BTC – A NEW TECHNOLOGY FOR HIGH EFFICIENCY BIOPOWER IN A DECARBONISED SOCIETY

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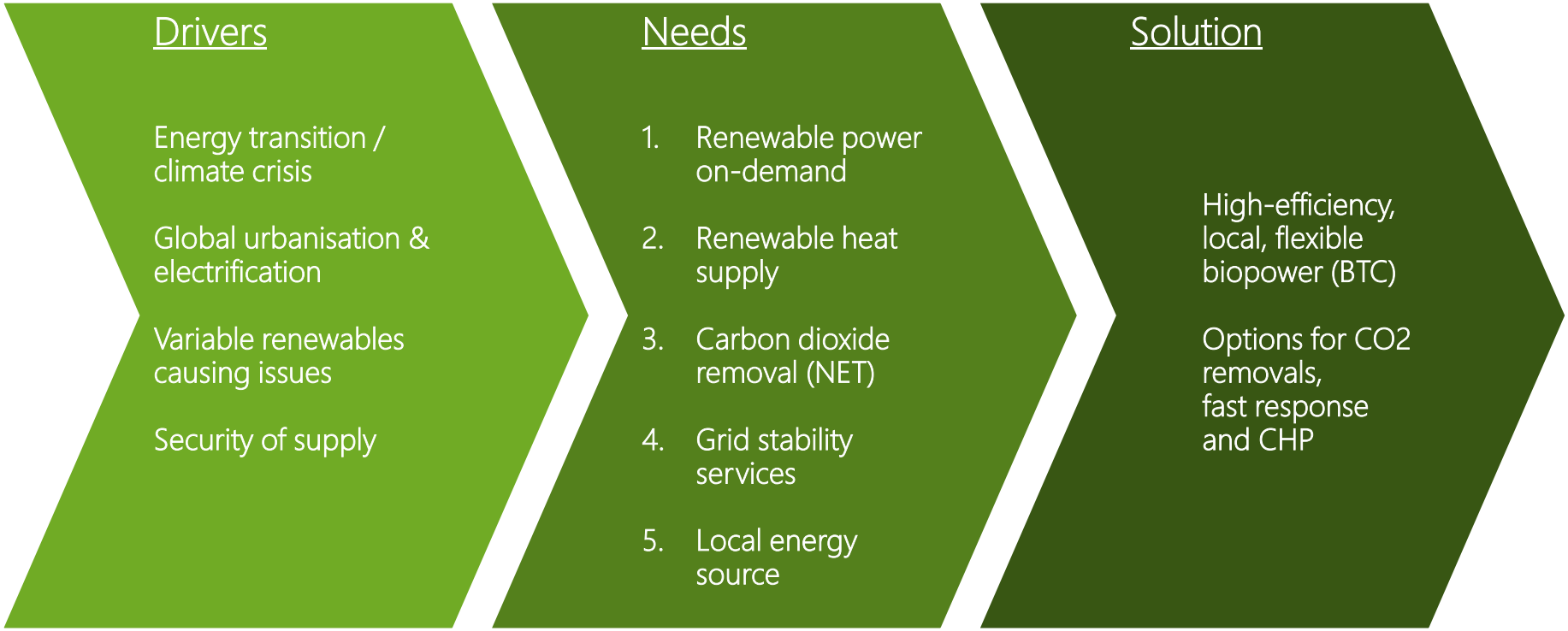
KEY DRIVERS IN THE ENERGY TRANSITION



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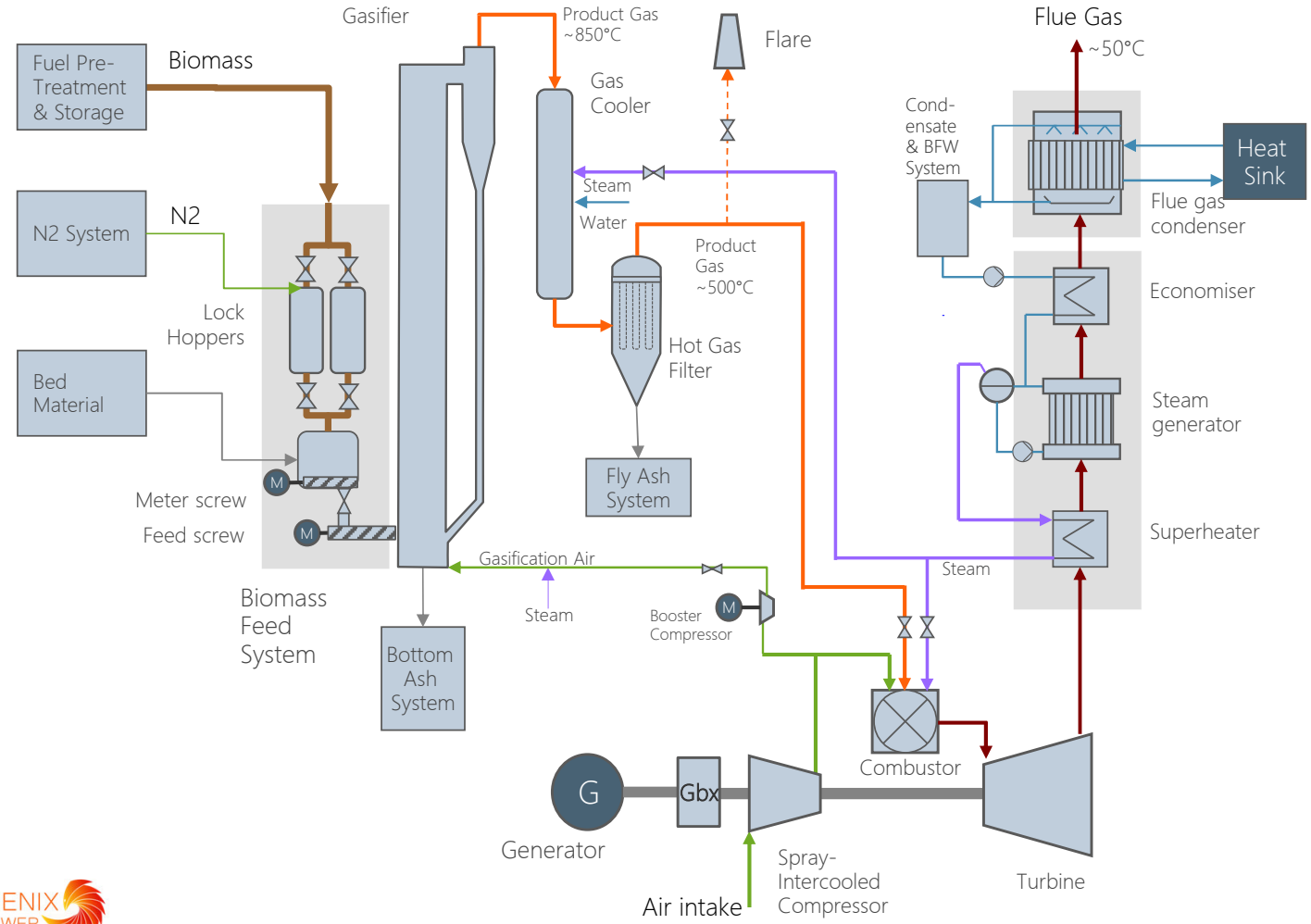
BTC SIMPLIFIED PROCESS SCHEMATIC



- High-efficiency power cycle with integrated gasification and steam-injected gas turbine
- Near-stoichiometric combustion and high GT pressure ratio
- Hot gas clean-up of syngas, including partial quench with saturated steam
- Water self-sufficient with flue gas condenser at useful waste heat levels (50-75 C)
- High fuel flexibility: both biomass and gaseous fuels
- Applications for powergen, CHP (district heat), BECCS

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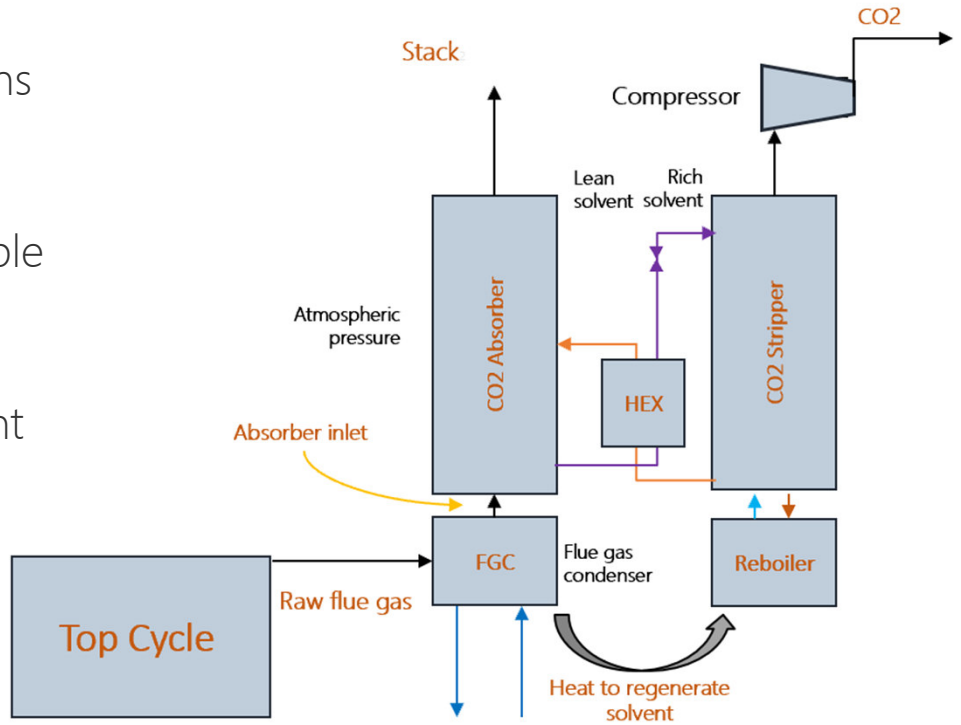
ABSORPTION TYPE CO2 CAPTURE CONCEPT FOR BTC BIOENERGY CARBON CAPTURE AND STORAGE (BECCS)

- Feasibility study with Drax co-producing negative emissions and electricity.
- Carbon dioxide removal (CDR) will be traded at comparable or even higher prices than fossil CO2 emissions (e.g. ETS).
- Benefit of near-stoichiometric combustion for cost-efficient CO2 capture.
- A post-combustion capture plant can be driven efficiently by waste heat from the flue gas condenser
- 100 €/ton CDR credit decreases marginal costs with 100€/MWh_e



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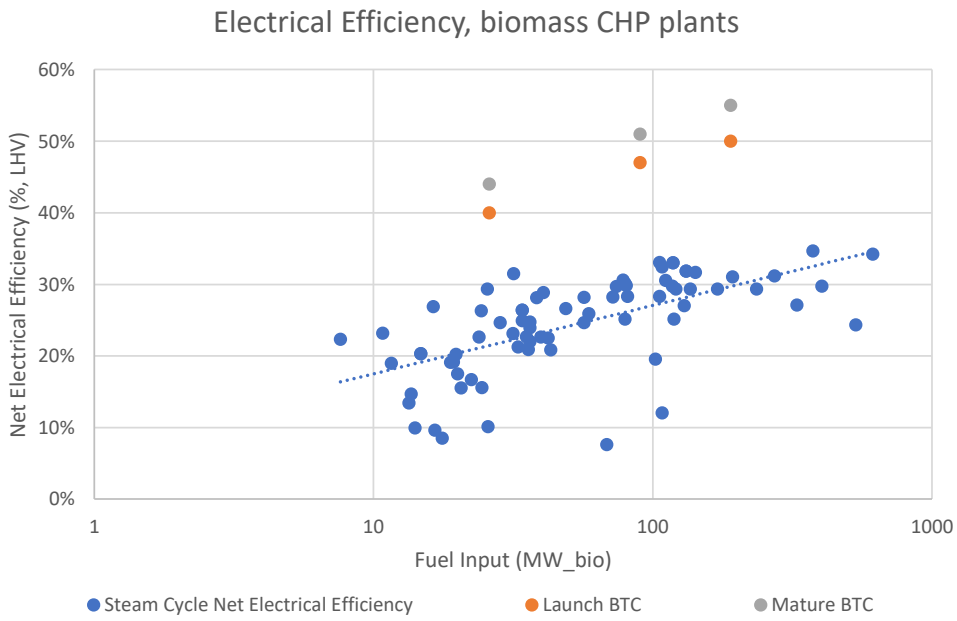
BTC PERFORMANCE TARGETS

		P10	P40	P100+
Feedstock		Forest residues, pellets, blends with agri residues Gaseous fuels (H2, NG)		
Thermal input (MWth)	MW	22-25	78-85	200
Net power output	MW	10	40	110
Net electrical efficiency*	(%, LHV)	40-44%	47-51%	50-55%
Mature with BECCS	(%, LHV)	36%	43%	46%
Working pressure	bar	20-24	28-33	35-40
Combustor outlet temperature	K	1450+	1500+	1600+
Cooling technology		Humid air	Humid air	Steam



Electrical efficiency of biomass-fired CHP plants for a given fuel supply

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BENEFITS FOR THE MARKETS

- Cost effective, plannable, local energy
  - Up to 2 times lower fuel costs for biopower than SC
  - Marginal heat supply costs in CHP are negative with electricity prices above 50 €/MWh (CHP)
  - Marginal electricity costs are negative with CDR credits above 100 €/ton
  - Fast response and fuel flexibility: operate the gas turbine on hydrogen, methane or syngas with ultra-low NOx

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OPERATING CONCEPT COMBUSTION

- Contours of adiabatic temperature (above) and extinction time (below) of equivalence ratio ϕ and steam ratio (Ω) for hydrogen combustion and a wet cycle at 30bara and 500°C Tinlet. An operational regime for lean premixed condition shifting towards humid rich conditions is indicated.
- The temperature can be adjusted within a similar range by increasing ϕ and Ω simultaneously
- The reactivity can be adjusted within a similar range by increasing ϕ and Ω simultaneously
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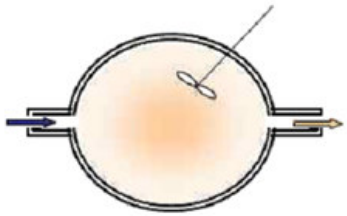
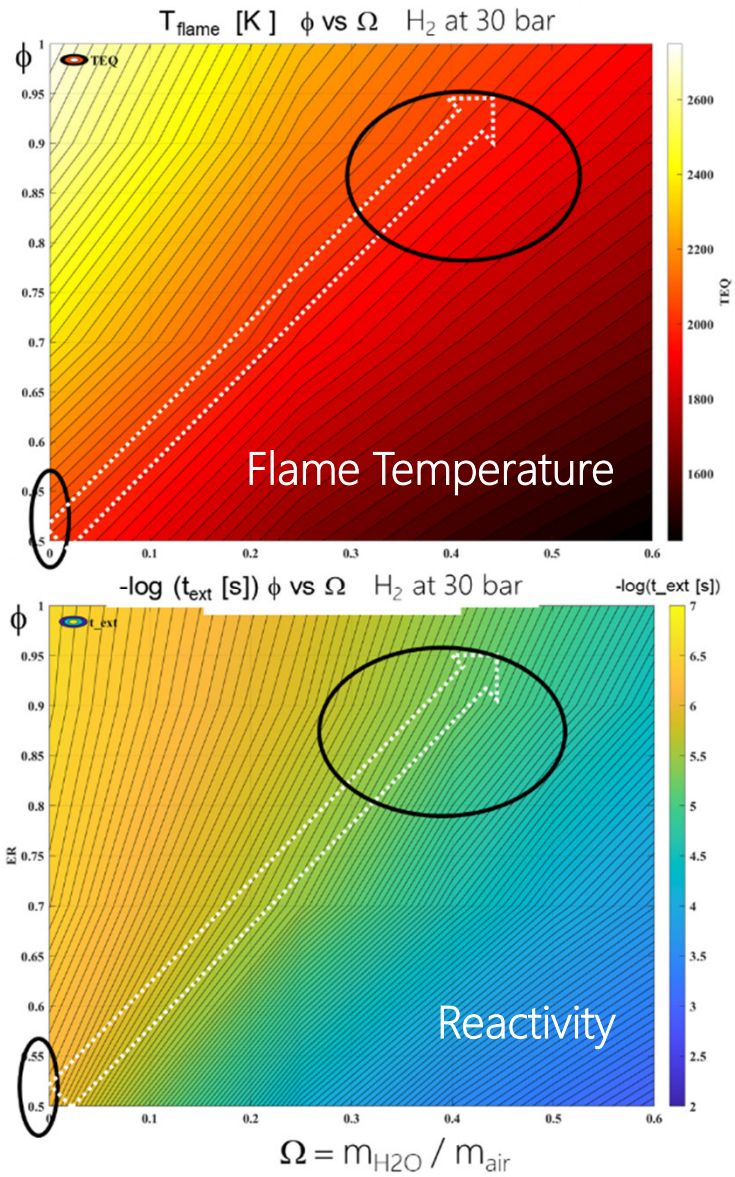


Perfectly Stirred Reactor (PSR)
(CSTR)



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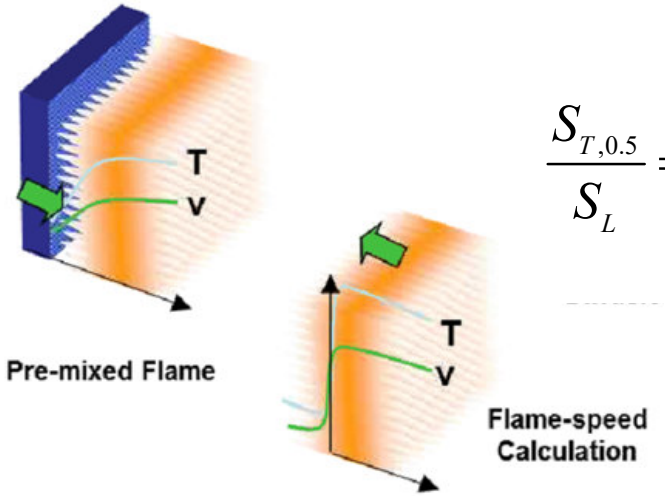
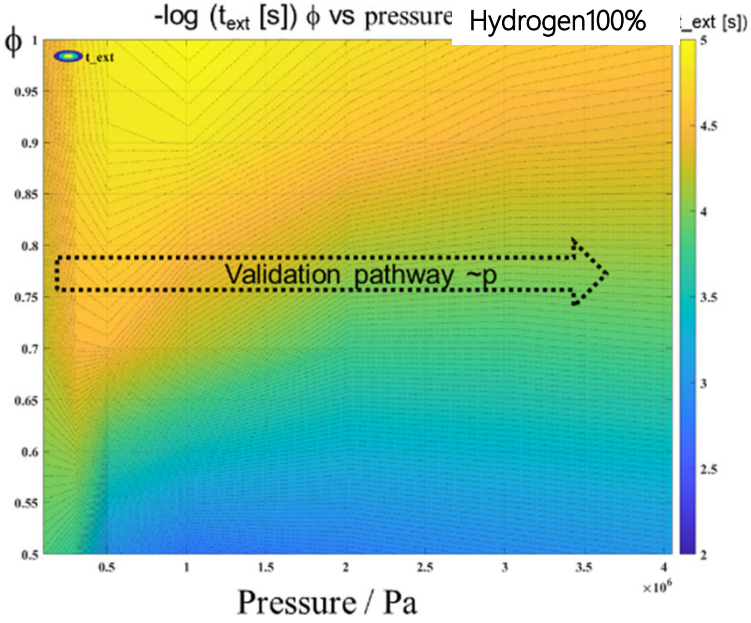
COMBUSTION HIGH PRESSURE PREDICTION

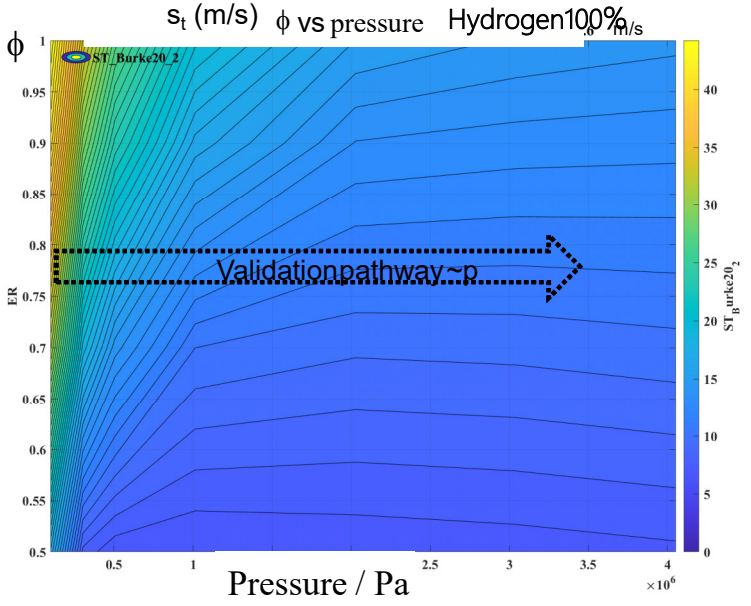
- Dependence of key reactivity parameter extinction time on pressure for bio-syngas

- To estimate the effect at engine pressure the reactivity concerning a PSR extinction time of turbulent flame speed can be utilised



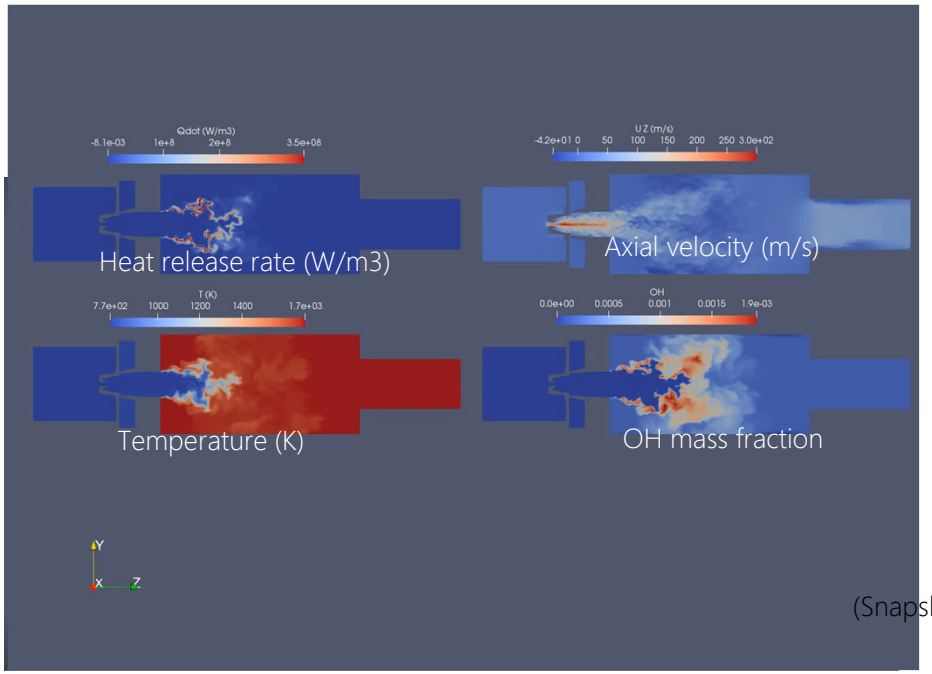
$$\frac{S_{T,0.5}}{S_L} = a + b\left(\frac{\Lambda}{\delta_L}\right)^c \left(\frac{u'}{S_L}\right)^d \phi^e Le^f \left(\frac{P}{P_{ref}}\right)^g$$

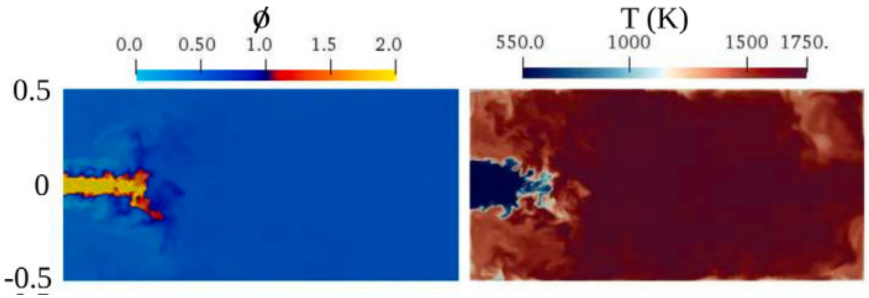




PHOENIX ADVANCED COMBUSTION SYSTEM (PACS)
SYNGAS COMBUSTION WITH CFD: LES

- Case: 100 kW | Syngas
- Chemical mechanism: SK17
- 100kW_Syngas_DoubleSwirler





- H2 atmospheric LES (EUROSTARS project-PACS)
- rich core
- Interesting for high NH_3 fuels (EUCANWIN poject)

(Snapshot of one instant)

ROYAL INSTITUTE OF TECHNOLOGY

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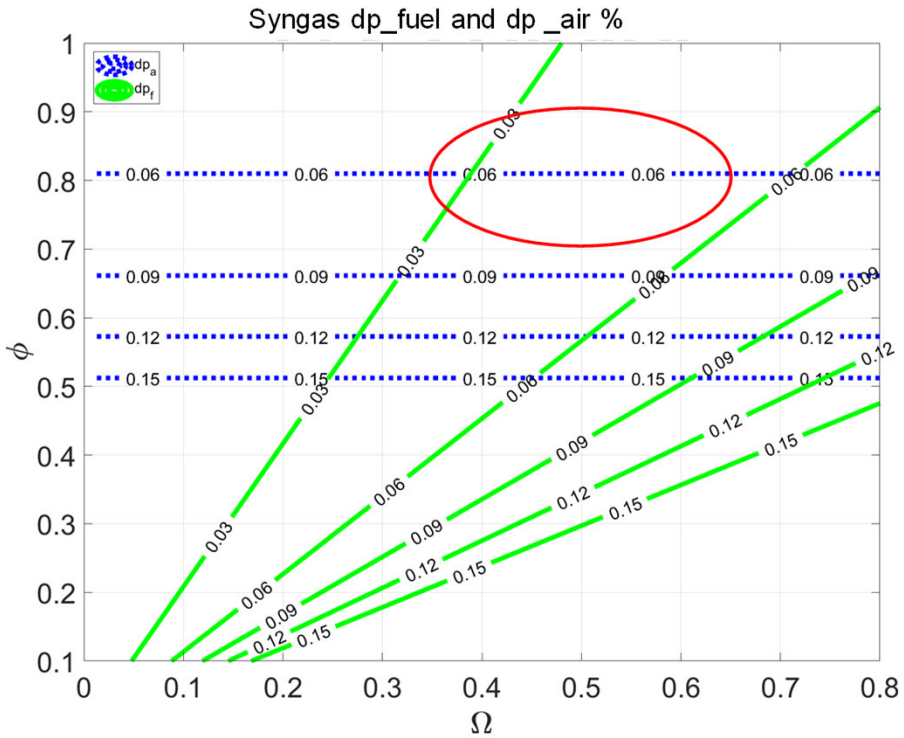
PRESSURE DROPS



Relative pressure drop for air (blue - dotted) and fuel (green - solid) in the double swirler with syngas. The predicted operation range is indicated in red.

- Fuel and air are introduced in a swirling flow leadign to a pressure drop

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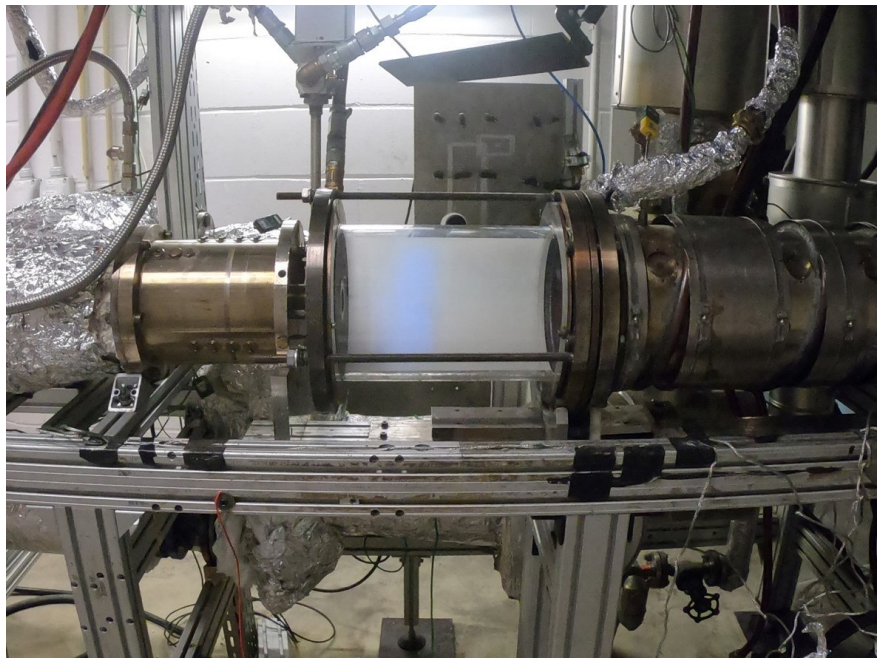
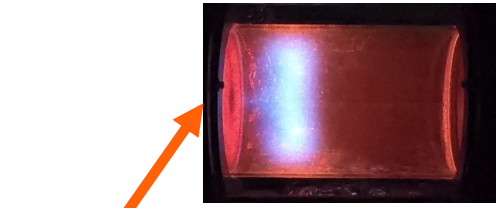
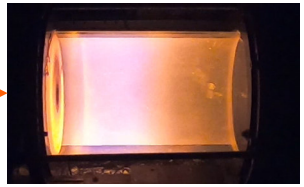
PHOENIX ADVANCED COMBUSTION SYSTEM: FUEL FLEXIBLE COMBUSTOR

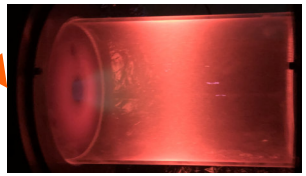




Natural gas



Biomass syngas -simulated



- 100% hydrogen

One GT combustion system for multiple fuels

- Ultra-low NOx with natural gas and / or hydrogen
- Much lower H2 flashback risk and very robust behavior with H2 for start-up

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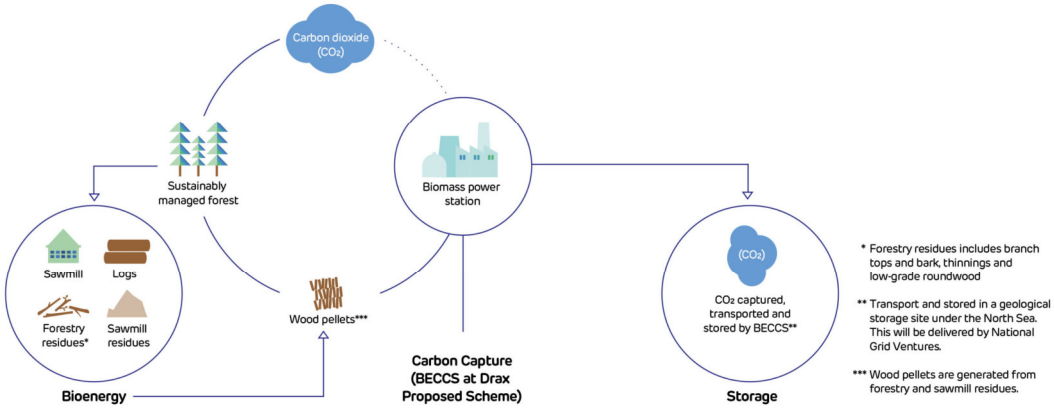
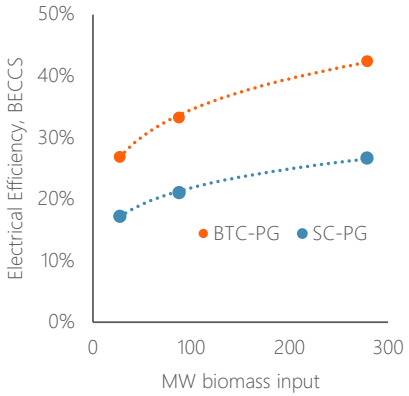
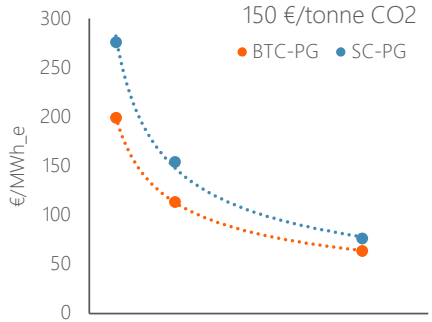
BTC-BECCS, DRAX PRE-STUDY

- BECCS can give high quality carbon dioxide removal
  - Compensate for overshoot of carbon budget
- CDR markets are still maturing but prices 100-300 €/tonne announced for high quality credits.
- Pre-study with Drax pre-study on BTC-CCS. Allows baseload with low – negative marginal costs
- Compared to steam cycle benchmark
  - 60+% more electricity per unit biomass
  - 20-40% lower specific cost for the plant
  - 10-30% lower LCOE with capture
- Highest economic advantage in markets with high fuel, electricity prices, moderate CDR credits (100-200)

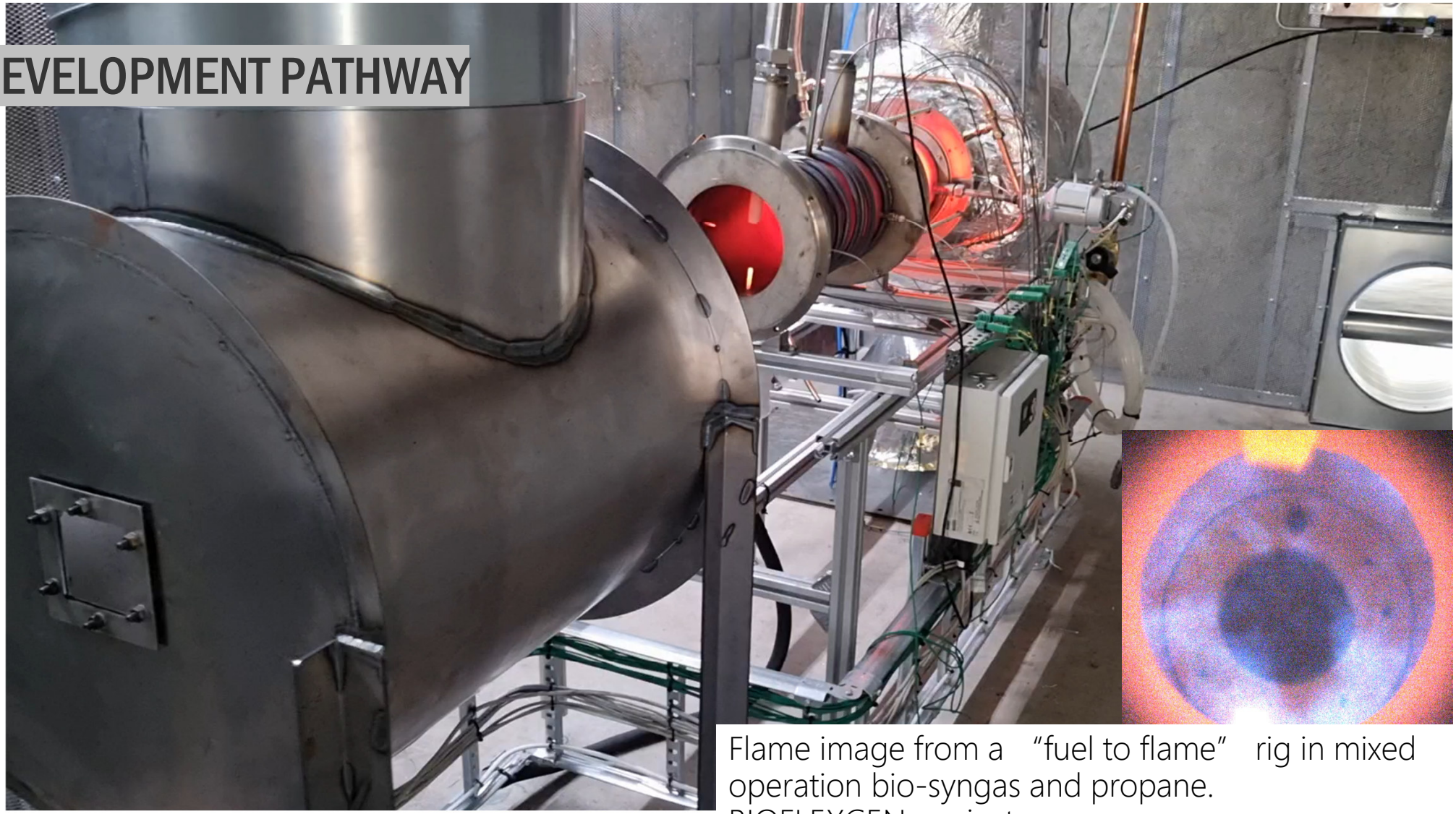


Source: Drax





DEVELOPMENT PATHWAY



Flame image from a "fuel to flame" rig in mixed operation bio-syngas and propane. BIOFLEXGEN-project

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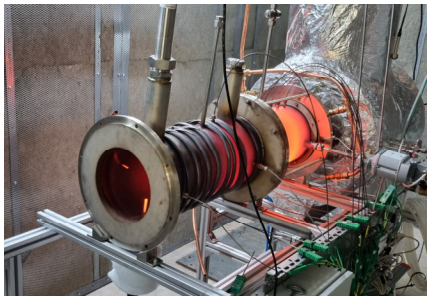
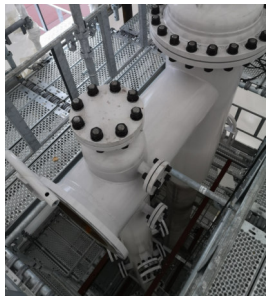
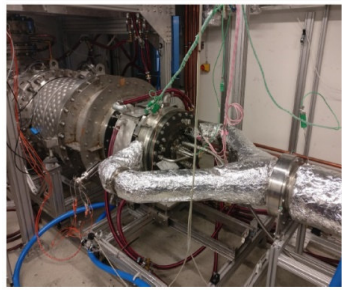
KEY DEVELOPMENTS UNDERWAY AT PHOENIX

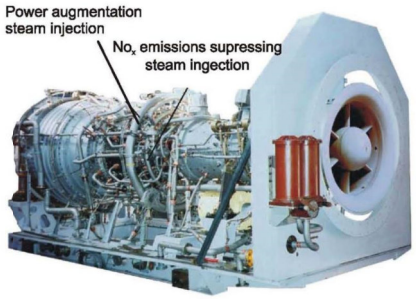
- Integrated gasification and combustion system (atmospheric)
- Pressurised validation of combustion system
- Pressurised validation of gasification system: cold & hot
- Gas turbine design effort with OEM
- System Integration & BECCS







BTC ANLÄGGNING



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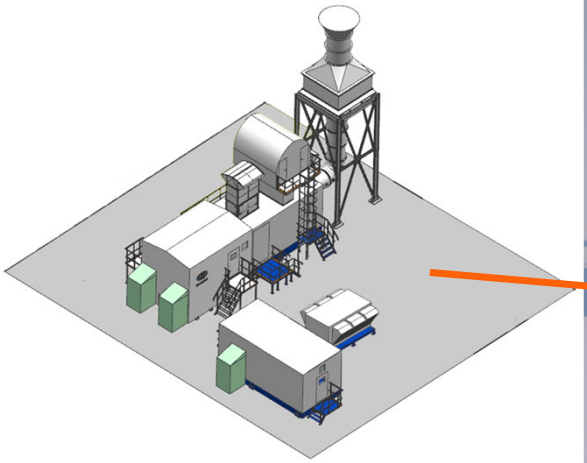
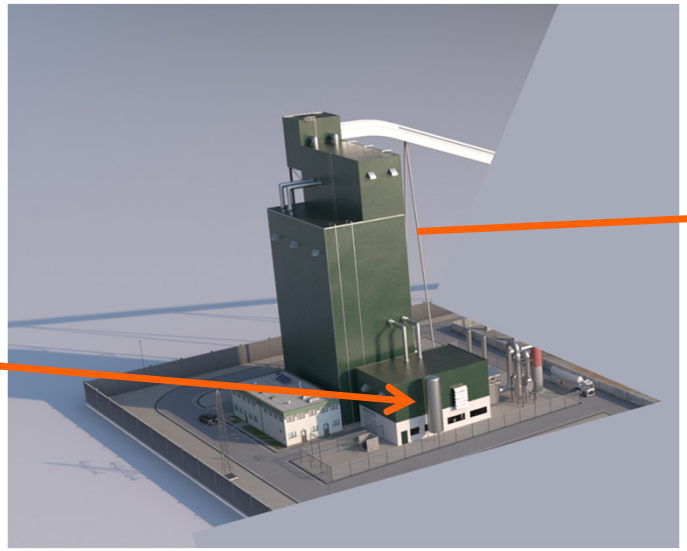
BTC DEMONSTRATION PLANT.

PHASE 0



Re-built gas turbine with Phoenix combustor.
H2, NG testing, steam.
~10 bar, 2 MWe

PHASE 1



BTC plant. Full-scale gasifier with re-built gas turbine.
Biomass pellets-fed.
~10 bar, 2 MWe

PHASE 2

BTC plant with new Top Cycle gas turbine. Full fuel yard. Full performance.
~20 bar, 10 MWe

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ACHIEVE

Advancing the Combustion of Hydrogen-AmmonIa blEnds for improVed Emissions and stability

Activity: HORIZON-JTI-CLEANH2-2023-04-02

COME JOIN US!

We've got mountains to climb
But can't do it alone!

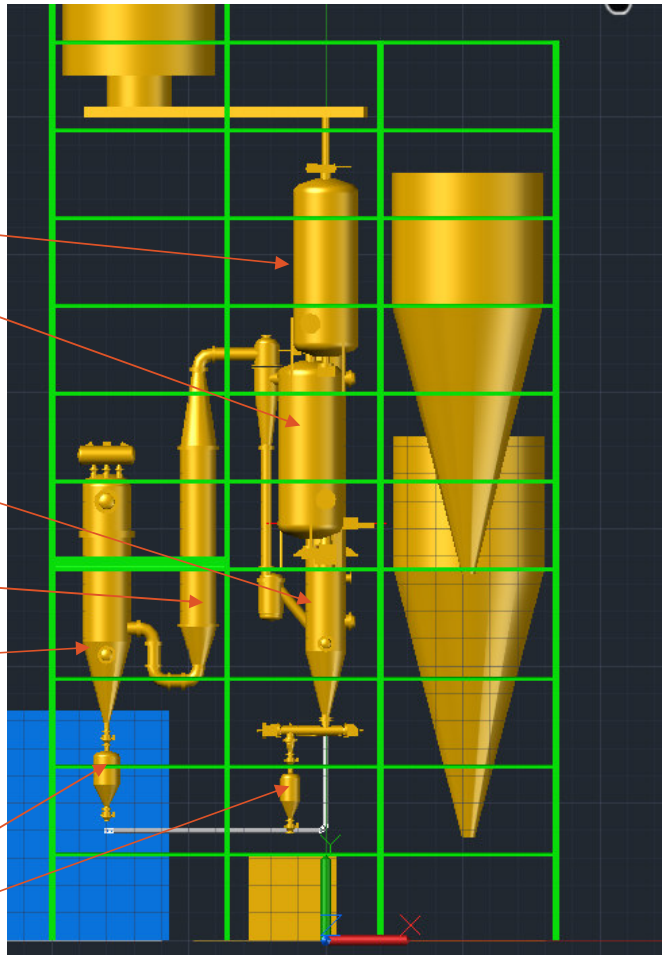
- End users
- Suppliers
- Partners
- Colleagues

High Efficiency Biopower	High Pressure Gasification
• Plannable, scalable, renewable power	• Sustainable fuels at lower cost

BACKUP

GAS PRODUCTION UNIT

- Biomass & Bed Material Feed System
  - Process with lock-hoppers (sluice) system to pressurize the solid materials with inert media, e.g. N2, CO2
- Gasification System
  - Hybrid fluidised bed (HFB) reactor with cyclone, standpipe and return leg.
  - Patented design to maintain high char conversion at high pressure.
- Gas Cooler System
  - Introduction of steam & water to cool the dusty hot gas flow
- Hot Gas Filter
  - Remove alkali metals, particles, (fly ash, bed material, char, soot)
  - Sintered ceramic or metallic candle filters with police filter to prevent carry-over to GT. Lower than 1 micron cut
  - Regular back-blowing to dislodge filter cake
- Ash Systems
  - De-pressurization and cooling of the bottom ash from the base of the gasifier and fly ash from the base of the filter



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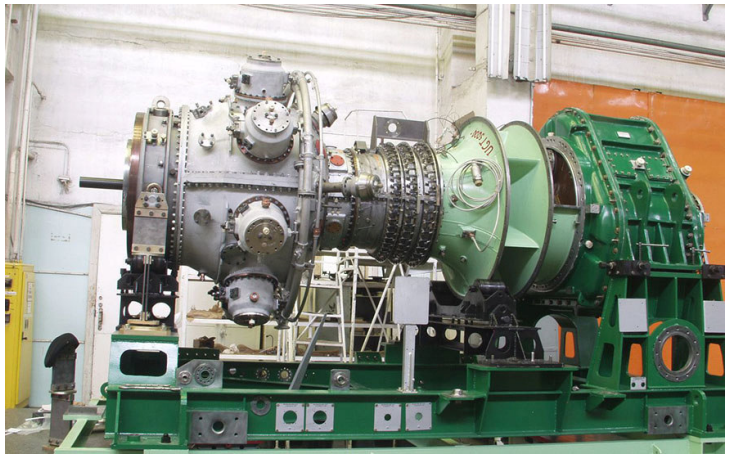
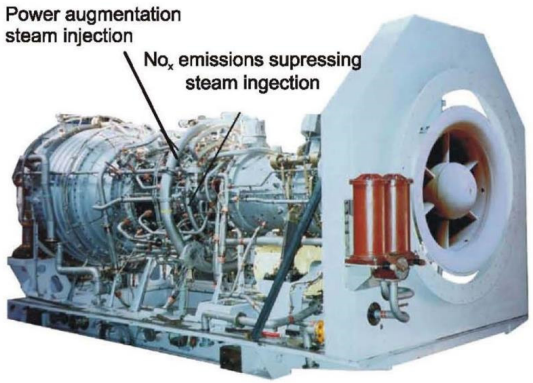
ZORYA MASHPROEKT

- Ukrainian OEM.
- Former supplier to Russian navy and O&G industry.

- Co-operation started 2020.
- MoU for joint development in 2021.
- Concept design for 10 & 25 MW engine complete.

- Next step: start engineering phase
- Work started on partners, financing and consortium for demonstration plant





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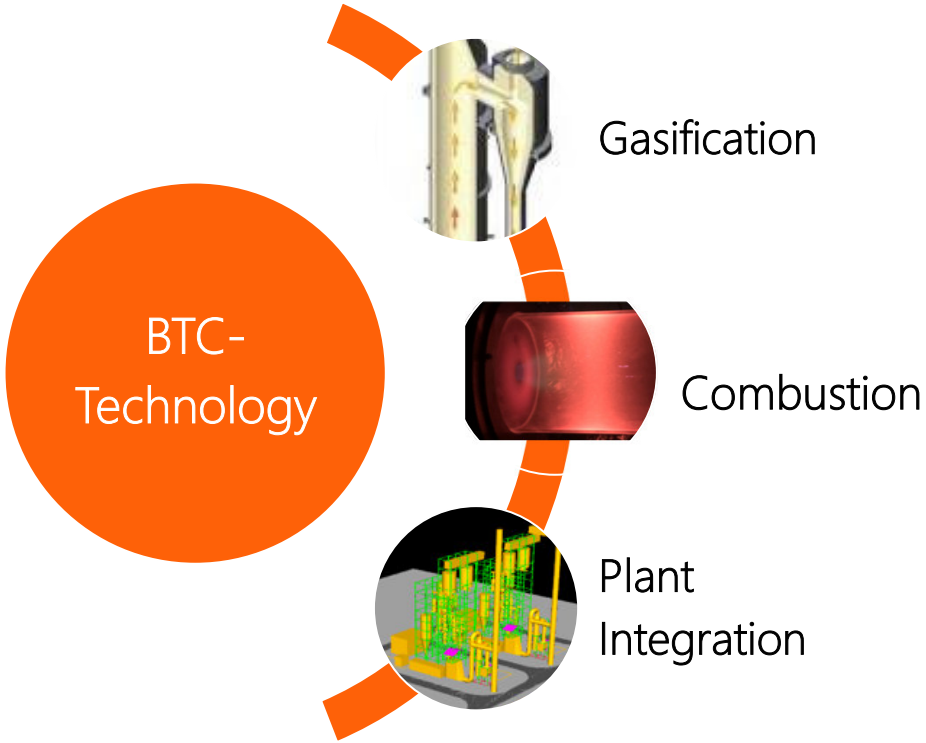
PHOENIX'S ROLE AND TECHNOLOGY

- Develop, design and supply
  - biomass gasification system
  - combustion system
  - plant integration

- Catalyse the partnerships and developments needed to commercialise the BTC technology



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BUILDING ON BIGCC EXPERIENCE

- Värnamo demo plant in Sweden (closed 1998)
- 18 MWth, 6 MWe BIGCC system
- Pressurised gasification in CFB
- Hot gas clean-up with steam generation
- Small combined cycle

- Outcome:
  - Pressurised gasification of biomass
  - Hot gas clean-up validated at scale
  - Fuel flexibility validated at scale
  - Gas turbine operations integrated with gasifier

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