PHOENIX BIOPOWER

DOUBLING THE EFFICIENCY OF POWER FROM BIOMASS

The 60-30 Mission

Michael Bartlett

eit InnoEnergy
Knowledge Innovation Community

PROBLEM DESCRIPTION

DRIVER	RESULTING IN	NEED
Global need for CO2 reductions Transition to renewable energy Phase-out of Nuclear	Massive growth in intermittent power Lack of plannable power Collapse of traditional business models	Plannable & profitable renewable power production

PHOENIX VISION – Highly efficient, cost-effective and plannable power from biomass

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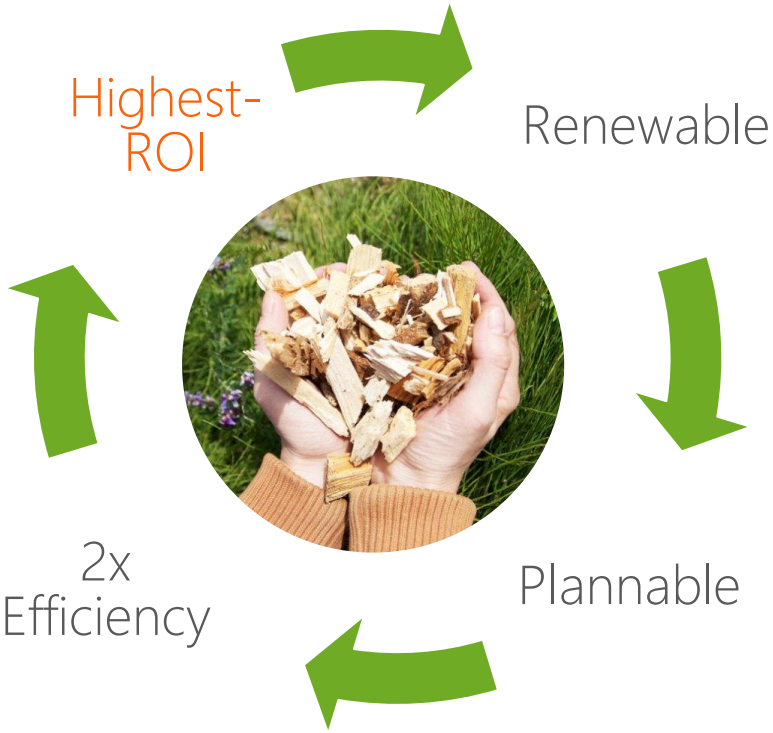
THE 60-30 MISSION:

60% ELECTRICAL EFFICIENCY BY 2030 FOR BIOMASS-FIRED POWER PLANTS



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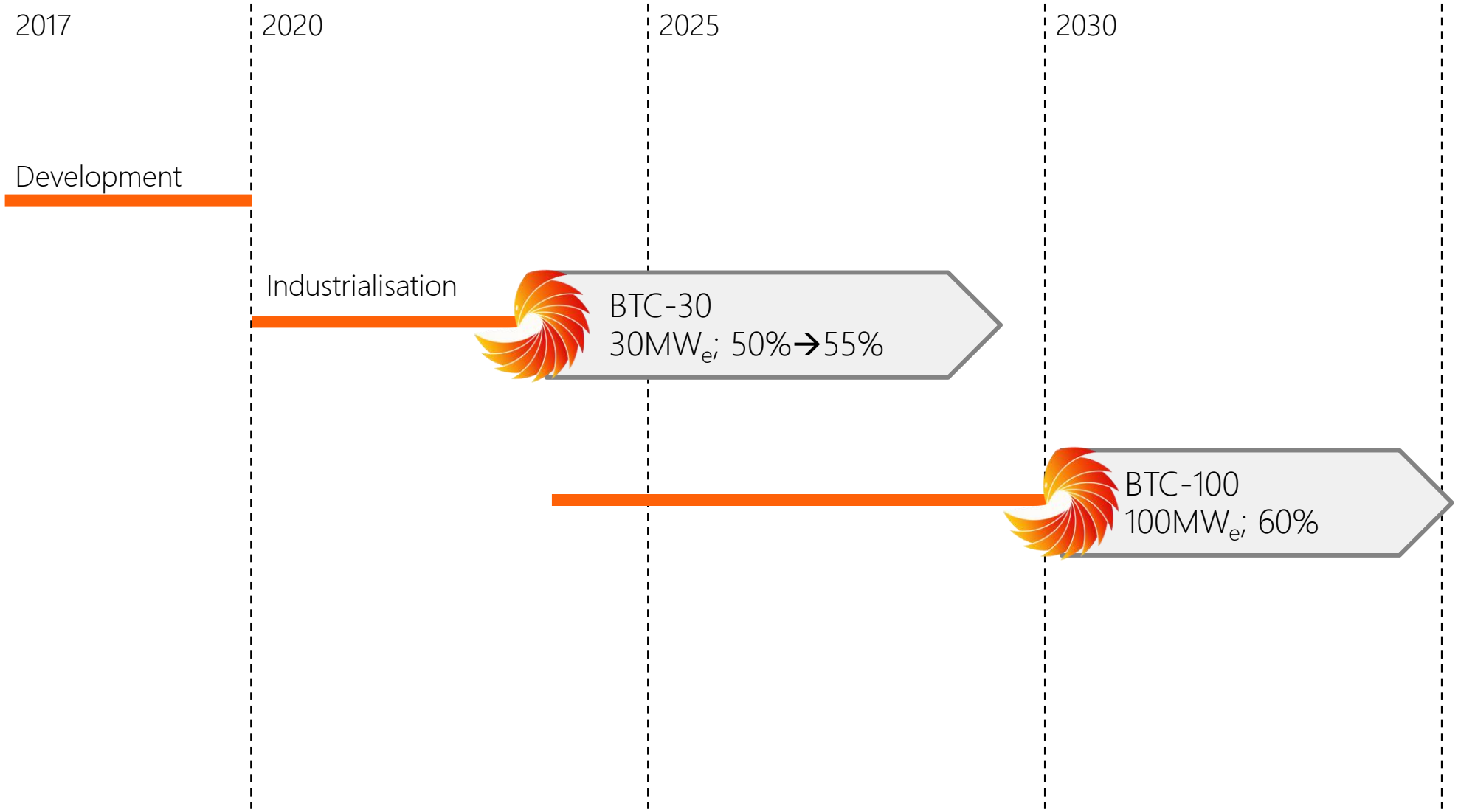
60-30 ROADMAP



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TEAM

Hans-Erik Hansson

- Co-Founder
- Inventor
- Initiator
- 30+ years experience with development in the energy industry

Michael Bartlett

- Co-Founder
- Head of R&D
- Project management and R&D background Scania, Vattenfall, GE
- PhD in Humidified Gas Turbines

Henrik Båge

- Co-Founder
- Head of Business Development
- 13 years in Cleantech
- Background in Finance industry

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PHOENIX BIOPOWER BACKGROUND & IP

- IP stems from Euroturbine AB
  - Natural gas-fired, steam-injected gas turbine
  - Development project with Vattenfall 2009-2012
  - Biomass-fired TopCycle patent application 2011
- Phoenix BioPower formed end 2016 with new leadership team & biomass focus
  - KIC InnoEnergy 2017
  - Development started

Protection mechanism	Background IP in Partners
Patents	• 5 patents: 3 gas turbine, 2 gasification + gas turbine • 16 applications in EP, US, CN, JP, RU • 8 granted, 8 pending • Process and plant configurations
Know-how	• Personnel, results, models, reports etc from 3M€ project with Vattenfall • Leveraging : 3 M€ wet combustion R&D at TU Berlin, 3 M€ biomass gasification R&D at RISE ETC

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INTRODUCING THE BTC PLANT

The Biomass-fired TopCycle Plant

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THE BTC TECHNOLOGY – BASIC PRINCIPLES

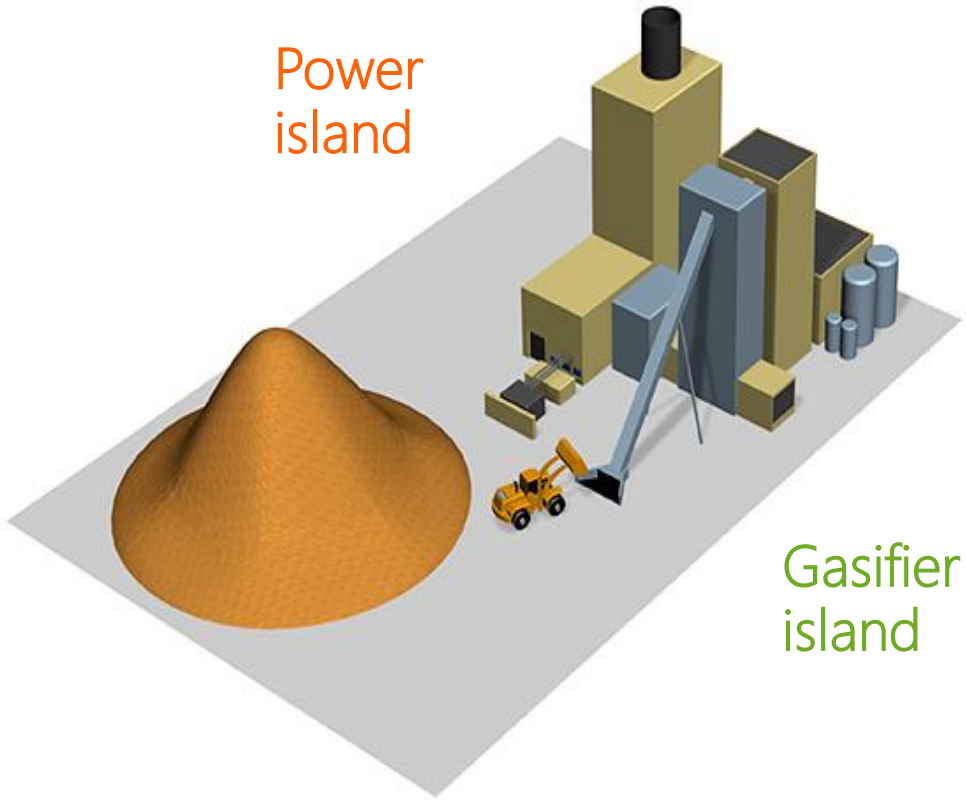
Biomass gasification at high pressure integrated with a steam-injected gas turbine.

Features:

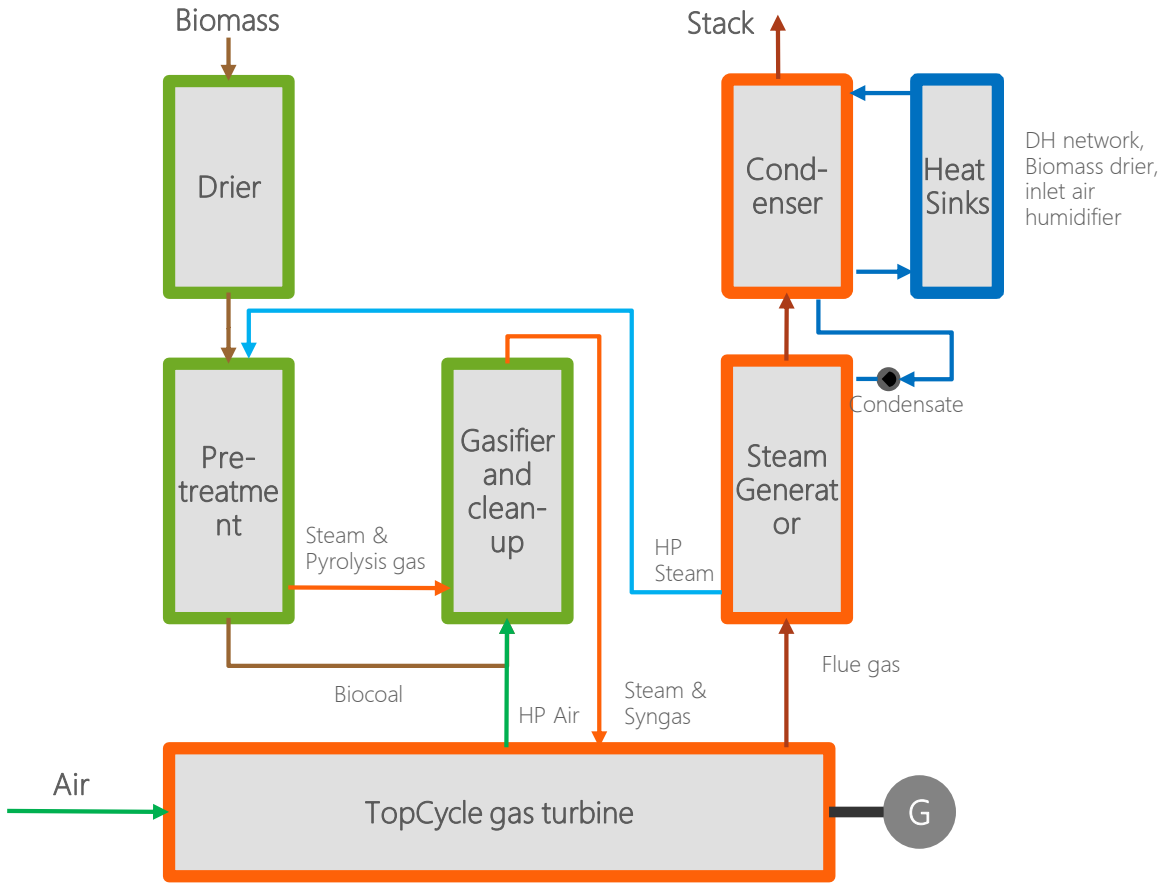
- High pressure operation
- Massive steam injection
- TopCycle gas turbine
- BTC heat integration

THE BTC PLANT FOR CHP AND POWER GENERATION MARKETS

Plant sketch



Process



HOW DOES THE BTC GENERATE VALUE?

BTC TARGETS

60%

electrical efficiency at 100 MWe

110%

total efficiency with district heat

40%

lower marginal cost in powergen

40%

lower LCOE in CHP

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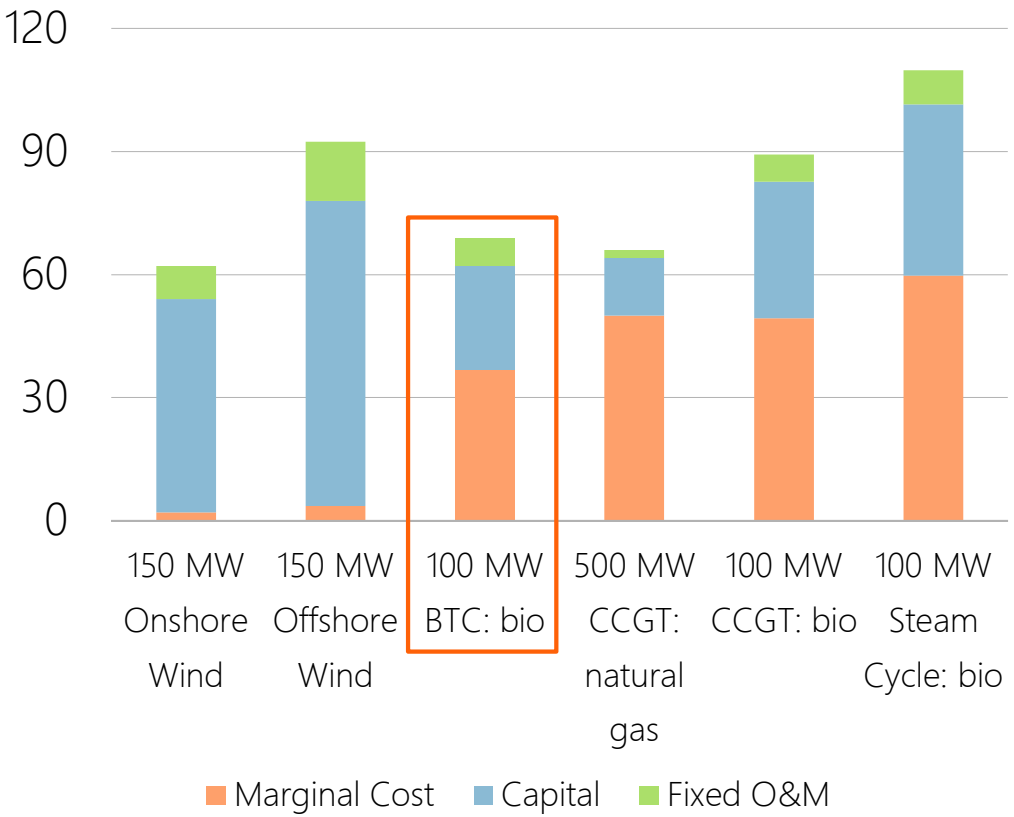
BTC OPPORTUNITY FOR POWER GENERATION (1.)

2030 Levelised Cost of Electricity, €/MWh[1]
No taxes, subsidies, heat income

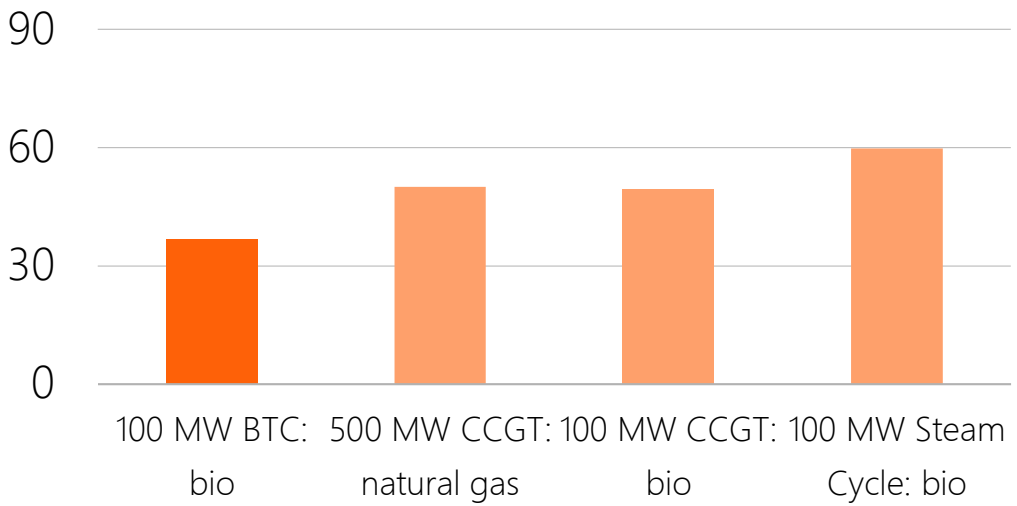


- "Conventional" LCOE at wind-parity
- Market value of BTC power will be higher
  - Wind = 40-85% average annual power price
  - Bio = 100-120% [2]
- Grid services potential for further income

1. All thermal plants 6000h/a, onshore 2500h/a, offshore 3500 h/a
2. IEA: NETP 2016 report. Profu: NEPP, Fjärrsyn, Pathways reports

BTC OPPORTUNITY FOR POWER GENERATION (2.)

2030 Short-run Marginal Cost of Electricity, €/MWh[1]
No taxes, subsidies, heat income

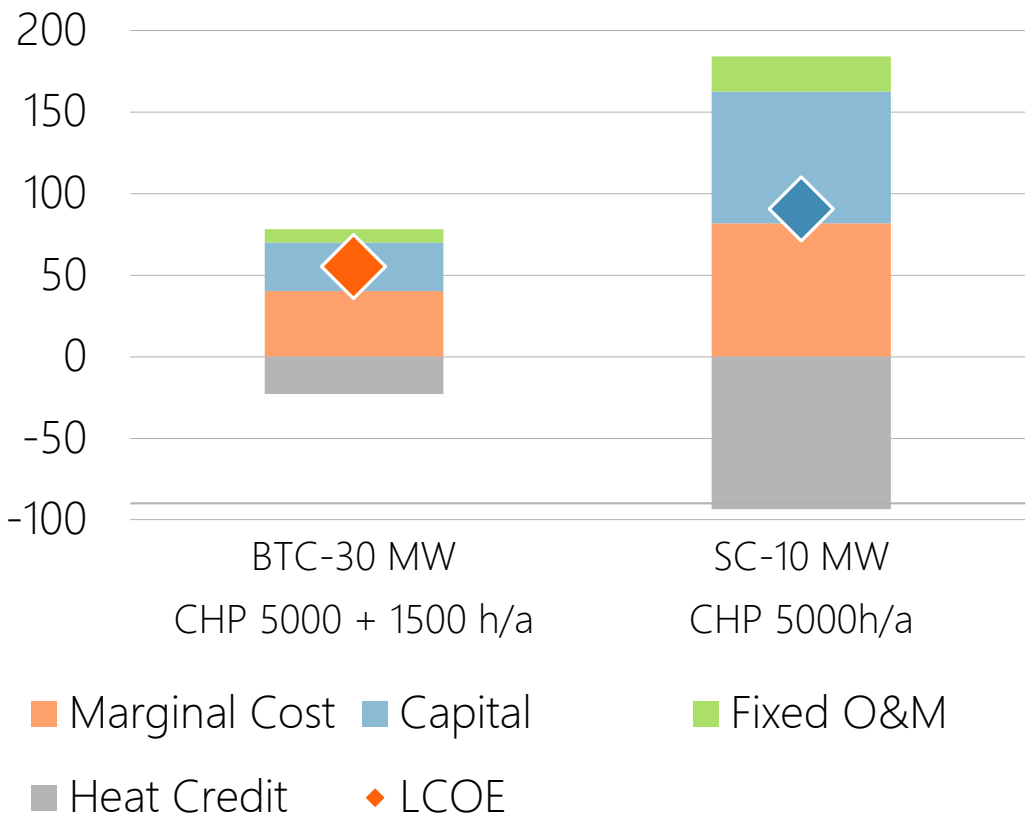


- Operating hours will be higher
  - BTC lowest marginal cost of plannable power
  - Marginal cost 40 €/MWh, no subsidies
  - NG will have carbon dioxide penalties

1. All thermal plants 6000h/a, onshore 2500h/a, offshore 3500 h/a. 20€/MWh biomass price

HIGH-VALUE BTC OPERATION WITH CHP

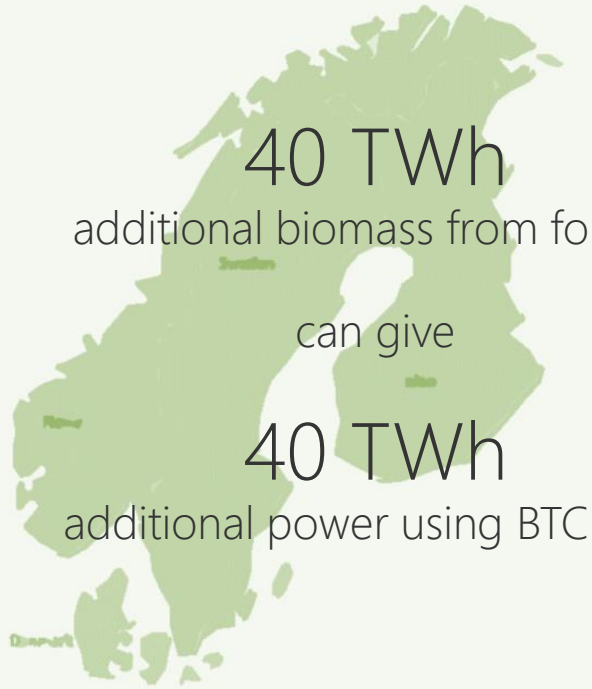
2030 Levelised Cost of Electricity, €/MWh[1]
27 MW heat delivery. No taxes, subsidies



- 3 times as much power delivered
- 40% lower LCOE → 56€/MWh no subsidies
- Marginal cost halved ~40€/WMh no subsidies
- Capital costs halved
  - Scaling effects (10 vs 30 MW)
  - High efficiency

1. 32 €/MWh heat credit, 5000h/a steam cycle. 6500 h/a BTC due to low marginal cost. BTC with 5000/h gives 60 €/MWhe

100% MARGINAL EFFICIENCY FROM SCARCE BIOMASS



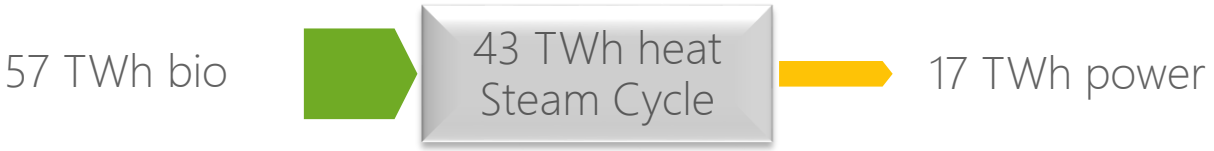
40 TWh
additional biomass from forests

can give

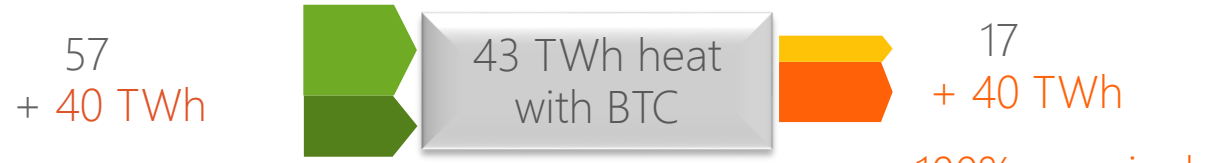
40 TWh
additional power using BTC CHP

Potential for sustainable increase in forest harvest = 60-240 TWh/a

Baseline: conventional CHP
30% el. / 105% total. 5000 h/a

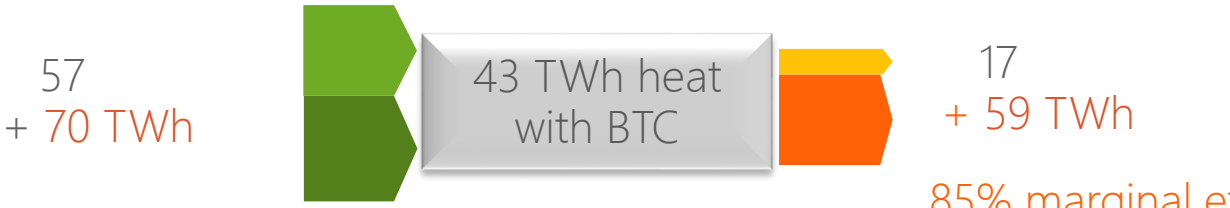


Case 1: BTC CHP
60% el. / 105% total, 5000 h/a



100% marginal efficiency

Case 2: BTC CHP + Condense
60% el. / 100% total, 6500 h/a



85% marginal efficiency

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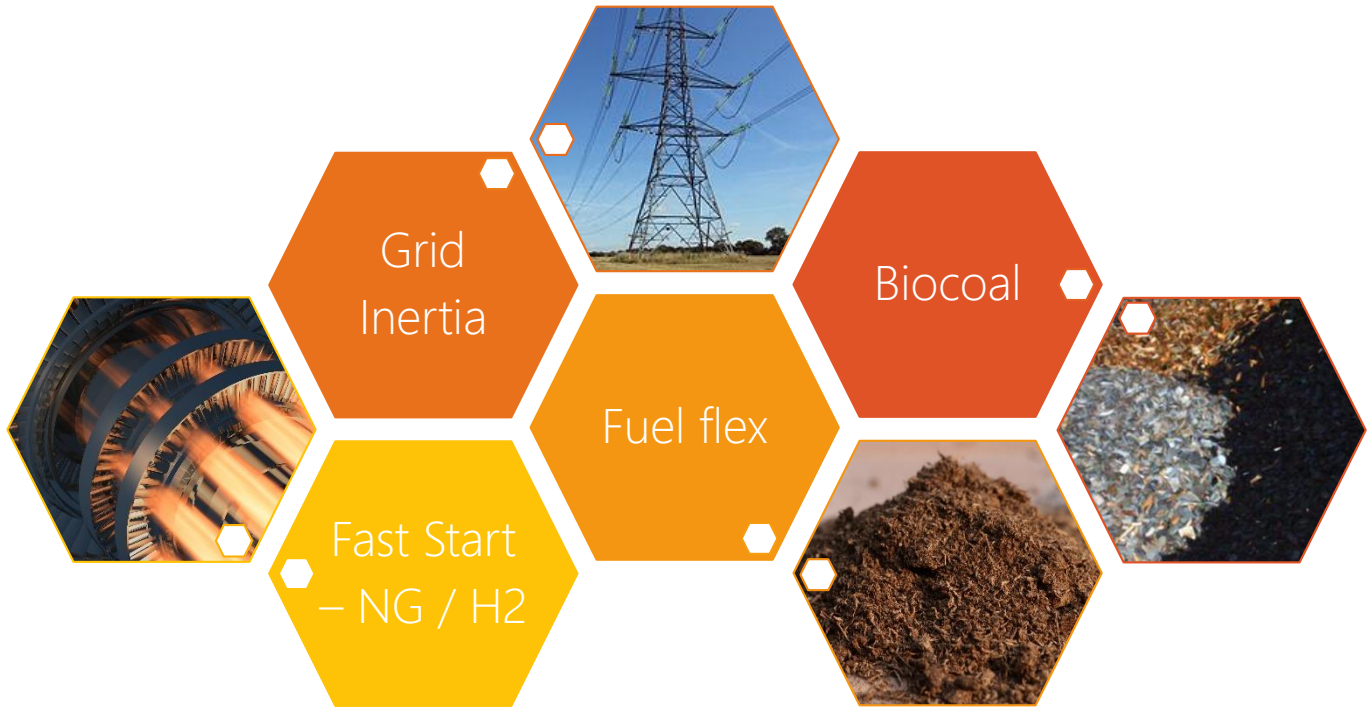
ADDITIONAL SERVICES



BTC DEVELOPMENT PROGRAM

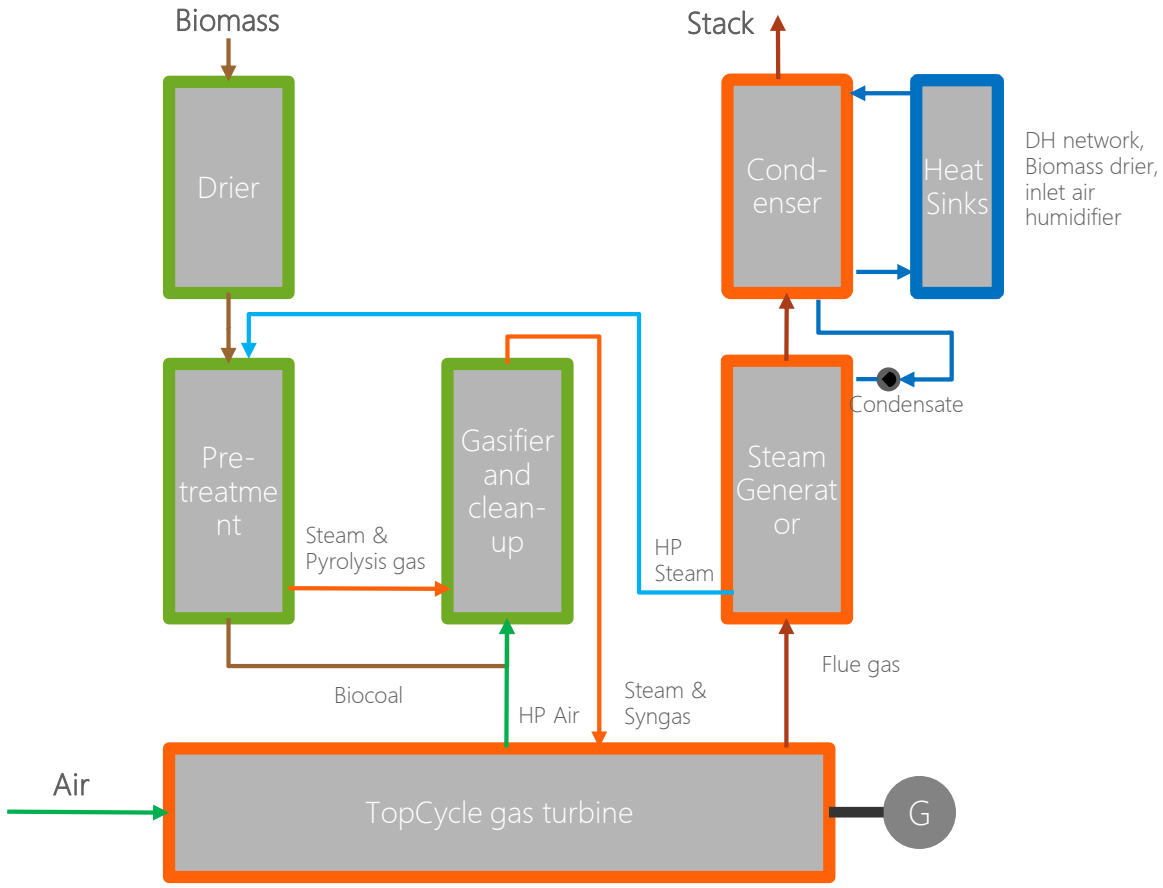
KEY DEVELOPMENT AREAS

Phoenix & Partners

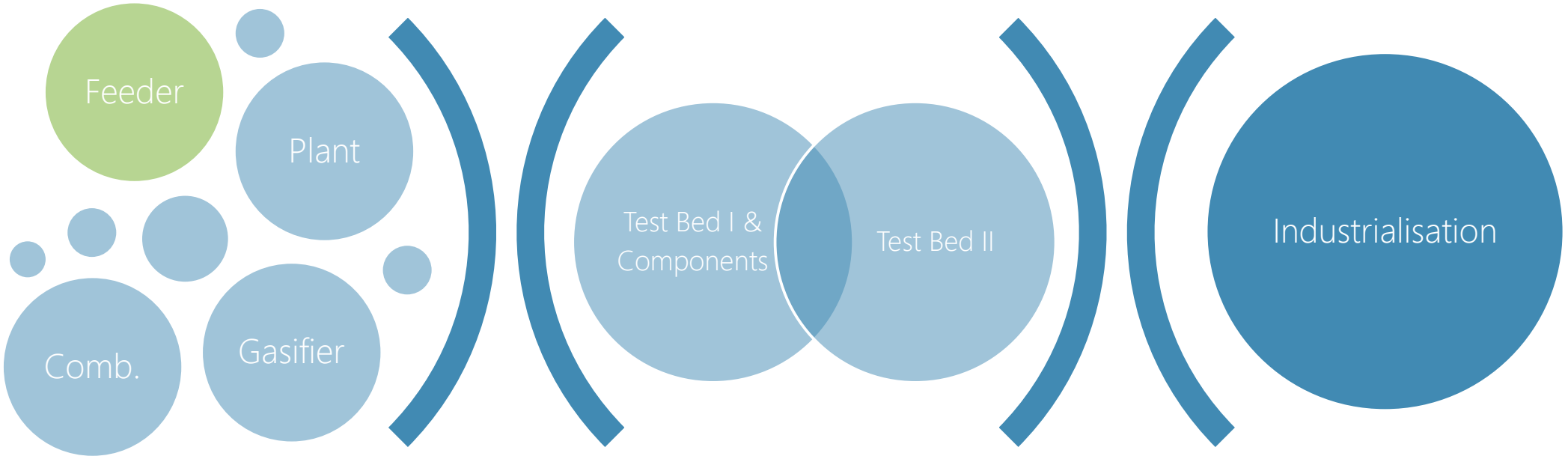
- Biomass pre-treatment
- Gasification with partial quench
- Gas turbine combustor
- Plant and integration

Partners

- High pressure GT expander
- GT integration & packaging



PROGRAMME OUTLINE



Phase 1: Feasibility
2017-2018

Phase 2: Development
2018-2020

Phase 3: Industrialisation
2021-2023

Component development 2017-2020

Test Bed 200kW_fuel 2018-2020

Test Bed 5MW_fuel 2020

Prototypes Atm <> Pressurised 1/200 scale

Rigs at TU Berlin, RISE Piteå, Phoenix Finspång

Integrated system, 1/200 scale, 40 bar

Phoenix labs

Verification, 1/10 scale, 70 bar

Phoenix labs

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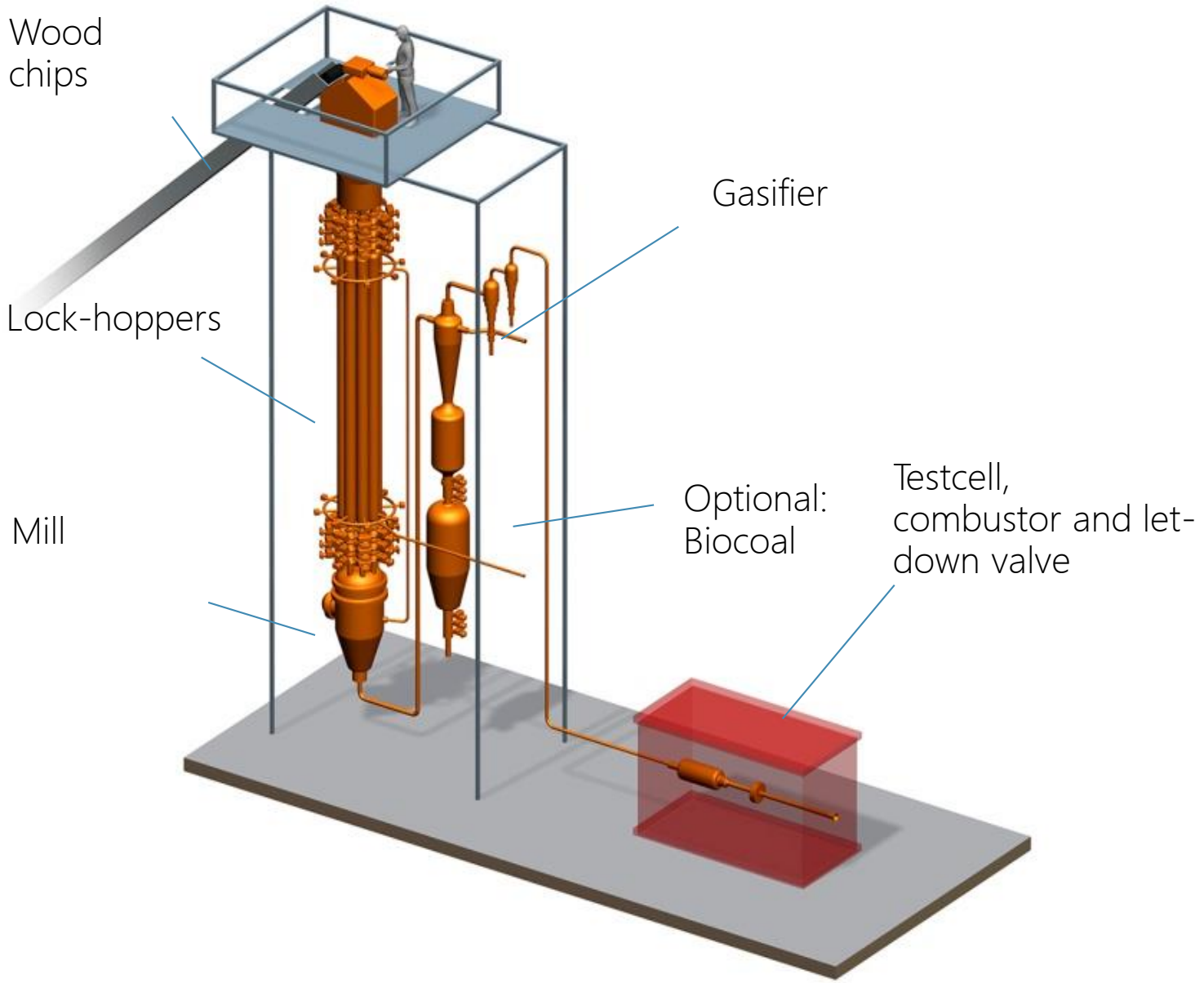
TEST BED


Wood chips
Gasifier
Lock-hoppers
Mill
Optional: Biocoal
Testcell, combustor and let-down valve

CO-OPERATION MODEL

WANT TO KNOW MORE?

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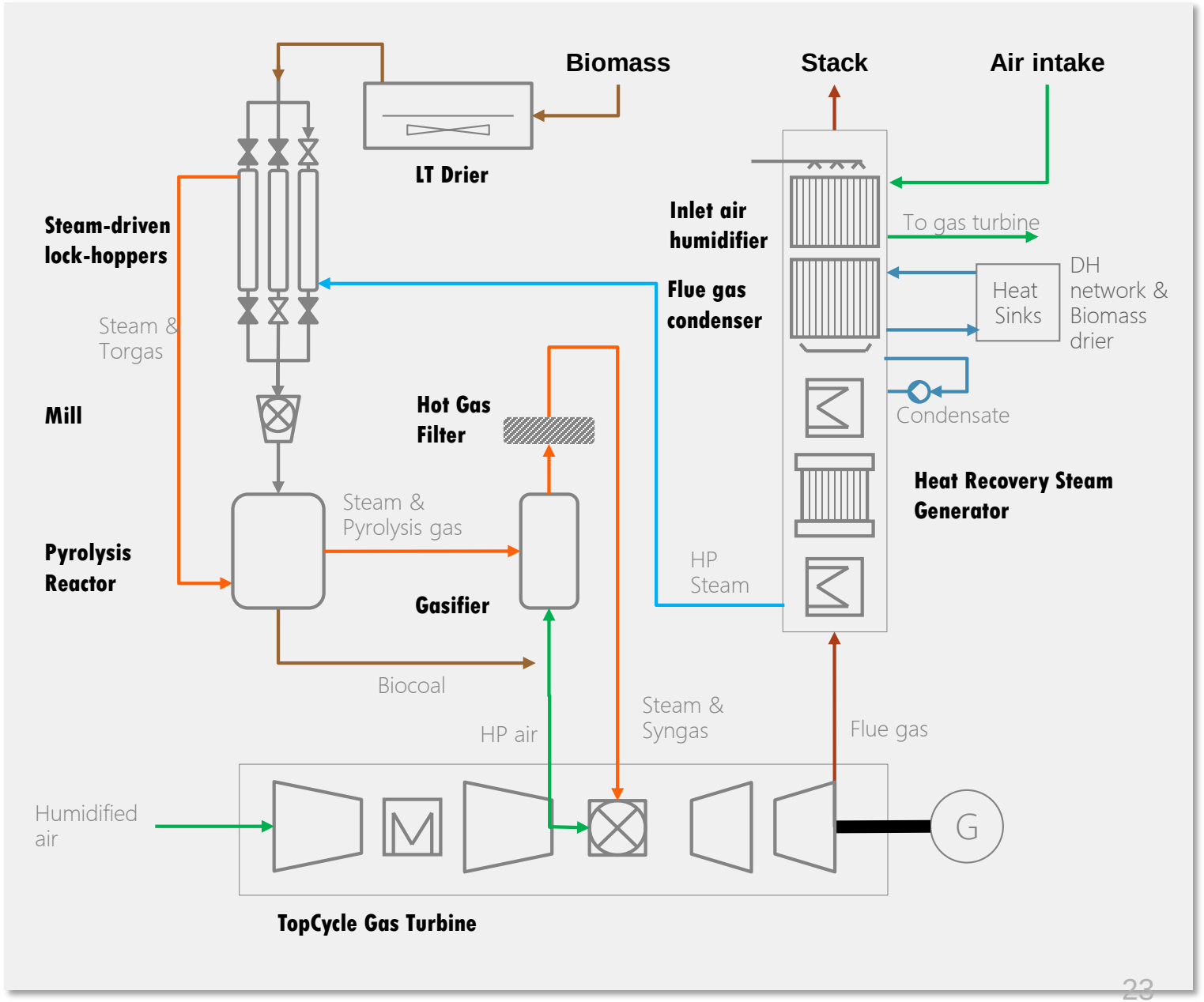
THE BTC PROCESS

- 70 bar biomass pre-treatment
  - Pressurisation, steam-driven lock-hopper
  - Torrefaction and pyrolysis
  - Milling at pressure
- Gasifier
  - Air-blown, entrained flow
  - Quenched with pyrolysis gas
  - Hot gas filter to remove particles, alkalis
- TopCycle gas turbine
  - Intercooled
  - Combustor with 3 MJ/Nm3 fuel & lambda 1,1
  - 50% vol. steam in expander
  - Steam and air cooled
- Heat recovery
  - Single pressure HRSG
  - SCR
  - Flue gas condenser providing heat at 78C
  - Condensate recovery and treatment



60%: CLIMBING THE EFFICIENCY LADDER

1. Move from steam cycle
   - Advanced gas turbine cycle efficiencies (53% NG)
2. Optimise TopCycle with gasifier exit heat
   - Increases combustor inlet temperature
   - Saves fuel and increases efficiency
3. Dry biomass with waste heat from flue gas condenser
   - Upgrades fuel more efficiently compared to steam
4. Increase gasification inlet temperature
   - Cold gas efficiency increase
5. Increase the turbine firing temperature (scale-up)