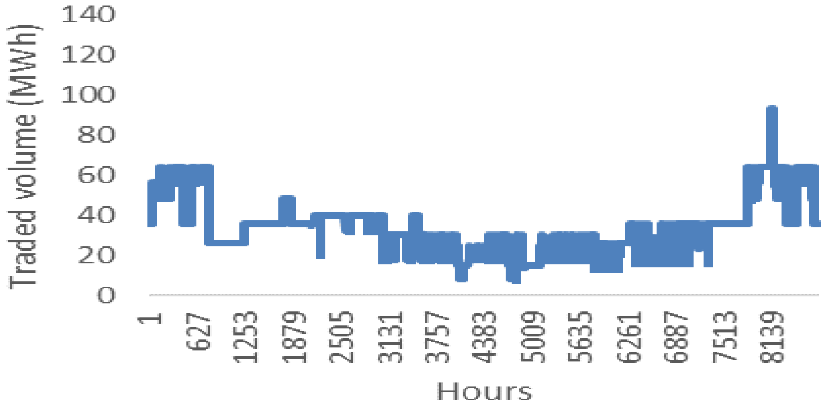


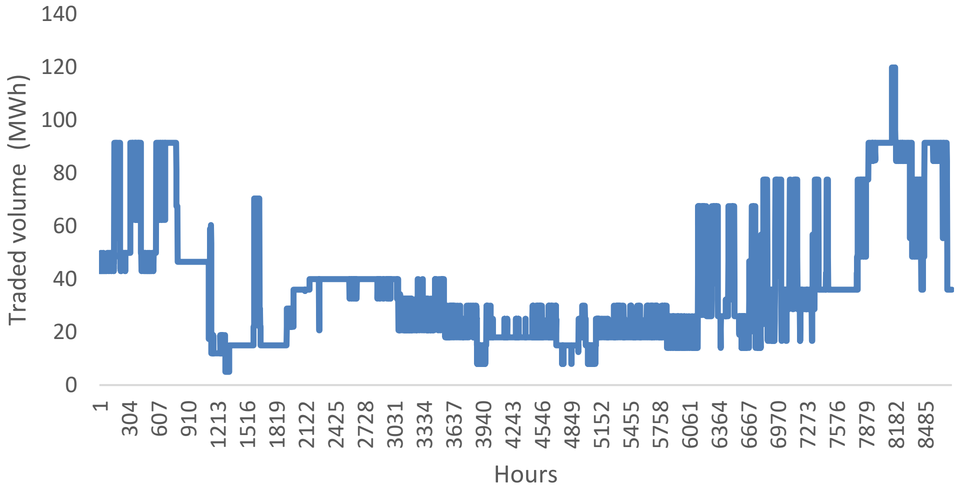


Left: day-ahead market hourly prices for SE3 and reference year of 2021, right: TvAB daily heat demand for 2021.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Swedish Business use case 1-Results





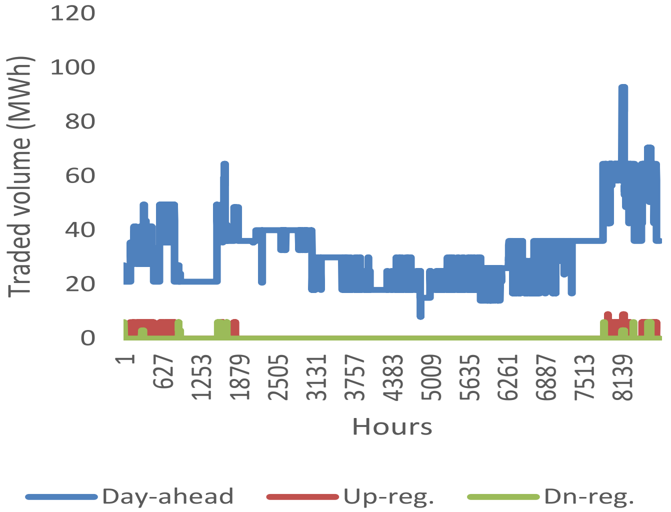
*Power quantity traded in day-ahead market, year 2021. Left: results from **Benchmark model**, right: results from **Updated model**.*

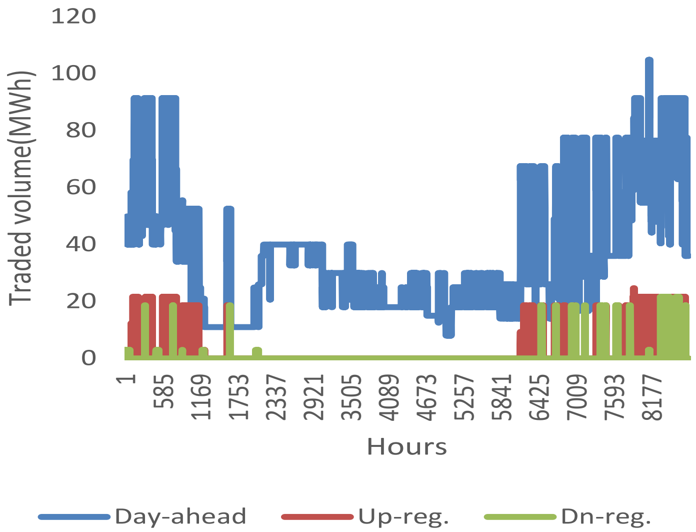
Dispatch, cost, and carbon results for baseline case and for reference year 2021.

Metric	Benchmark model	Updated model	% difference
El. power dispatch (GWh)	372	410.3	10.3% increase
Heat power dispatch (GWh)	1547	1547	-
Proportion renewable dispatch (%)	18%	21.4%	18.8% increase
Proportion fossil fuel dispatch (%)	82%	78.6%	4.2% decrease
Total cost of dispatch (MSEK)	102.5	135.56	32.3% increase
Total revenue (MSEK)	258.6	337	30.3% increase
Total profit (MSEK)	**156.1**	**201.56**	29.12% increase
Carbon emissions ($MTCO_2$)	315	307.88	2.22% decrease

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Swedish Business use case 2-Results





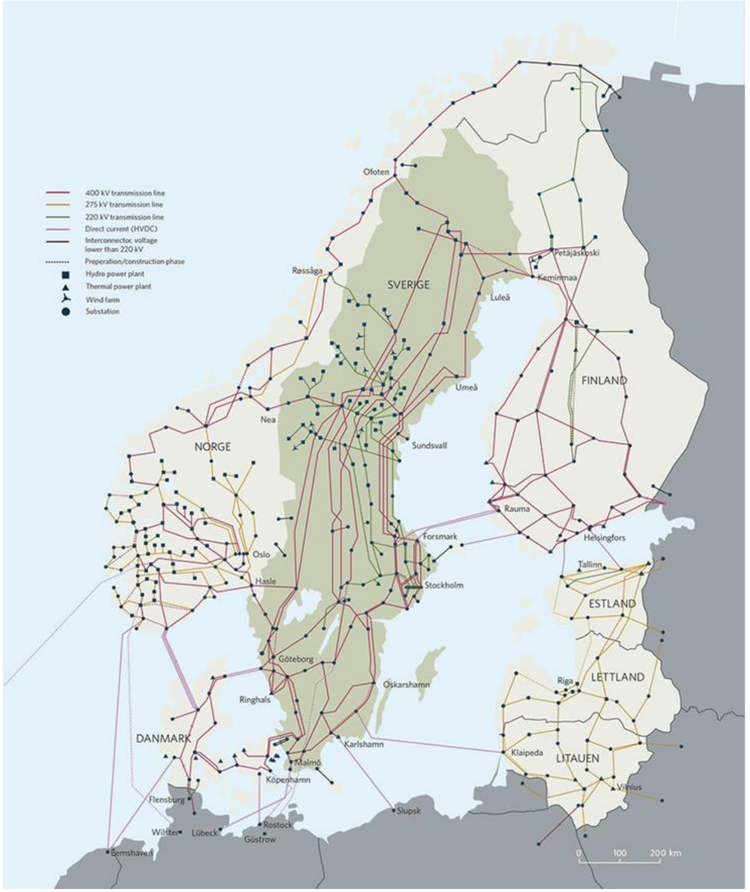
*Power quantity traded in day-ahead and mFRR markets, year 2021. Left: results from **Benchmark model**, right: results from **Updated model**.*

Dispatch, cost, and carbon results for baseline case (day-ahead and mFRR markets) and for reference year 2021.

Metric	Benchmark model	Updated model	% difference
El. power dispatch (GWh)	352.33	407.3	15,6% increase
Heat power dispatch (GWh)	1547	1547	-
Proportion renewable dispatch (%)	17%	21.6%	27% increase
Proportion fossil fuel dispatch (%)	83%	78.4%	5.5% decrease
Total cost of dispatch (MSEK)	92.98	130.6	40.5% increase
Total revenue (MSEK)	251.84	341.93	35.77% increase
Total profit (MSEK)	**158.85**	**211.3**	33% increase
Carbon emissions ($MTCO_2$)	314.5	306.5	2.5% decrease

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Overview of Swedish Electricity sector



Map of Nordic and Baltic bidding zones, 2022. Source: Svenska kraftnät.

Electricity production and consumption in Sweden per price zone, 2021. Source: Svenska kraftnät.

TWh by electricity region in 2021

	SE1	SE2	SE3	SE4	Total
Production					
Hydroelectric power	22.1	38.8	11.4	1.3	73.6
Nuclear power	0.0	0.0	51.4	0.0	51.4
Solar and wind power	4.6	10.8	8.5	4.2	28.1
Other thermal power	0.2	1.1	5.4	1.6	8.3
Total	26.9	50.7	76.7	7.1	161.4
Usage (incl. grid losses)	10.7	15.4	85.9	23.9	135.9

Map of Nordic and Baltic bidding zones, 2022. Source: Svenska kraftnät.

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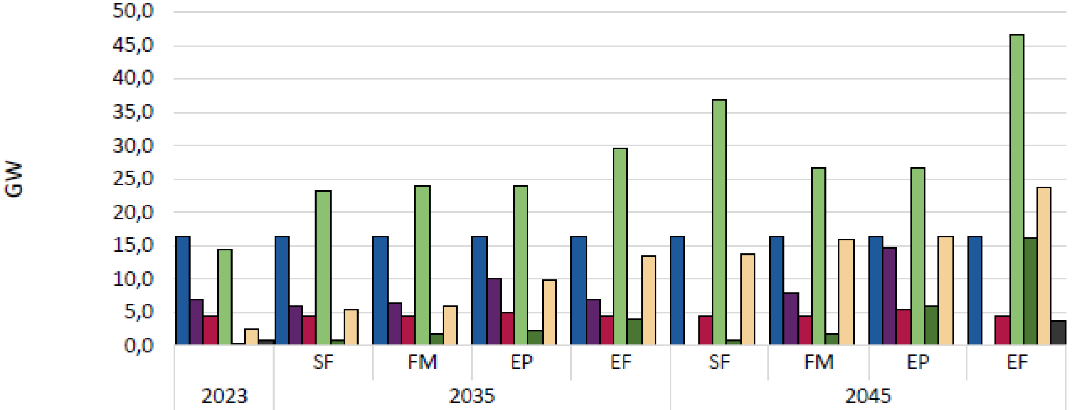
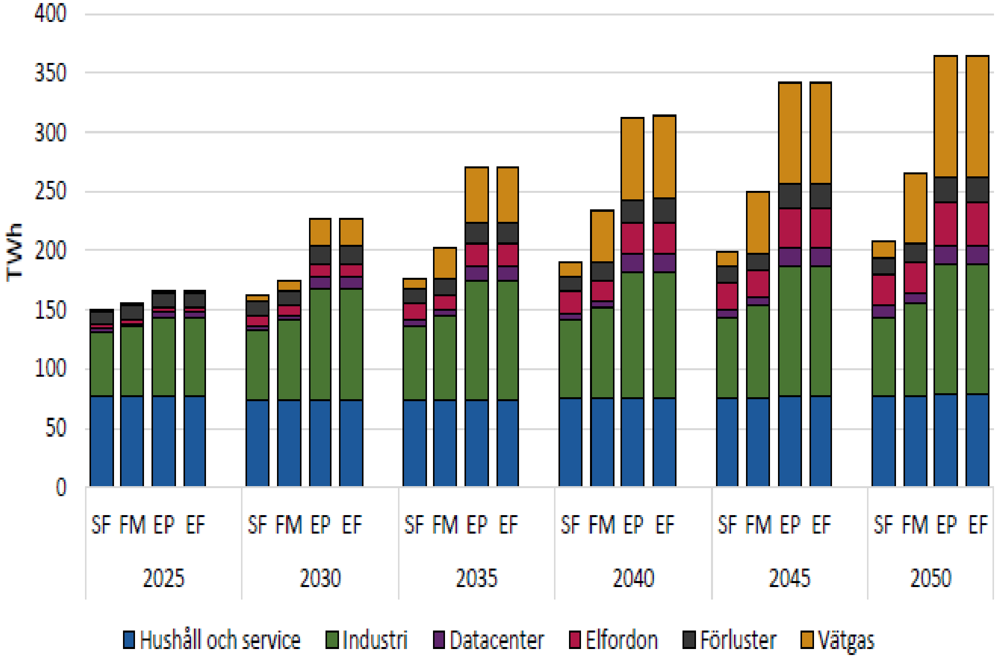
Swedish TSO’s scenarios for long term market analyses



	2023	2035 SF	2035 FM	2035 EP	2035 EF	2045 SF	2045 FM	2045 EP	2045 EF
Vattenkraft	16,3	16,3	16,3	16,3	16,3	16,3	16,3	16,3	16,3
Kärnkraft	6,9	5,9	6,5	10,1	6,9	0,0	7,8	14,7	0,0
Kraftvärme	4,4	4,5	4,3	4,8	4,3	4,6	4,3	5,3	4,3
Vindkraft land	14,5	23,3	23,8	23,8	29,4	36,8	26,7	26,7	46,6
Vindkraft hav	0,2	0,7	1,7	2,3	4,1	0,7	1,7	5,9	16,2
Solkraft	2,4	5,5	5,9	9,8	13,6	13,7	16,0	16,5	23,7
Övrig termisk	0,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	3,7

Vattenkraft Kärnkraft Kraftvärme Vindkraft land Vindkraft hav Solkraft Övrig termisk

Installed production capacity in Sweden for different scenarios . Vattenkraft-hydropower, Kärnkraft- nuclear power, Kraftvärme-CHP, Vindkraft land-onshore wind, Vindkraft hav- offshore wind, Solkraft-solar power, Övrig termisk-other thermal.



Electricity consumption in Sweden in all scenarios. Hushåll and service-household and service, Industri-Industry, Datacenter- data center, Elfordon-EVs, Förluster-losses, Vätgas-hydrogen.

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Swedish system modelling

Demand profiles & flexibility constraints

Transmission constraints

Dispatchable generation capacity and operational constraints

Renewable generation installed capacity and hourly availability time series

Open TEPES

Cost minimisation objective function

Minimise costs of investment and generation dispatch over the planning period

Modelling constraints

- Supply-demand matching
- Linearised power flow
- Availability and operation
- Flexibility and storage

Outputs

Locational Marginal prices

Dispatch and curtailment volumes

Investment technologies/volumes

Total system costs

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BTC system integration –Sweden 2045

Heat and electricity investment per technology for 2045 with BTC.

Candidate for investment	Investment electricity (MW)	Investment Heat (MW)	LCOE (EUR/MWh)	LCOH (EUR/MWh)
Nuclear_new	2750	.	37.7	.
CHP_biomass_new	1913	5739	46.36	15.45
BTC	7920	3586	124	197.38
Heat_pump_new	.	1217	.	3.9
CHP_waste_new	15	45	64	21.38

Heat and electricity investment per technology for 2045 without BTC.

Candidate for investment	Investment Electricity (MW)	Investment heat (MW)	LCOE (EUR/MWH)	LCOH (EUR/MWH)
Nuclear_new	7800	.	49	.
CHP_biomass_new	3561	10683	42	14
BTC	.	.	.	.
Heat_pump_new		1399	.	11.33
CHP_waste_new	15	45	64	21.38

Swedish system costs and balance with/without BTC 2045.

Cost Type	2045 with BTC (MEUR)	2045 w/o BTC (MEUR)
Total system cost	**5765**	**26619**
Investment cost	3112	3225
Operational cost	1022	810.6
Consumption operation cost	0.1	0.028
Emission cost	220	108
Reliability Cost	1410	22476
System balance		
Heat Not served (GWh)	0	0
Electricity not served (GWh)	141	2247

BTC integration in the system, where the need for investment in electricity generating technologies is high, reduced the electricity not served volume, thus, significantly decreases the total system cost.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Conclusion- Sweden

- Results from the Swedish use cases
  - Disregarding the investment cost BTC integration in TvAB portfolio increases the generated profit,
  - sensitivity analysis show that portfolio's total profit highly depends on the biomass prices,
  - with the inclusion of investment expenses for BTC units, the annual investment cost is at least 2.5 times higher than the annual profit,
  - low marginal cost of production from waste incineration plant limits BTC dispatch (about 2000 hours), despite high prices and volatility,
  - to increase the viability of investing in BTC in a portfolio dominated by waste-incineration, the case may need to consider investing in larger heat storage.
- Results from system level analysis
  - In the systems 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.

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Bio-FlexGen

BTC integration in Spanish system

The European Bioenergy Future 21 November 2024 at BluePoints Brussels

Jose Pablo Chaves Ávila, Comillas Pontifical University

Spanish use cases: Industrial applications

BENCHMARK CASES: NO BTC

2021 scenarios

2021 Spanish day-ahead and secondary reserves availability prices

Sulquisa

- 3 natural gas-fueled CHP units.
- Based on **2019 historical operation data series**: CHP electricity and steam generation, fuel consumption, and demand.

CEMEX PowerGen

- No heat demand.
- All electricity is imported from the grid.
- CEMEX did not provide operating reserves in 2021.

CEMEX CHP

- Drying heat demand provided by hot gases of kiln (fuel oil).
- Only fuel and emissions costs associated with burning fuel oil for drying purposes are considered.
- No participation in balancing market

CEMEX Hydrogen

- Same as CEMEX PowerGen.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – with BTC

UPDATED MODEL

BTC integrated

2021 scenarios

2021 Spanish day-ahead and secondary reserves availability prices

Sulquisa

- 15 MW heat pump downstream the BTC (COP=3).
- 10 MW natural gas-fueled steam (peak) boiler.
- Excess steam is cooled down to 80°C through cooling tower.

CEMEX PowerGen

- BTC can provide upwards and downwards secondary reserves capacity.
- All BTC heat production must be cooled.

CEMEX CHP

- 6 MW fuel oil-fueled assisting boiler.
- No participation in balancing market.

CEMEX Hydrogen

- Hydrogen is used as: start-up fuel and (partial) kiln fuel.
- Model PROTIO [1] was used to determine the investment decisions and LCOH.

[1] A. Ramos, Instituto de Investigación Tecnológica, [Online]. Available: https://pascua.iit.comillas.edu/aramos/protio/index.html. [Accessed 03 2024].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (I)

1. Use case **Sulquisa**

Table 7: Results Sulquisa use case

Metric	Benchmark	Updated	Difference
El. power dispatch [GWh]	82.26	56.61	-31.2%
El. power bought [GWh]	1.10	9.11	730.2%
El. power sold [GWh]	24.97	7.34	-70.6%
Heat power dispatch [GWh]	126.82	126.82	-
Proportion renewable dispatch [%]	0%	89.6%	-
Proportion fossil dispatch [%]	100%	10.4%	-89.6%
Carbon emissions [MtonCO2]	0.042	0.008	-81.6%
Total dispatch cost [M€]	-18.96	-7.60	59.9%
Eq. annual investment cost [M€]	0.00	-5.47	-
Total dispatch revenue [M€]	2.94	1.09	-63.0%
Total profit [M€]	**-16.02**	**-11.98**	**25.2%**

Part of the BTC electricity production is consumed by the heat pump → less is sold, but at higher prices.

Main fuel change implies reduction in fuel and emission costs.

Difference of 4 M€/year.

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Spanish use cases – Results (II)

1. Use case **Sulquisa**

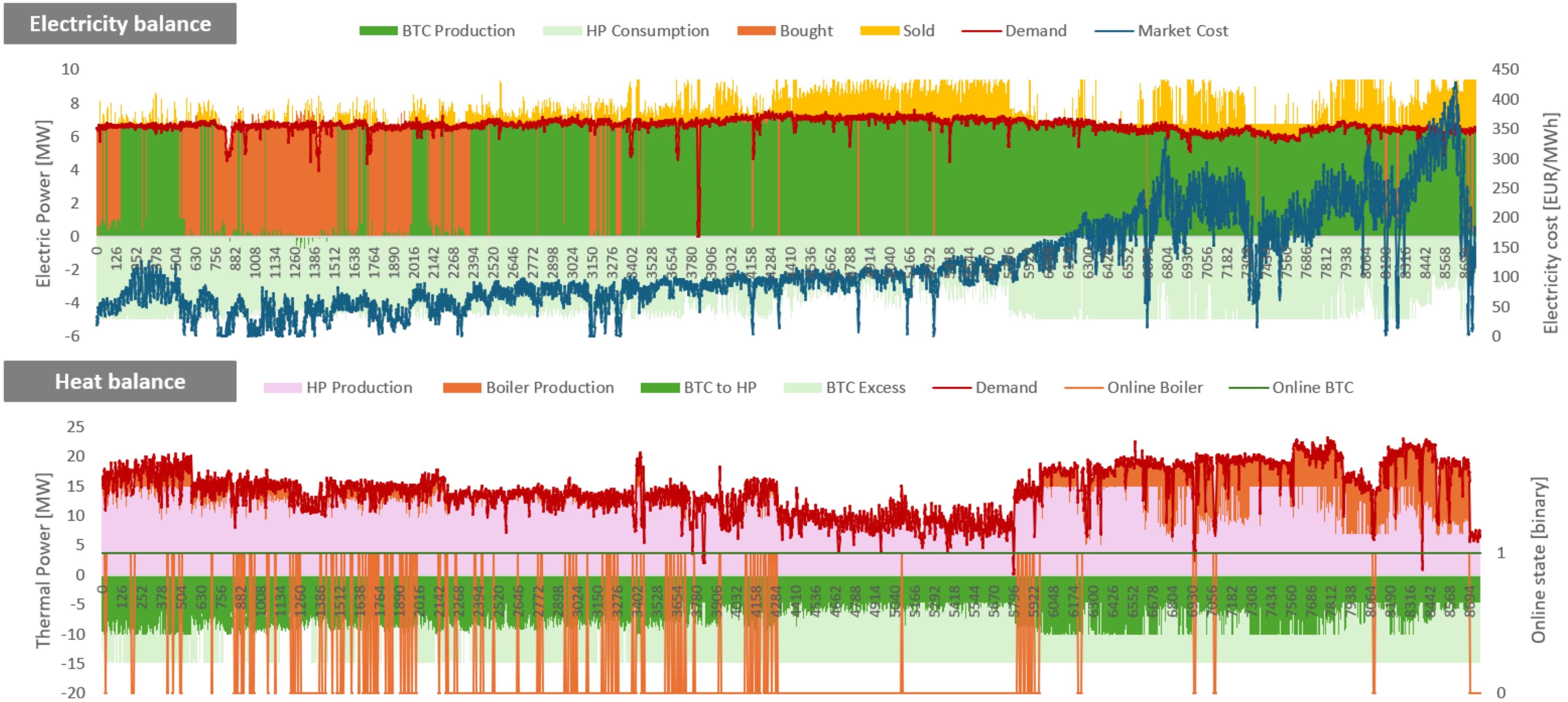


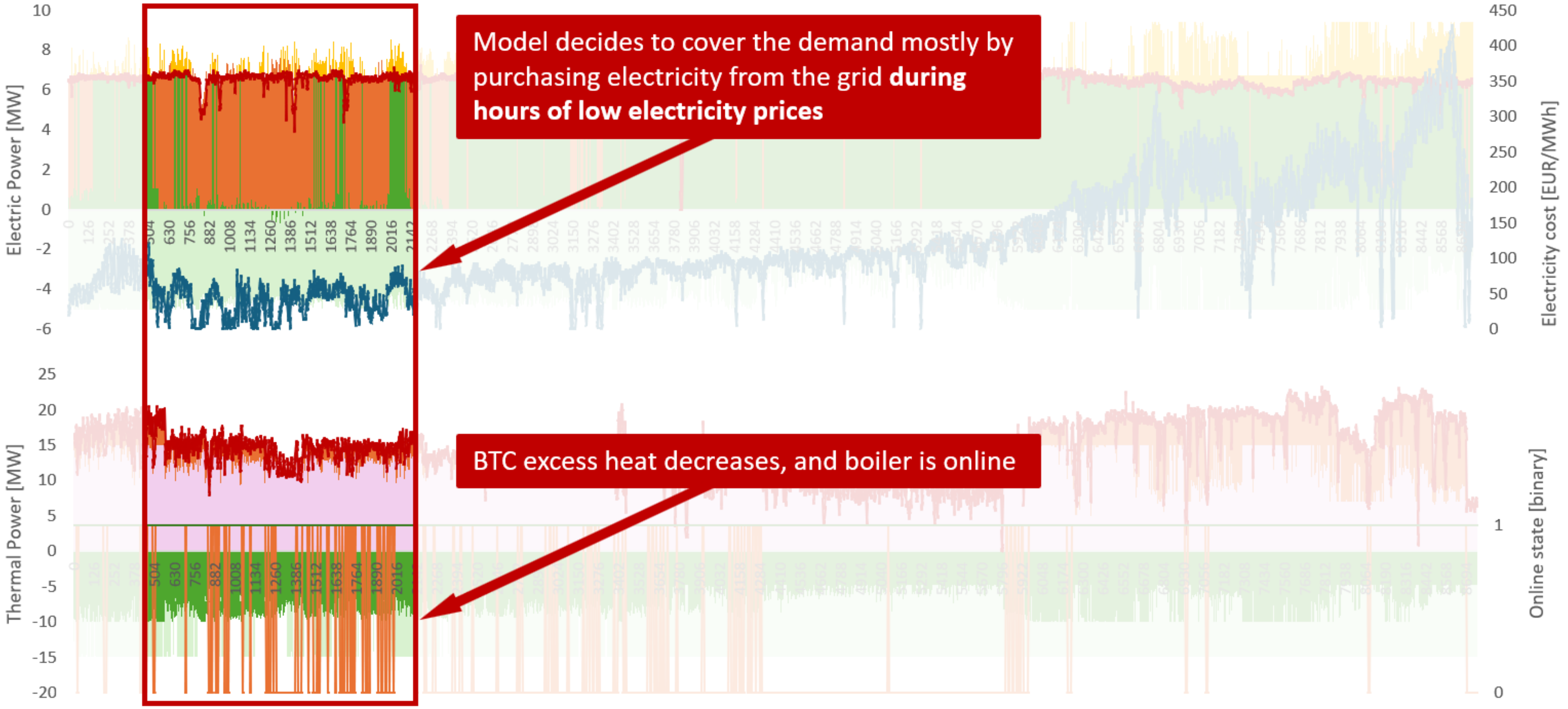
Figure 10: Electricity (top) and heat (bottom) balance results. Sulquisa Use case, updated model.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (III)

1. Use case **Sulquisa**

Figure 10: Electricity (top) and heat (bottom) balance results. Sulquisa Use case, updated model.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (IV)

2. Use case **CEMEX Power-Gen**

Table 8: Results CEMEX Power-Gen use case, Alcanar facility

Alcanar			
Metric	**Benchmark**	**Updated**	**Difference**
El. power dispatch [GWh]	0.00	142.52	-
El. power bought [GWh]	154.00	32.04	-79.2%
El. power sold [GWh]	0.00	20.56	-
Secondary reserves [GW]	0.00	132.52	-
Total dispatch cost [M€]	-18.44	-11.19	39.3%
Eq. annual investment cost [M€]	0.00	-8.14	-
Total dispatch revenue [M€]	0.00	6.91	-
Total profit [M€]	**-18.44**	**-12.42**	**32.6%**

Table 9: Results CEMEX Power-Gen use case, Alicante facility

Alicante			
Metric	**Benchmark**	**Updated**	**Difference**
El. power dispatch [GWh]	0.00	141.67	-
El. power bought [GWh]	109.12	11.68	-89.3%
El. power sold [GWh]	0.00	44.23	-
Secondary reserves [GW]	0.00	135.48	-
Total dispatch cost [M€]	-12.92	-9.04	30.0%
Eq. annual investment cost [M€]	0.00	-8.14	-
Total dispatch revenue [M€]	0.00	10.11	-
Total profit [M€]	**-12.92**	**-7.07**	**45.3%**

6 and 5.85 M€/year difference, respectively

Alicante's demand is 30% lower → excess electricity volumes increase

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (V)

3. Use case **CEMEX CHP**

Table 10: Results CEMEX CHP use case

Metric	Benchmark	Updated	Difference
El. power dispatch [GWh]	0.00	153.48	-
El. power bought [GWh]	154.00	30.08	-80.5%
El. power sold [GWh]	0.00	29.56	-
Heat power dispatch [GWh]	28.85	28.85	-
Proportion renewable dispatch [%]	n/a	99.05%	-
Proportion fossil dispatch [%]	n/a	0.95%	-
Carbon emissions [MtonCO2]	0.008	0.006	-21.2%
Total di spatch cost [M€]	-19.97	-10.31	48.4%
Eq. annual investment cost [M€]	-0.11	-8.30	-
Total dispatch revenue [M€]	0.00	3.73	-
Total profit [M€]	**-20.08**	**-14.88**	**25.9%**

No reserves provision → higher electricity dispatch, but less revenues.

Alternative fuels drying line investment considered for both cases.

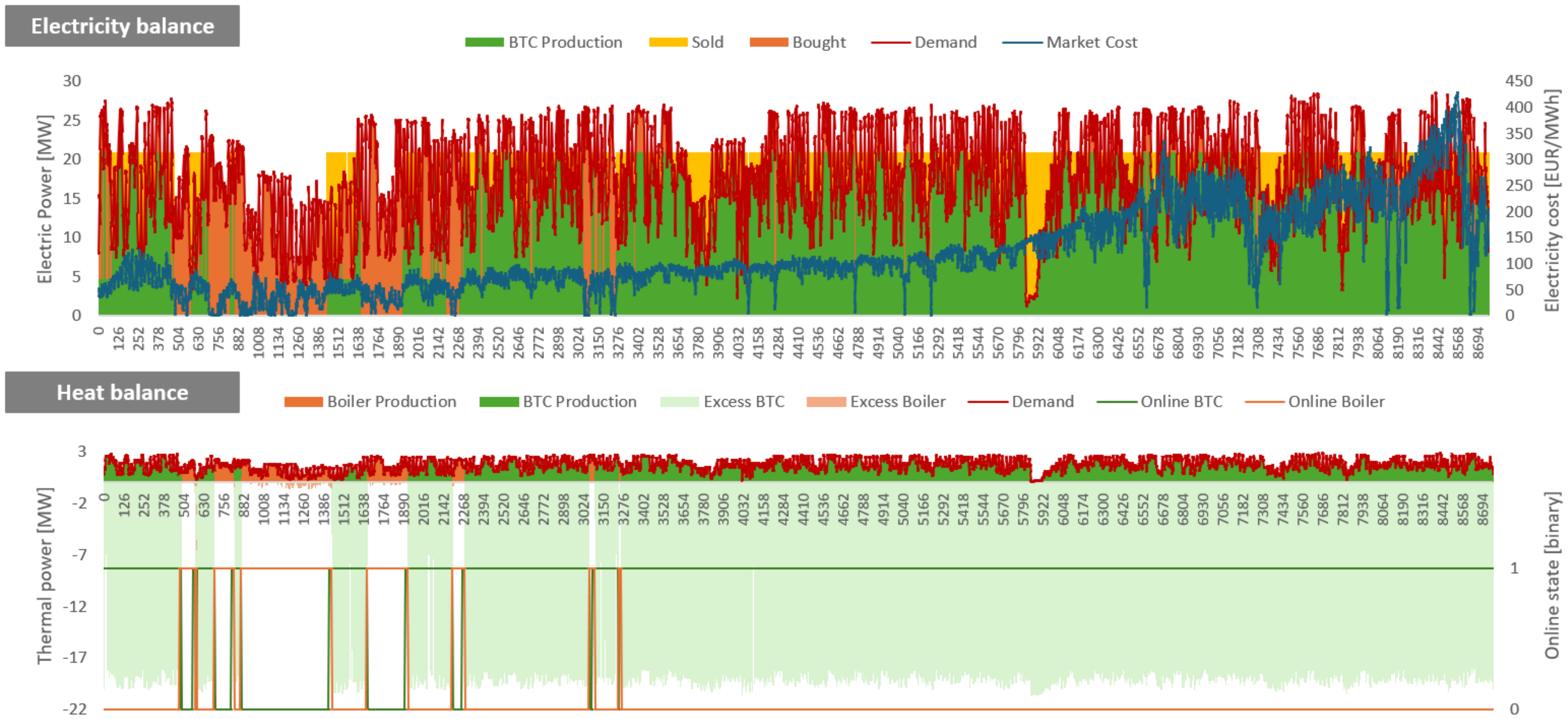
Difference of 5.2 M€/year

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (VI)

3. Use case **CEMEX CHP**

Figure 11: Electricity (top) and heat (bottom) balance results. CEMEX CHP Use case, updated model.



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Spanish use cases – Results (VI)

3. Use case **CEMEX CHP**

Figure 11: Electricity (top) and heat (bottom) balance results. CEMEX CHP Use case, updated model.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (VII)

4. Use case **CEMEX Hydrogen**

Hydrogen consumption:

- Alcanar: 1040 tonH2/year
- Alicante: 810 tonH2/year

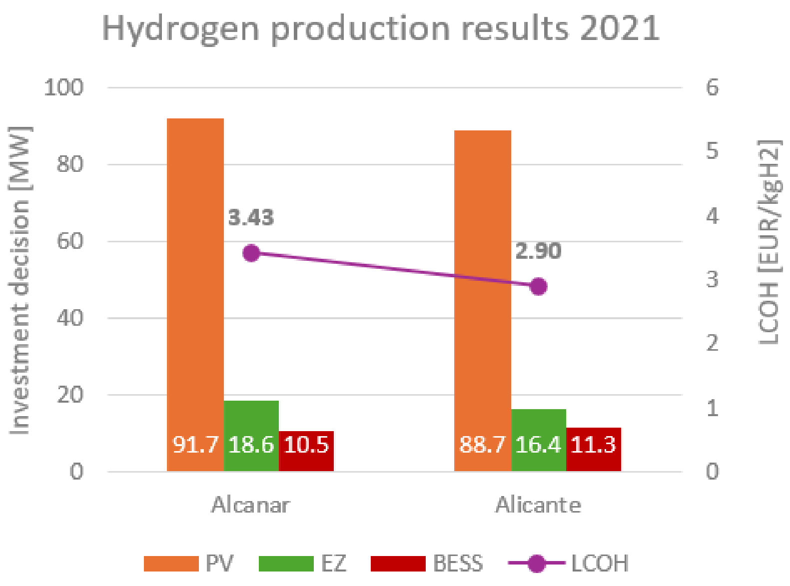


Figure 12: Hydrogen production results, CEMEX Hydrogen use case. 2021 baseline scenario

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

Spanish use cases – Results (VIII)

4. Use case **CEMEX Hydrogen**

Table 11: Results CEMEX Hydrogen use case, Alcanar facility

Alcanar			
Metric	**Benchmark**	**Updated**	**Difference**
El. power dispatch [GWh]	0.00	142.51	-
El. power bought [GWh]	154.00	32.05	-79.2%
El. power sold [GWh]	0.00	20.56	-
Secondary reserves [GW]	0.00	132.52	-
Total dispatch cost [M€]	-18.44	-11.20	39.3%
Eq. annual investment cost [M€]	0.00	-8.14	-
Total dispatch revenue [M€]	0.00	6.91	-
Total profit [M€]	**-18.44**	**-12.43**	**32.6%**

Alcanar - Kiln fuel partial replacement			
Metric	**Benchmark**	**Updated**	**Difference**
Heat power dispatch [GWh]	34.67	34.67	-
Proportion renewable dispatch [%]	0%	100%	-
Proportion fossil dispatch [%]	100%	0%	-
Carbon emissions [MtonCO2]	0.009	0.000	-100.0%
Total dispatch cost [M€]	**-1.84**	**-3.57**	**-93.7%**

Table 12: Results CEMEX Hydrogen use case, Alicante facility

Alicante			
Metric	**Benchmark**	**Updated**	**Difference**
El. power dispatch [GWh]	0.00	141.66	-
El. power bought [GWh]	109.12	11.70	-89.3%
El. power sold [GWh]	0.00	44.22	-
Secondary reserves [GW]	0.00	135.48	-
Total dispatch cost [M€]	-12.92	-9.04	30.0%
Eq. annual investment cost [M€]	0.00	-8.14	
Total dispatch revenue [M€]	0.00	10.11	-
Total profit [M€]	**-12.92**	**-7.07**	**45.3%**

Alicante - Kiln fuel partial replacement			
Metric	**Benchmark**	**Updated**	**Difference**
Heat power dispatch [GWh]	27.00	27.00	-
Proportion renewable dispatch [%]	0%	100%	-
Proportion fossil dispatch [%]	100%	0%	-
Carbon emissions [MtonCO2]	0.007	0.000	-100.0%
Total dispatch cost [M€]	**-1.43**	**-2.35**	**-63.7%**

See similar results to PowerGen use cases → speeding up BTC start-up sequences has a hardly appreciable impact when considering an entire year.

Burning hydrogen is more costly.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101037085.

BTC system integration -2030

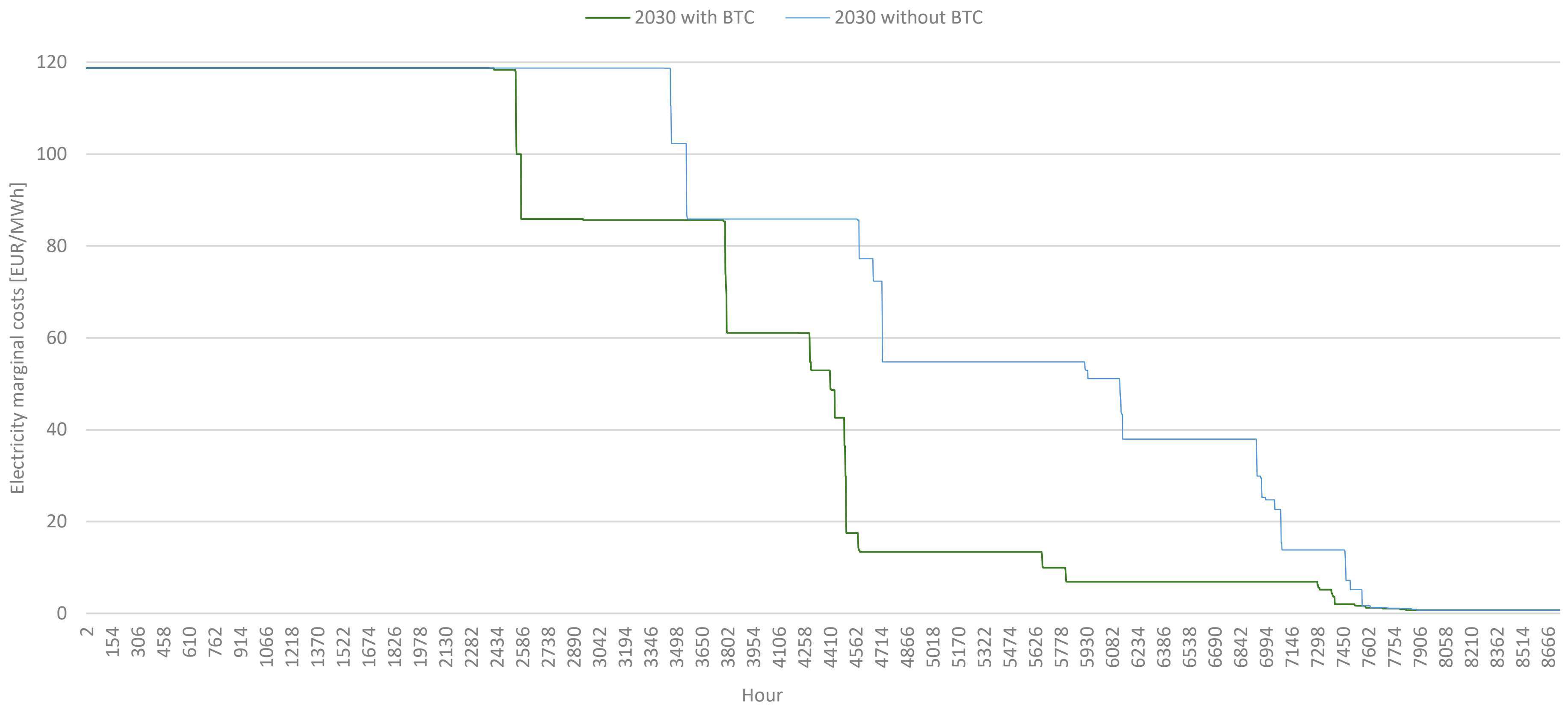
Technology	Investment El. [MW]	Investment Heat [MW]	LCOE [EUR/MWh]	LCOH [EUR/MWh]
Candidate Units				
Batteries	0	-	-	-
Closed Loop PHS (new)	3,247	-	29.1	-
CHP Gas	1,159	1,500	17.2	13.3
CHP Biomass	158	1,500	26.4	2.8
BTC	2,373	1,500	35.3	55.8
Boiler Biomass	-	481	-	3.7
Boiler Coal	-	0	-	-
Boiler Electric	-	1,500	-	0.7
Boiler Gas	-	0	-	-
Boiler H2	-	0	-	-
Boiler Oil	-	0	-	-
Heat Pump	-	1,298	-	4.5

BTC significantly impacts the total generation mix, reducing the generation of CCGT by replacing more than 15 TWh of electric generation and reducing conventional cogeneration. On the other hand, BTC favours generation from existing closed-loop pump hydro storage.

Technology	Electricity Gen [GWh]	Electricity Cons [GWh]	Curtailment [GWh]	Heat Gen [GWh]	Emissions [MtCO2]
Non-candidate units					
Onshore wind	117,002	-	0	-	-
Offshore wind	9,294	-	1,304	-	-
Solar PV	124,545	-	7,606	-	-
Solar Thermal	5,070	-	-	-	-
Hydropower (no PHS)	13,422	-	357	-	-
Open Loop PHS	11,433	-5,947	-	-	-
Closed Loop PHS	5,432	-7,243	-	-	-
Nuclear	26,035	-	-	-	-
CCGT	4,567	-	-	-	2.284
Electrolyzers	-	-52,000	-	-	-
Electric Vehicles	-	-5,596	-	-	-
Candidate Units					
Batteries	0	0	-	-	-
Closed Loop PHS (new)	4,804	-6,406	-	-	-
CHP Gas	4,608	-	-	5,963	1.567
CHP Biomass	1,232	-	-	11,705	-
BTC	15,059	-	-	9,520	-
Boiler Biomass	-	-	-	504	-
Boiler Coal	-	-	-	0	-
Boiler Electric	-	-4,268	-	3,587	-
Boiler Gas	-	-	-	0	-
Boiler H2	-	-	-	0	-
Boiler Oil	-	-	-	0	-
Heat Pump	-	-2,145	-	6,347	-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037085.

BTC system integration -2030 effect on prices



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Conclusion- Spain

- Results from the Spanish use cases
  - the 2021 baseline scenario results showed that BTC technology could achieve higher revenues and lower costs in all cases to cover electricity and heat industrial demands (with and without investment cost).
  - the 2023 sensitivity analysis reflected the impact of lower electricity prices and fuel costs on BTC performance, showing lower profitability for BTC.
  - however, on-site hydrogen production for burning purposes has proved to be more costly than fossil fuels in both 2021 and 2023 scenarios.
- BTC was found also competitive at the system level considering other generation and energy storage alternatives

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The Bio-FlexGen team

https://bioflexgen.eu/