Defossilising the energy supply of a chemical production site

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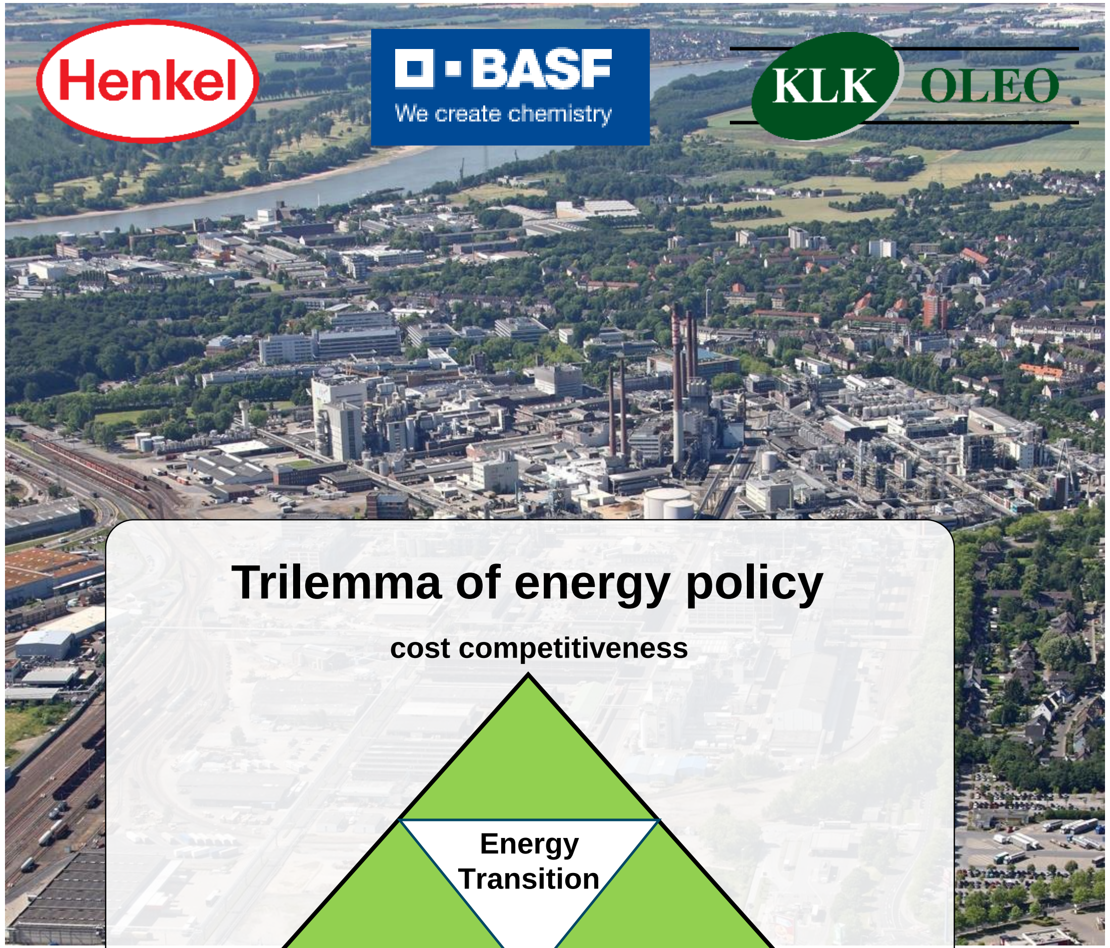
Agenda

- Motivation and overview project StoREN
- Concepts, boundary conditions and methodology
- Results
- Conclusions

Motivation and overview project StoREN

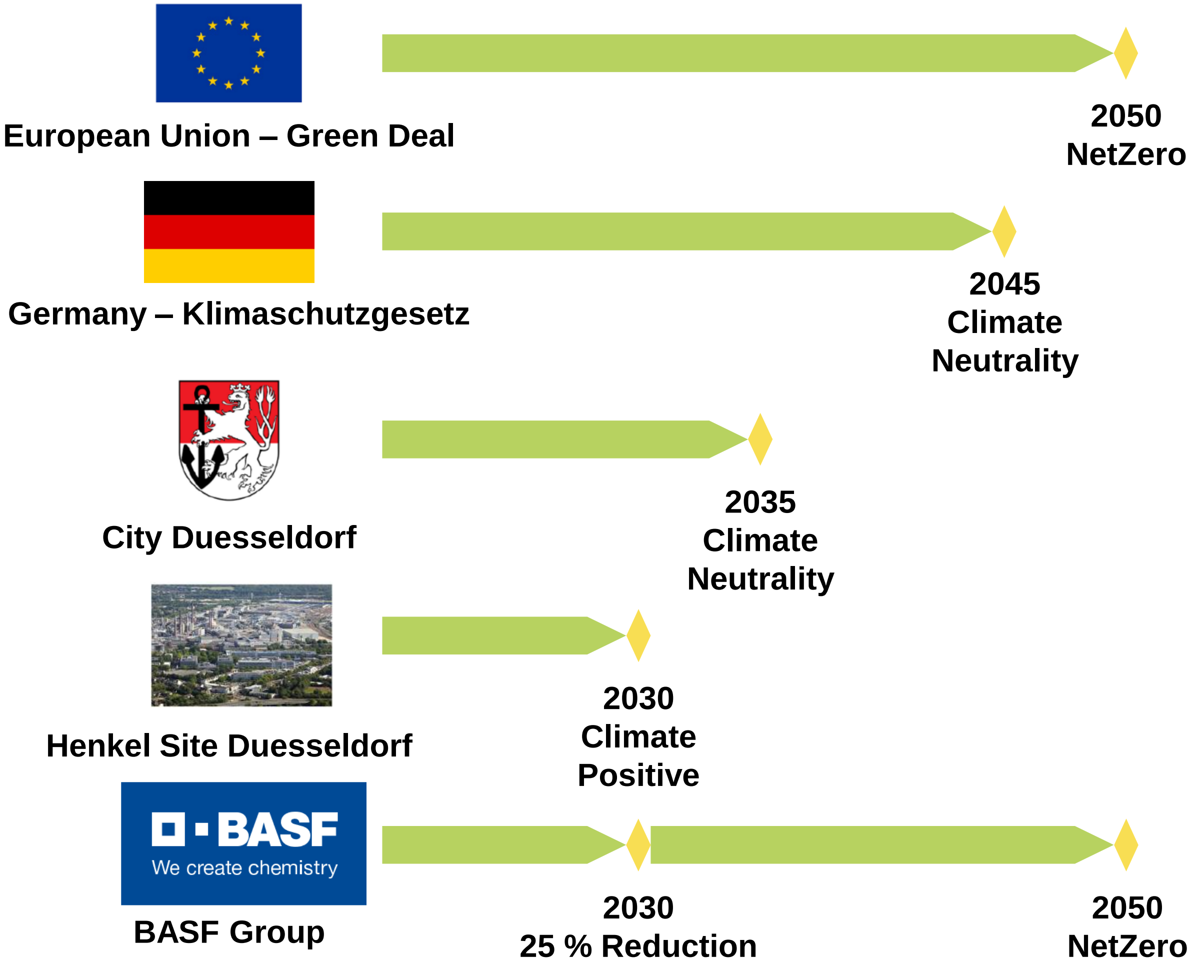
Motivation

Chemical production site Duesseldorf-Holthausen with power plant



source: BASF

NetZero Roadmaps Stakeholders



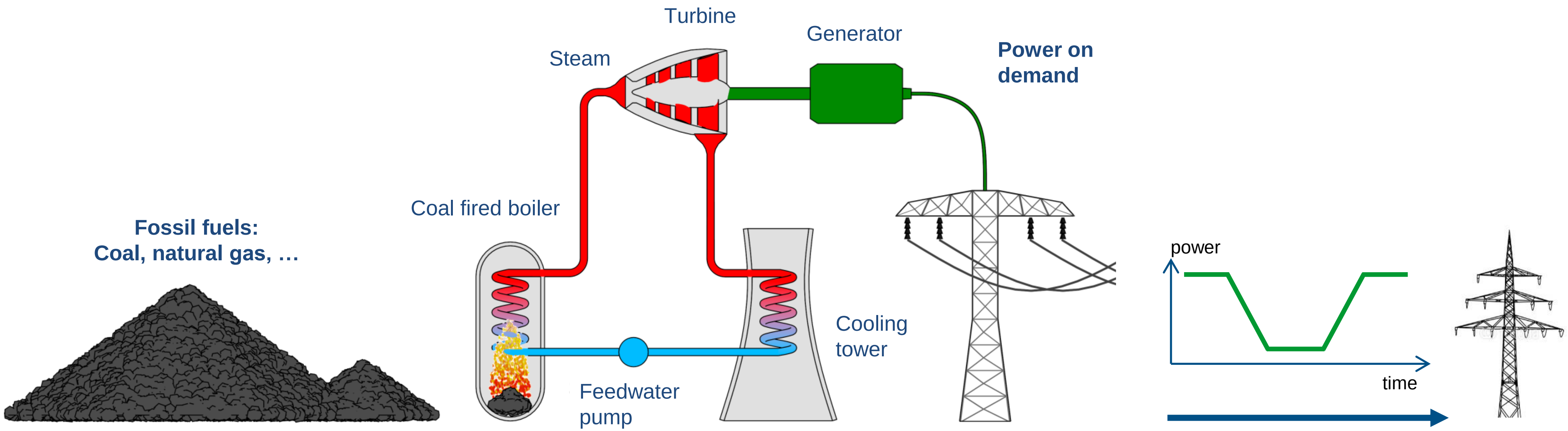
StoREN – Project overview

- Overall goal: **development and demonstration of CO2-free electricity and heat generation at the Holthausen industrial park** through electrification (power-to-heat and thermal storage) and the use of CO2-free fuels.
- The focus of this project is the **conversion of the existing industrial power plant** in Holthausen into a **CO2-free thermal power plant**.
- To minimize the project risks, a **2-phase** approach was adopted:
  - **Phase 1: Proof of techno-economic feasibility → completed**
  - Phase 2: Demonstration → in preparation, funding necessary
- Phase 1: **various concepts** using renewable energy sources were **developed and analyzed**, which were defined on the basis of **thermal storage power plants** and **other innovative technologies**.
- The focus here was on ensuring **short-term implementability** and **bankability** despite the innovative use of technology.
- The **overall goals for the energy supply** are **CO2 neutrality**, **security of supply**, **economic efficiency** and a high degree of planning security for the future (**resilience**).

Vorhaben	**StoREN – Phase 1** Dekarbonisierung der Strom- und Wärme-erzeugung mit Erneuerbaren im Industriepark Holthausen mit Wärmespeicherkraftwerken und anderen innovativen Technologien
Laufzeit	01.01.2023 bis 31.12.2023
Autoren des Berichts:	Arnulf Reitze[1], Stefano Giuliano[2], Gerrit Koll[2,] Christiane Glasmacher-Remberg[1] Eike Mahnke[1], Michel Pepers[1], Judith Jäger[2], Martin Bolten[2], Michael Dragovic[3], Frank Thom[3], Manja Ostermann[3], Philipp Pötzsch[3], Daniel Meierhöfer[3], Michael Roling[3] [1] BASF, [2] DLR, [3] Henkel
Förderung	EFO 0187A, EFO 0187B Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen

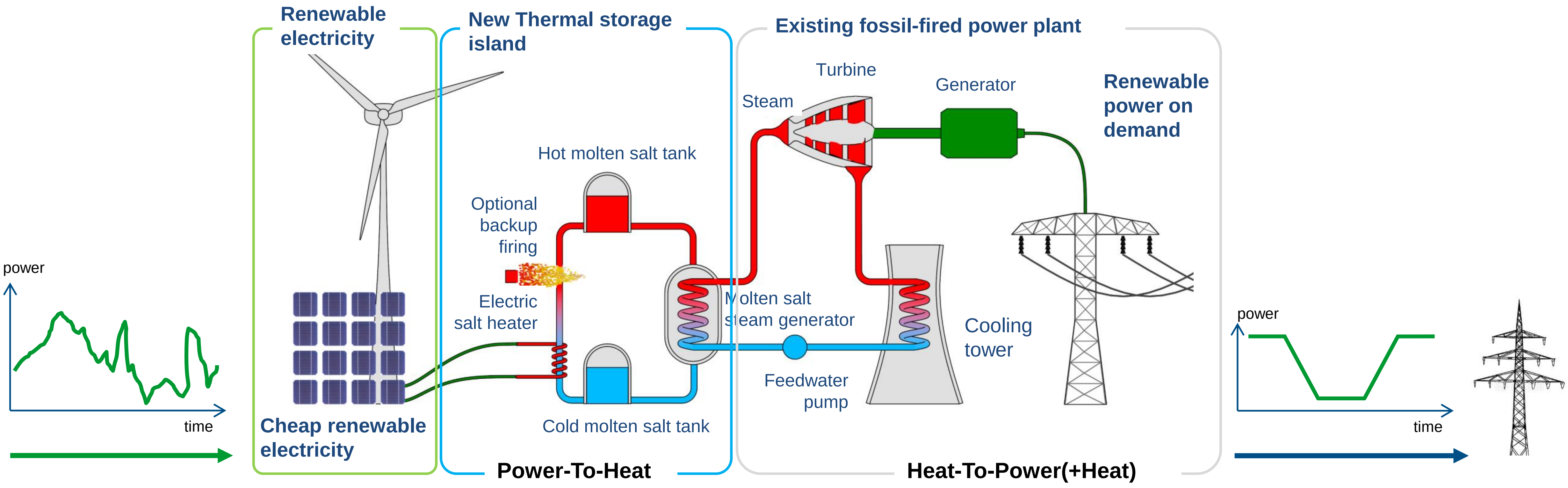
Project report available soon!

What is a Thermal storage power plant/ Carnot Battery?
Starting point: Fossil-fired power plant



- Pathways to decarbonization:
  - Electrification with green electricity
  - Fuel switch to green fuels
  - solar thermal energy
  - Combinations → hybrid

This is a Thermal storage power plant / Carnot Battery!
CC or steam power plant + Power-To-Heat + Thermal storage → renewable baseload power plant



Fluctuating renewable power generation from solar, wind etc. ➡ Fluctuating renewable power is stored in thermal energy storage ➡ Renewable power on demand (depending on storage size)

Concepts, boundary conditions and methodology

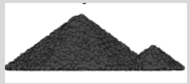
Defossilising the energy supply of an industrial park

Challenges

- Variable costs & availability
- Rising demand & prices
- CO_2 certificates & costs
- Production waste air & residues
- Emergency power backup
- Redundancy

Energy carrier

Fossil fuels



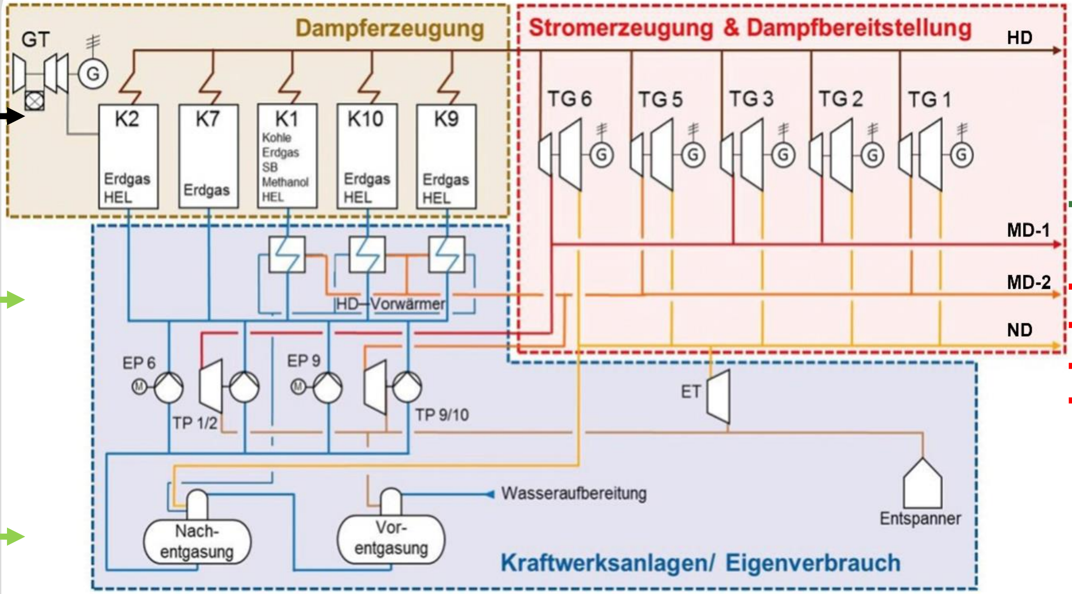
Production residues

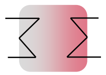
H2 / alternative green fuels

green electricity

Heat recovery

Existing fossil-fired power plant



CC	Steam-boiler	Thermal storage	E-Heater E-Boiler	Heat pump	Battery
					

+ new technologies

Energy

network Industrial park

Power

Process heat
HP
MP-1
MP-2
LP

Production

- Process optimization
- New processes

+ new processes

Requirements

- Maximum security of supply
- CO2 target achievement
- Low LCOE
- Low investment
- Resilience to energy source failure
- Low sensitivity to market changes
- Market ready technology
- Low plant complexity

Legend: existing, fossil fuels | Energy carrier for decarbonization

Source figure for existing power plant: Nina Wolter, Thomas Zekorn, Matthias Neef: Ermittlung und Prognose von Jahres-Energiebilanzen mit Hilfe stationärer thermodynamischer Prozesssimulationen am Beispiel eines Industriekraftwerks, BWK – Das Energie-Fachmagazin 6/2016

Concepts of the energy system

Two groups were defined for the step-by-step analysis of the concepts for the transformation of the existing power plant:

1. **mono-energetic concepts**: These concepts are characterized by the fact that only one energy source and one technology path is used.
2. **hybrid concepts**: These concepts are characterized by the fact that several energy sources and/or several technology paths are combined to form an optimal overall plant.

Existing	Mono-energetic concepts								
B1	M0	M1	M2	M3	M4a	M4b	M5	M6	M7
Nat.Gas CC	Nat.Gas CC	Biogas CC	H2 CC	Syngas CC	Synfuel CC	Biodiesel CC	Biomass ST	Electr. E-Boiler	Electr. ST + E-Heater + HT-Storage (CarnotBat)
	Reference	Fuel switch						Electrification	

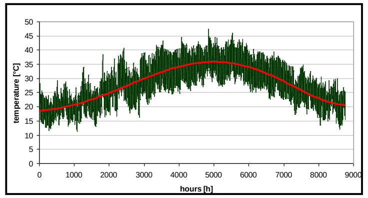
Hybrid concepts																
H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17
Nat.Gas CC	Nat.Gas CC	Biogas CC	H2 CC	Biomass ST	Electr. E-Boiler	Electr. E-Boiler	Electr. E-Boiler	Electr. E-Boiler	Electr. E-Heater + HT-Storage	Electr. E-Heater + HT-Storage	Electr. E-Boiler	Electr. ST + E-Heater + HT-Storage (CarnotBat)	Electr. ST + E-Heater + HT-Storage (CarnotBat)	Electr. ST + E-Heater + HT-Storage (CarnotBat)	Electr. ST + E-Heater + HT-Storage (CarnotBat)	Electr. CC + E-Heater + HT-Storage (CarnotBat)
Electr.	Electr. +CCS	Electr.	Electr.	Electr.	Nat.Gas	Biogas	H2	Biomass	Nat.Gas	Biogas	Biogas +HP	Nat.Gas	Biogas	H2	Biogas +HP	Biogas
Reference		Fuel switch			Electrification without power plant (GT, ST)							Electrification with power plant (GT, ST)				

CC: Combined Cycle; ST: Steam Turbine; HT-Storage: High Temperature Thermal Storage;
CCS: Carbon Capture Storage; CarnotBat: Carnot Battery; HP: low temperature Heat pump

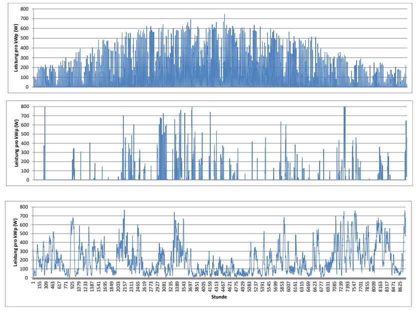
Systems Modelling
A structured approach to techno-economic evaluation

- *Definition of boundary conditions*
- *Conceptual brainstorming*
- *Concepts pre-selection*
- *Detailed plant design*
- *(Multi-) annual simulation*
- *Design optimization*
- *Techno-economic evaluation*
- *Final Assessment and Ranking*

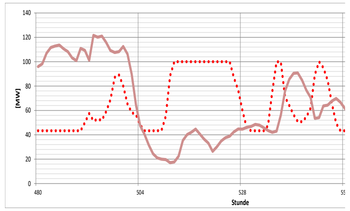
Climate data

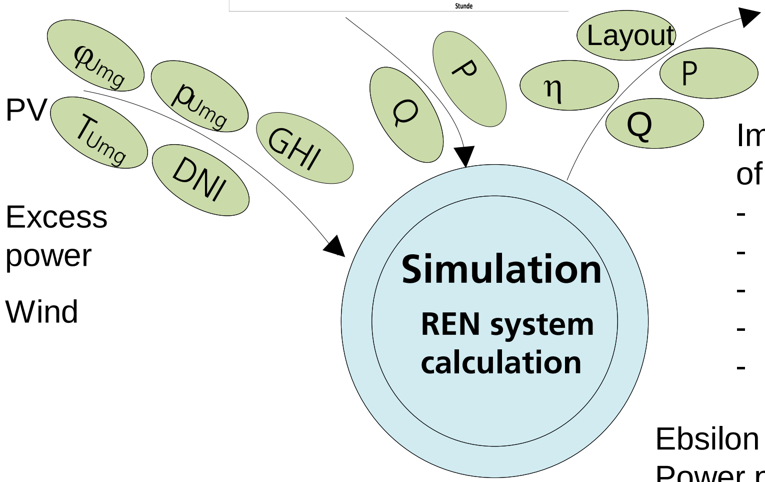


Renewable resource data



Load profile



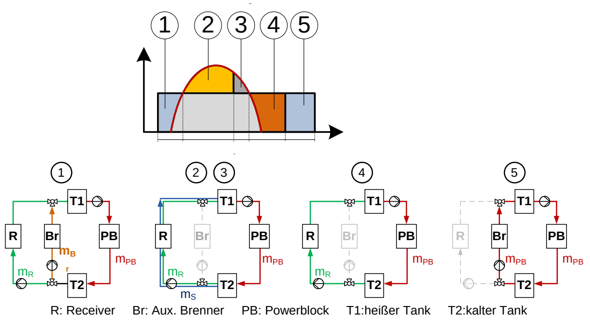


Simulation output

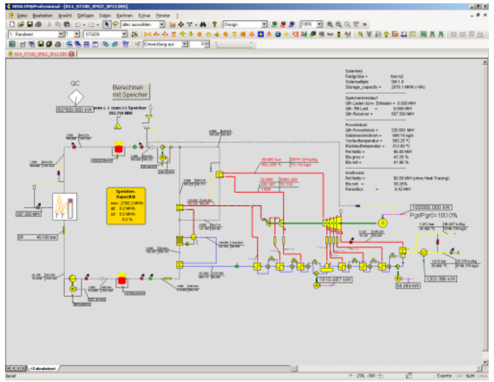
Implementation and coupling of new technologies:
- Thermal Storage
- Battery
- Heat pump
- Heat recovery
- etc.

Renewable Energy Systems

Operational strategy

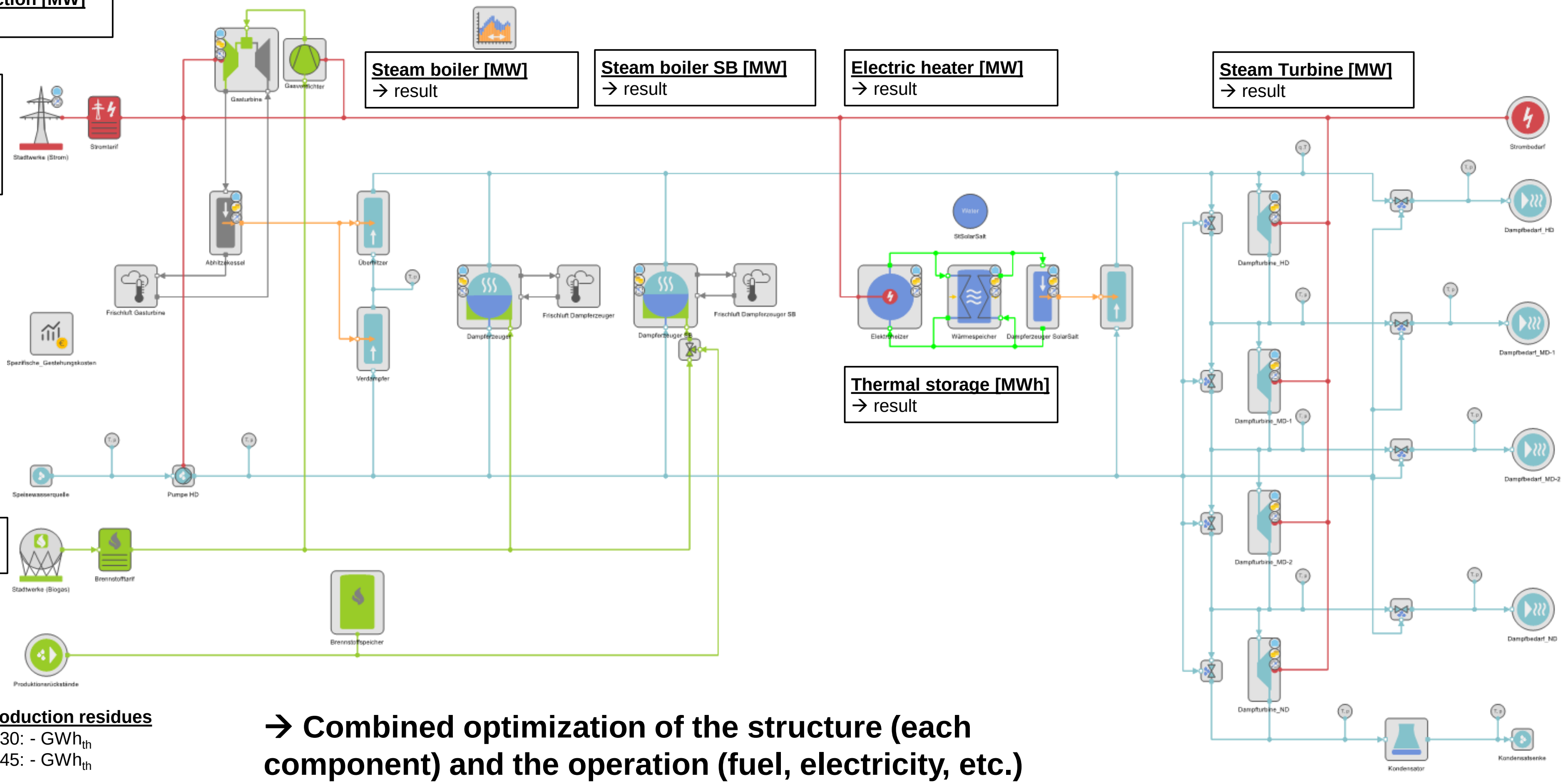


Ebsilon model
Power plant simulation for specific performance points



Example of a energy system model

CC Carnot Battery with Biogas + electricity grid: Transformation from 2030 to 2045



Gas Turbine [MW]
→ result

Grid connection [MW]
→ result

Power supply [GWh$_{el}$]
→ result
(2030, 2045:HPFC, PPA Baseload, PPA PAP S, PPA PAP SW)

Steam boiler [MW]
→ result

Steam boiler SB [MW]
→ result

Electric heater [MW]
→ result

Steam Turbine [MW]
→ result

Thermal storage [MWh]
→ result

Power demand
2030: --- GWh$_{el}$
2045: --- GWh$_{el}$

Heat demand HP
2030: --- GWh$_{th}$
2045: --- GWh$_{th}$

Heat demand MP-1
2030: --- GWh$_{th}$
2045: --- GWh$_{th}$

Heat demand MP-2
2030: --- GWh$_{th}$
2045: --- GWh$_{th}$

Heat demand LP
2030: --- GWh$_{th}$
2045: --- GWh$_{th}$

Fuel supply [GWh$_{th}$]
→ result

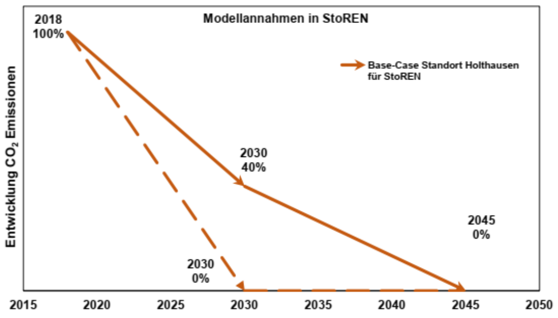
Production residues
2030: - GWh$_{th}$
2045: - GWh$_{th}$

→ Combined optimization of the structure (each component) and the operation (fuel, electricity, etc.)

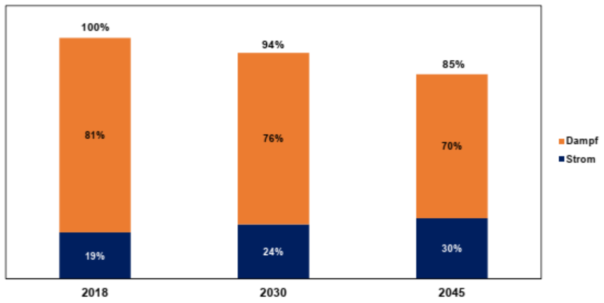
Specifications and boundary conditions

Detailed Databook with all technical and economic specifications

CO2 reduction goals and model years: Basis 2018 + 2030 + 2045



Current status and demand analysis industrial park Holthausen



+ load profiles steam and power demand 2018 and 2030/ 2045 (forecast)

StoREN Spezifikationen und Rahmenbedingungen (Lastenheft, data book):
AP2: Bedarfsanalyse und Projektrandbedingungen

Inhaltsverzeichnis

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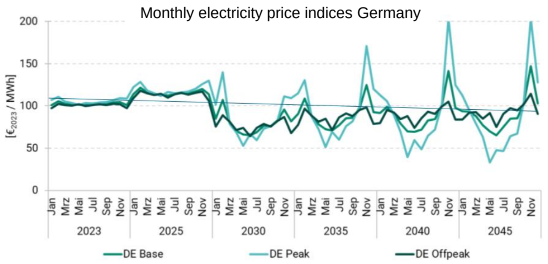
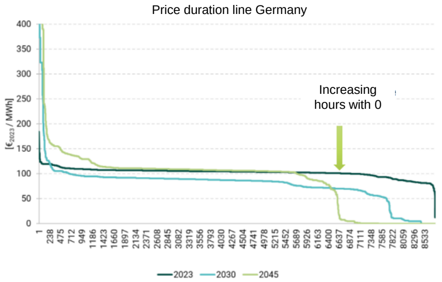
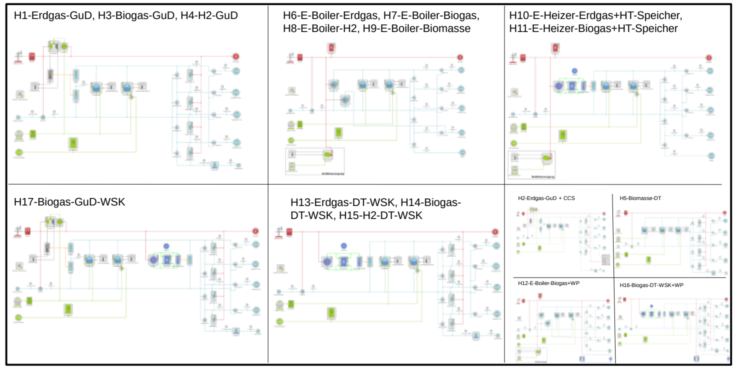
Electricity cost (HPFC, green PPA) with charges and grid fees

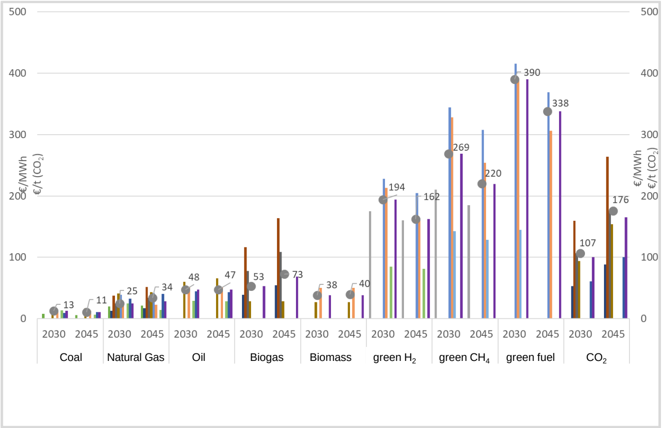




technical and economic specifications for each concept



Fuel cost and CO2 cost



Fuel prices used in StoREN

fuel:2030/45

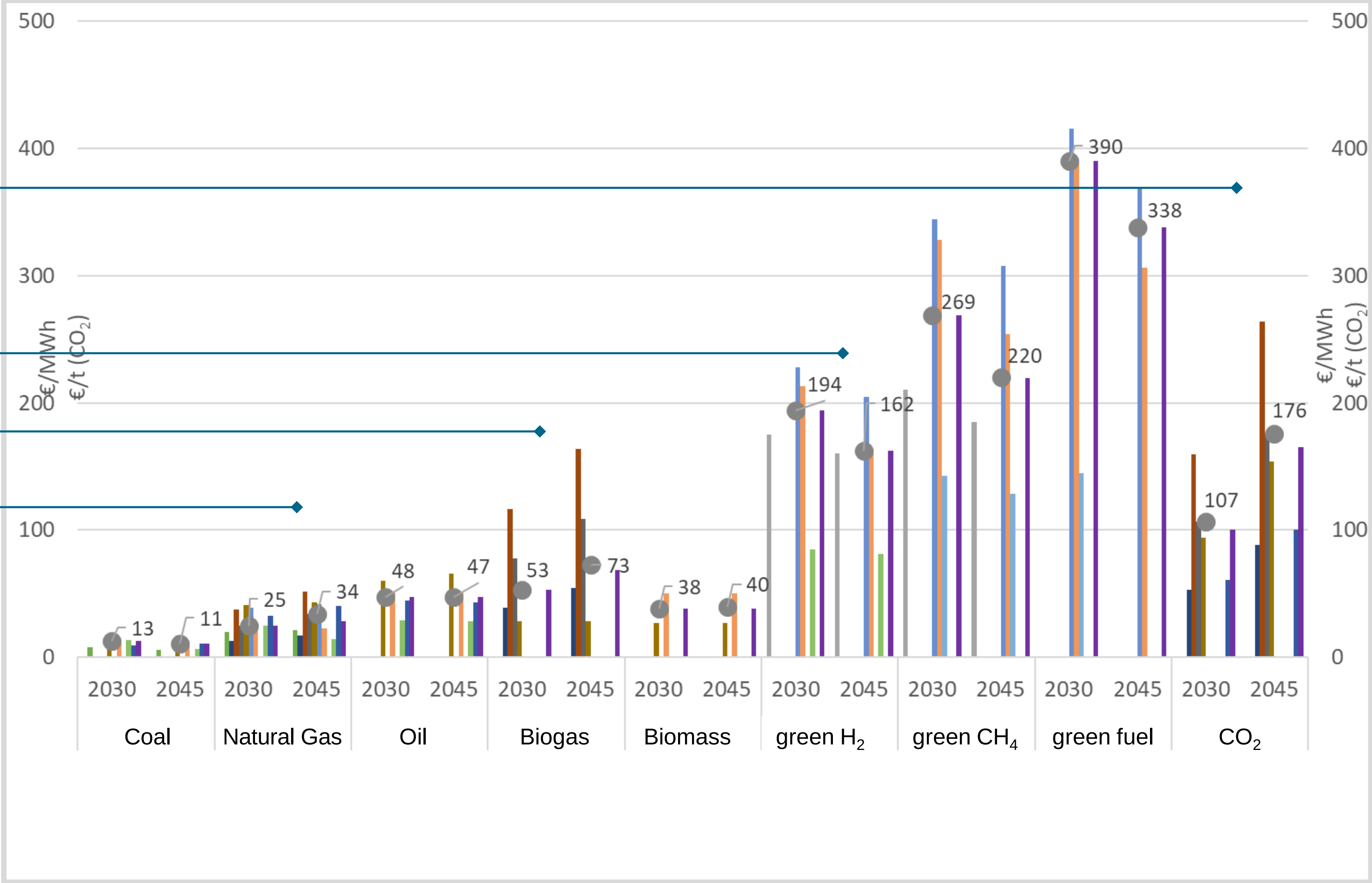
CO_2 :107/176 €/t

in €/MWh

green H_2:194/162

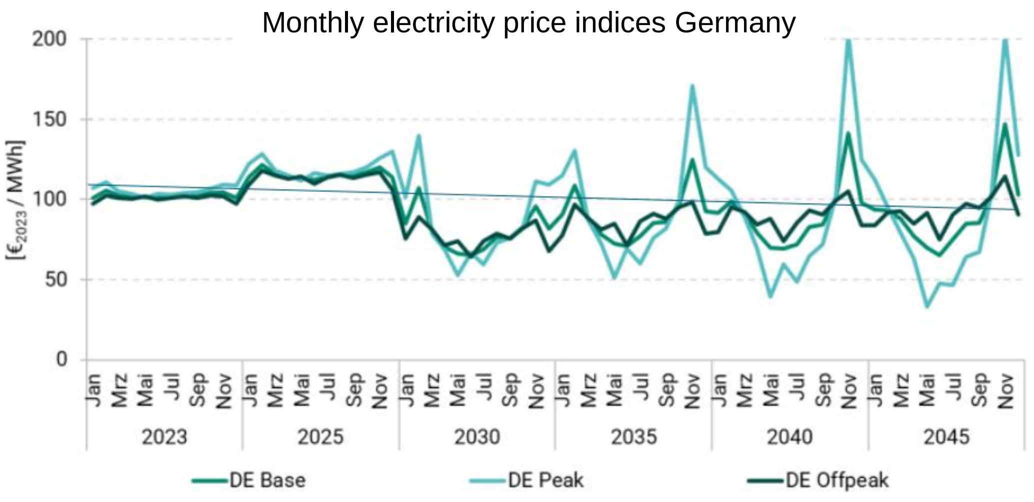
Biogas: 53/75

Natural Gas: 25/34

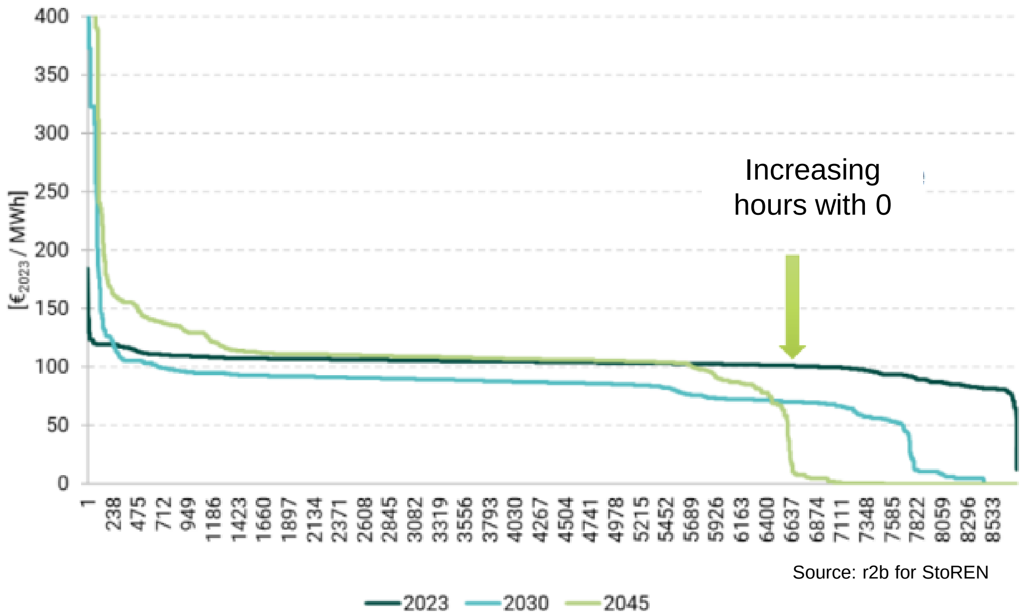


Electricity prices (HPFC day-ahead, green PPA) used in StoREN

Hourly price forward courve (HPFC)



Source: r2b for StoREN



Source: r2b for StoREN

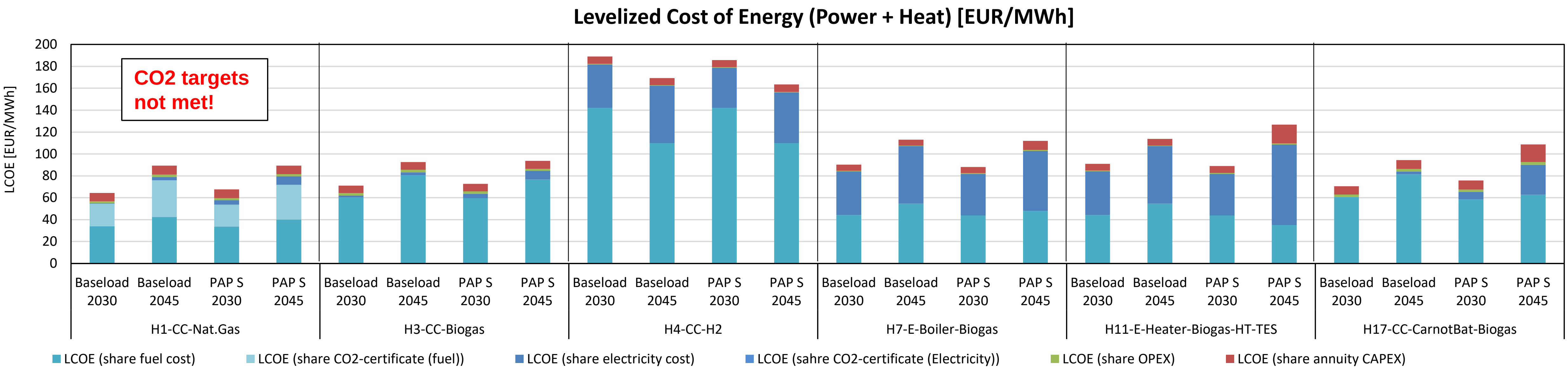
Green Power Purchase Agreement (PPA)

	Solar (large ground-mounted PV)			Combination Wind Onshore, Offshore, large ground-mounted PV		
Price component [€$_{2023}$/MWh]	2023	2030	2045	2023	2030	2045
Base price	102.50	79.49	90.53	102.50	79.49	90.53
Market value	99.62	55.95	45.00	99.43	63.45	59.43
PPA price pay-as-produced	**103.78**	**57.45**	**43.31**	**103.36**	**65.79**	**59.55**
PPA price baseload	**137.41**	**104.84**	**116.00**	**137.17**	**105.68**	**117.81**

Source: r2b for StoREN

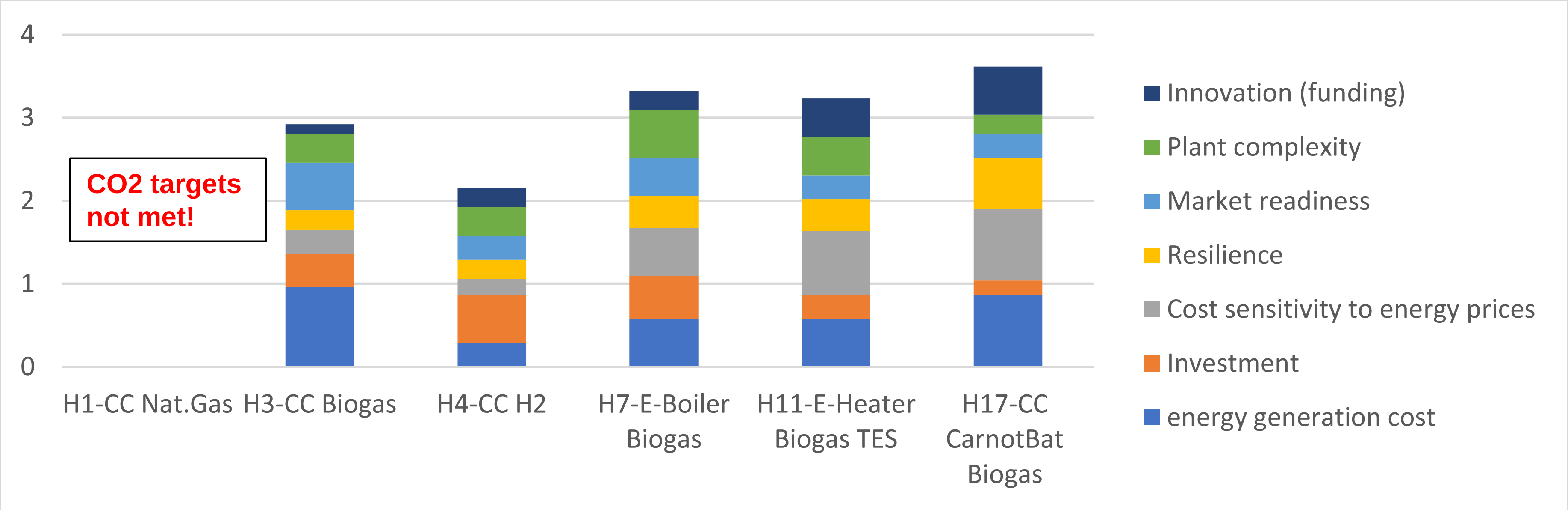
Results

Energy generation cost (LCOE) of hybrid concepts



- The energy costs (fuel + electricity) clearly outweigh the annuity + operating costs
- H1 (natural gas), H3 (biogas) and H17 (CarnotBat biogas) close together, e-boiler/ e-heater (H7, H11) variants slightly behind (as no GT)
- Natural gas price remains low (according to scenarios), but LCOE similar to biogas due to CO_2 costs.
- In 2030, more fuel is used due to the still low fuel prices, in 2045 electricity prices continue to fall, therefore more electricity is used (for concepts with e-boiler/ e-heater).
- H4 (hydrogen) has significantly higher generation costs

Assessment and final ranking of concepts



- Must requirements: compliance with CO_2 targets, security of supply given
- H1 was not included in the assessment due to non-compliance with CO_2 targets
- Variants H7, H11 and H17 perform best and are close to each other
- H17 is the best-rated variant due to its high resilience and comparatively low cost sensitivity to energy price changes
- H4 is the worst rated due to high energy production costs

Summary

Conclusions

- Various concepts for the **defossilising** the energy supply of the Holthausen **industrial park with Carnot Battery and other innovative technologies** were analyzed.
- Extensive **techno-economic optimizations and parameter studies** with various energy sources were carried out for the model years 2030 and 2045. This was based on the extensive **system and modelling expertise from the CSP sector**.
- Boundary conditions: limited (2030) and no (2045) fossil fuels due to CO2 achievement, increasing volatility in electricity prices, tense market for green fuels
- **Natural gas variants usually cannot meet the CO2 targets** or will be less economical in future due to CO2 costs.
- Mono-energetic concepts have no advantages in terms of economic efficiency, security of supply and resilience → **Robust future energy supply systems for industry are hybrid systems** that use both green electricity and green fuels.
- By 2045, over 80% of electricity generation will consist of **renewable electricity** (PV, wind) and **prices will continue to fall**. This will make electricity the primary form of energy for heat supply → **Rapid grid expansion** is required for locations where on-site self-generation is not possible.
- 3 concepts are clearly ahead in terms of **LCOE (2030: ~70/ 2045:~90…110 €/MWh)**:
  - Combined Cycle with Biogas without storage (Var. H3) - high dependency on gas price
  - E-Boiler in combination with biogas (Var. H7) - without own electricity generation
  - Combination of both: Combined Cycle with Biogas and E-Heater and thermal storage (Var. H17) -> combination of both advantages
- **Preferred variant H17 (Combined Cycle with Biogas - E-Heater and thermal storage)**:
  low energy generation costs & optimally resilient to market changes
- For **industrial parks with sufficient space, solar resources and suitable temperature ranges**: consider **on-site self-generation with CSP/CST**!

Thank you for your attention!

contact: stefano.giuliano@dlr.de

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Project report available soon!

DLR