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0°C, but 0 CO_2 emissions? Exploring pathways to decarbonise district heating

Aurora Public Webinar

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Introducing today's speakers

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Source: Aurora Energy Research

District heating will play a key role in the German heating mix via sector coupling with power - decarbonising both poses unique challenges

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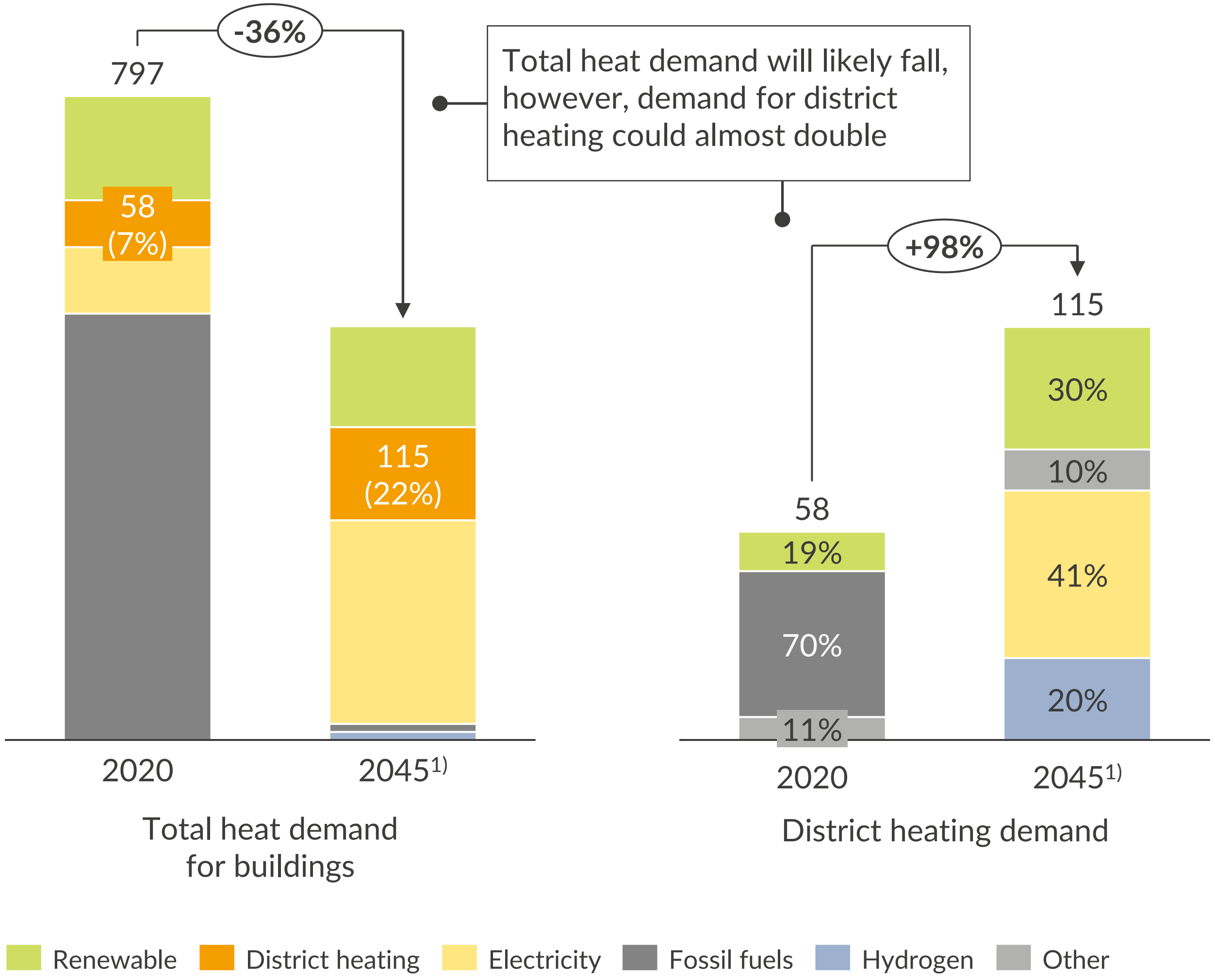
Development of heat provision by energy carrier

TWh



Key challenges and considerations

Sector coupling: power to heat

- What does increased electrification of heating imply for the power sector?
- What are the limits to the integration of heat pumps?

Decarbonisation: alternatives to fossil fuel

- How to compete against and replace fossil fuel burning as the most common way to generate heat?
- How much can heating demand for buildings be reduced with improved insulation and energy efficiency measures?
- Will district heating need to play a bigger role to enable the integration of renewable and low temperature heat sources?
- What role do municipalities play for planning future heating systems; e.g. “connection and usage obligations”?

1) Average assessment of different projections in the literature

Sources: Aurora Energy Research, AGEB, BMWi, Agora, Dena, BDI, Ariadne, AGFW

Seasonal variation in temperatures and demand requires a flexible district heating system to serve peak load at high temperatures

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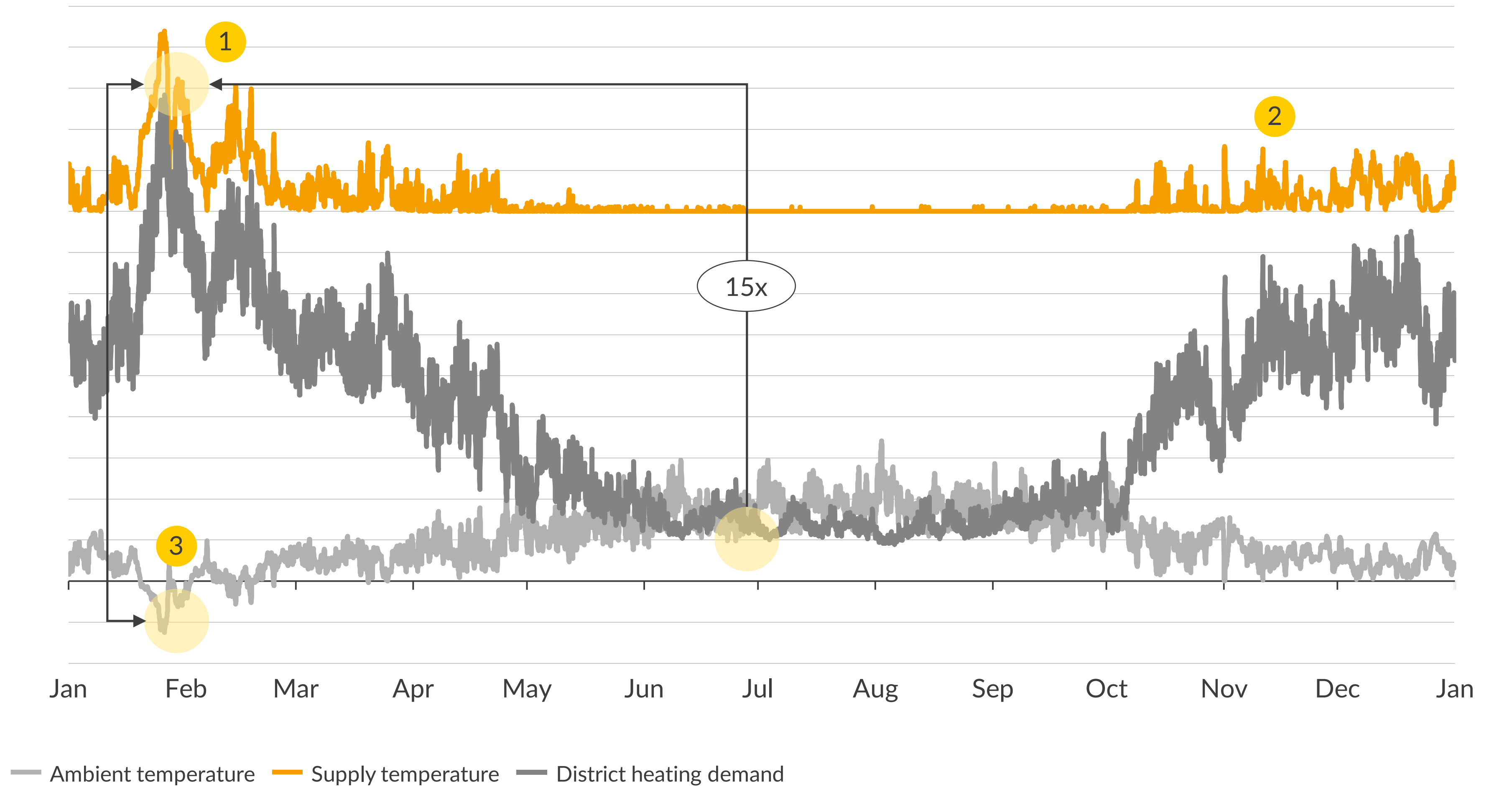
Hourly temperatures and heat demand

°C, MW_{th}(normalised)



Sources: Aurora Energy Research

Key challenges and considerations

1 **Security of supply**

- Large dynamic range: winter peak load is up to 15x larger than summer baseload
- Backup capacity is needed for extreme weather with low temperatures and to cover outages of single units

2 **Supply temperature**

- Water flow is limited by the pipelines of the heating grid
- Higher temperatures are required in winter to deliver more energy through the grid

3 **Ambient heat sources**

- Heat demand is high when ambient temperature is low
- Amplifies the challenge to integrate ambient heat sources; e.g. surface water

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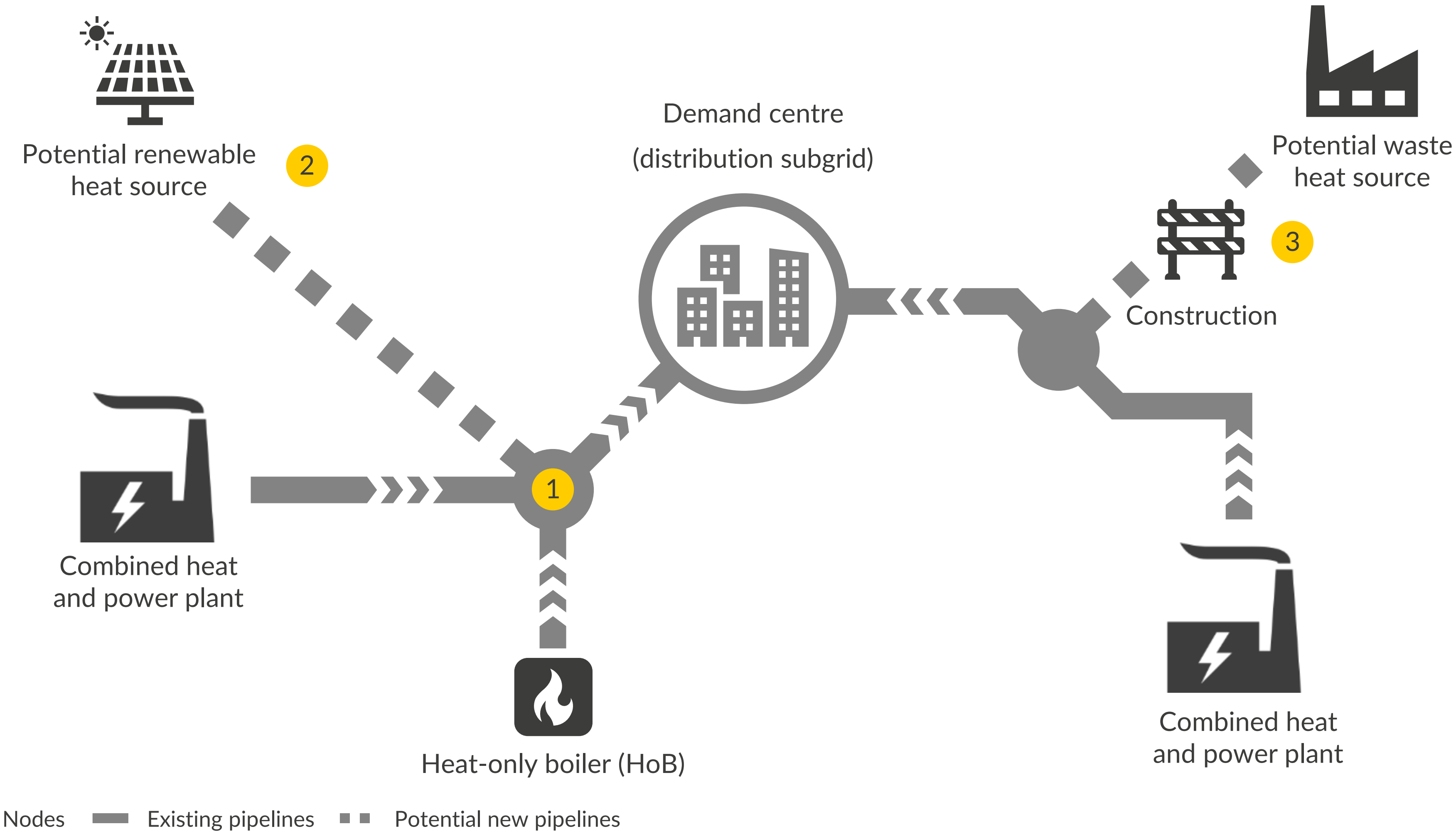
Supply options for district heating systems are limited by the technical grid architecture and the location of potential heat sources

Schematic layout of an example district heating grid



Key challenges and considerations

1 Flow constraints

- Energy is transported in the form of hot water (or steam)
- Need to maintain pressure levels and the direction of heat delivery

2 Local availability

- Potential heat sources may be far from customers and need to be grid-connected
- Temperature levels have to match supply temperature or may need to be topped up

3 Disruptive grid works

- Buildings, streets, and other infrastructure limit changes to the network
- Use existing grid as much as possible, despite pipe limits

Sources: Aurora Energy Research, ZEN Report No. 9 2018

Based on our modelling expertise and framework we have developed AER-DH to find optimal transition paths for district heating system

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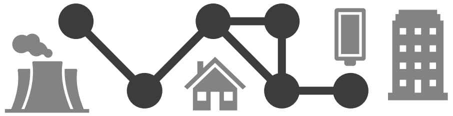
Global Commodities (AER-GLO) ⟷ Gas (AER-GAS) ⟷ Power markets (AER-ES) ⟷ Hydrogen (AER-HY)

→ District Heating (AER-DH)

INPUTS

- Technology & local potentials
- Grid structure & constraints
- Demand & supply temp.
- Commodity prices[1)]
- Weather; e.g. temperature
- Policy; e.g. CO_2 target, subsidies



Dispatch model

- Hourly granularity
- Iterative modelling
- Dynamic dispatch of plant and storage
- Endogenous flows with hydraulic constraints

Continuous iteration until an equilibrium is reached

Investment decisions module

- Capacity build / exit / mothballing
- IRR / NPV driven
- Detailed technology and portfolio assessments

OUTPUTS

- Capacity mix
- Generation mix
- Full costs of heat
- CO_2 Emissions
- Profit / Loss and NPV
- Power-to-Heat & cogeneration

Key Features

- Endogenous district heating portfolio optimization of decarbonization options based on individual local potentials and constraints
- Dynamics in pipeline network:
  - Mass flow limited to maintain pressure differentials and flow directions
  - Mix different heat sources to achieve supply temperatures
- Sector coupling with power:
  - PtH dispatch based on hourly power prices
  - Optimised cogeneration based on heating needs, fuel prices, and power prices
- Explicit carbon budget as additional constraint

1) Gas, coal, oil and carbon prices fundamentally modelled in-house with integrated commodities and gas market model

Source: Aurora Energy Research

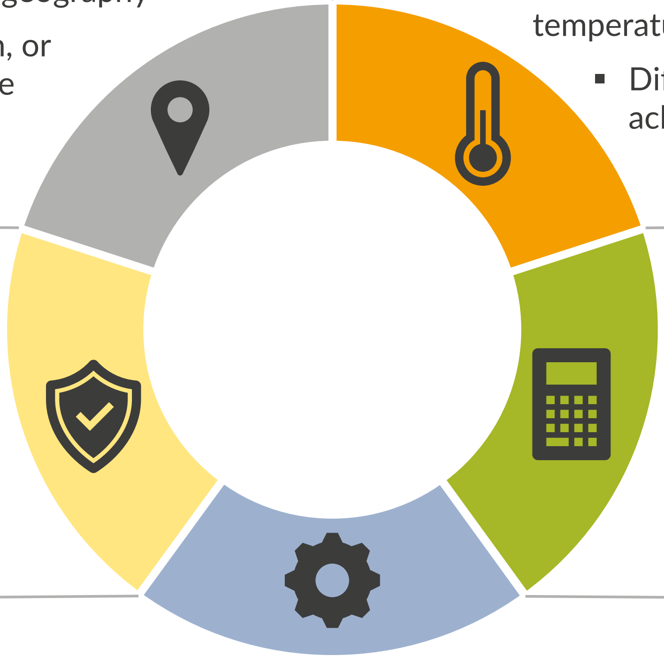
Aside from costs, decarbonisation options for district heating systems have to consider technical and local constraints

Local availability & restrictions

- Tapping into a potential resource depends on its location and may not be available at the existing grid
- Potential of natural resources vary by geography
- Due to other infrastructure, regulation, or buildings access or development of the source may be difficult or restricted

Temperature

- Higher supply temperatures are required in winter to compensate for higher demand and distribution losses
  - However, many potential heat sources have lower temperatures and would need to be topped up
    - Different temperatures can be mixed to achieve the required supply temperatures



Reliability

- District operators may not be able to dispatch the heat source at will; e.g. industrial waste or renewable sources
- Some sources rely on external factors; e.g. power grid, weather (temperature, sunshine, etc.)

Investment cost

- CAPEX include costs for the device and installation, such as ground-works (e.g. drilling), construction, grid connection and integration, as well as project development
- Project lifetime and discounting are key assumptions to evaluate options

Operational cost

- The variable costs for inputs, such as fuel and electricity, need to consider consumer fees and market prices that may vary over time; e.g. hourly power prices
- Costs for operation & maintenance as well as contracted prices for third party heat providers (e.g. industrial waste heat) need to be considered for dispatch

Comments

- Assessing the different techno-economical and local dimensions is essential for identifying and evaluating a well-balanced portfolio
  - Technical and economic parameters may improve in the future
  - However, local availability, restrictions and reliability, will vary for individual grids and systems
- Different technologies and options could be compared along these 5 key dimensions

Source: Aurora Energy Research

Options for district heating to abate CO_2 emissions include fuel switching, new heat sources, deployment of flexible technologies and grid works

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Current systems mostly rely on

a) Fossil fuels

- Coal
- Natural gas
- Oil

Used in:
- Heat only boiler
- CHP cogeneration

b) Other fuels

- Waste[1)]

Investigated decarbonisation options

1. **Fuel switch**
   - Biomass
   - Biogas
   - Hydrogen
   - Synthetic fuels
2. **New direct heat sources**
   - Industrial waste heat
   - Geothermal
3. **New indirect sources via heat pumps**
   - Sewage water
   - River / sea water
   - Solar thermal
   - Electrode boilers
4. **Flexibilisation via storage**
   - Day-to-day storage
   - Seasonal storage

Further options (not investigated)

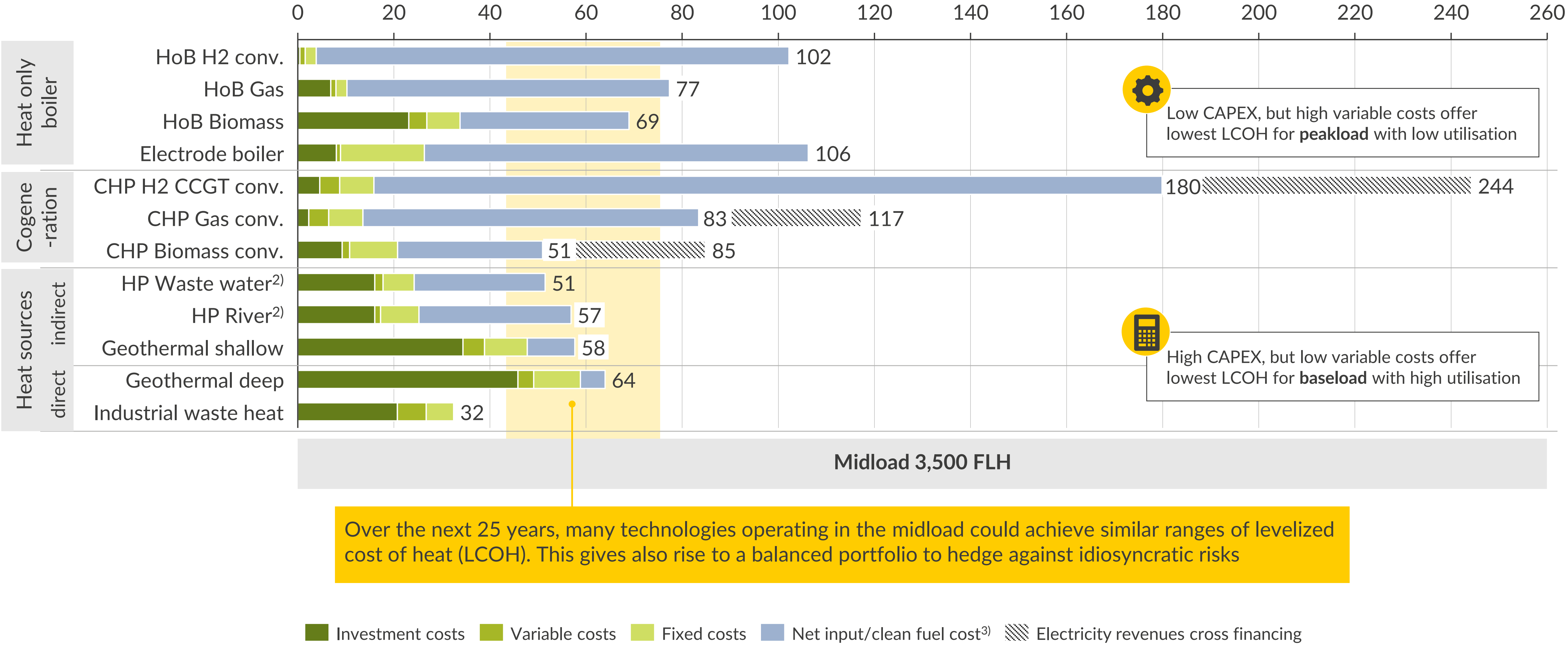
- Grid modifications to alleviate technical constraints of the pipes, e.g.
  – Larger pipe diameters to increase flow
  – Improve pipe insulation to reduce losses
- Lower temperature levels of the grid
  – Might require above grid modifications
  – Potentially install heat pumps at customer sites to bring up temperature levels
  – Enables integration of lower temperature sources without heat pumps or temperature top ups
- Continued operation with carbon capture and storage (CCS)

1) In Germany energy from waste incineration is often classified as 50% renewable, 50% non-renewable

Source: Aurora Energy Research

The optimal technology choice to serve midload depends on the individual balance of investment and variable costs relative to utilisation

Levelised cost of heat (LCOH)[1] by heat source and technology
EUR/MWh_{th}



Over the next 25 years, many technologies operating in the midload could achieve similar ranges of levelized cost of heat (LCOH). This gives also rise to a balanced portfolio to hedge against idiosyncratic risks

1) 20 year lifetime, assume average commodity or power prices 2025-2050 2) Includes 300k EUR/MW investment subsidy 3) for power consuming technologies assumed that EEG levies for electricity consumption will be discontinued

Sources: Aurora Energy Research, Danish Energy Agency, PBL, Goldman Sachs

Hamburg's district heating grid is one of the largest in Germany, with most heat supplied by two coal CHPs outside the city

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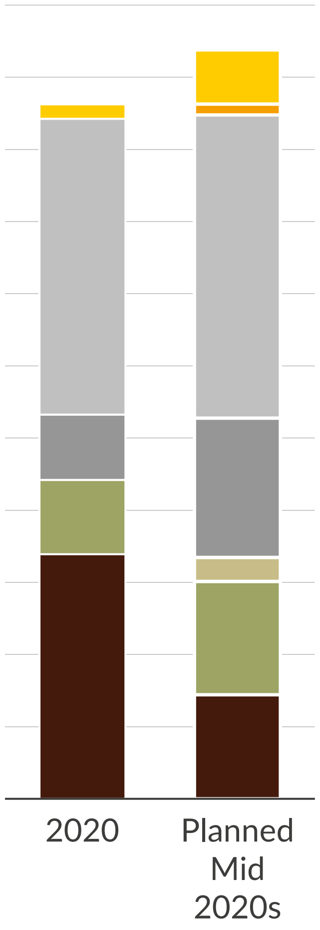
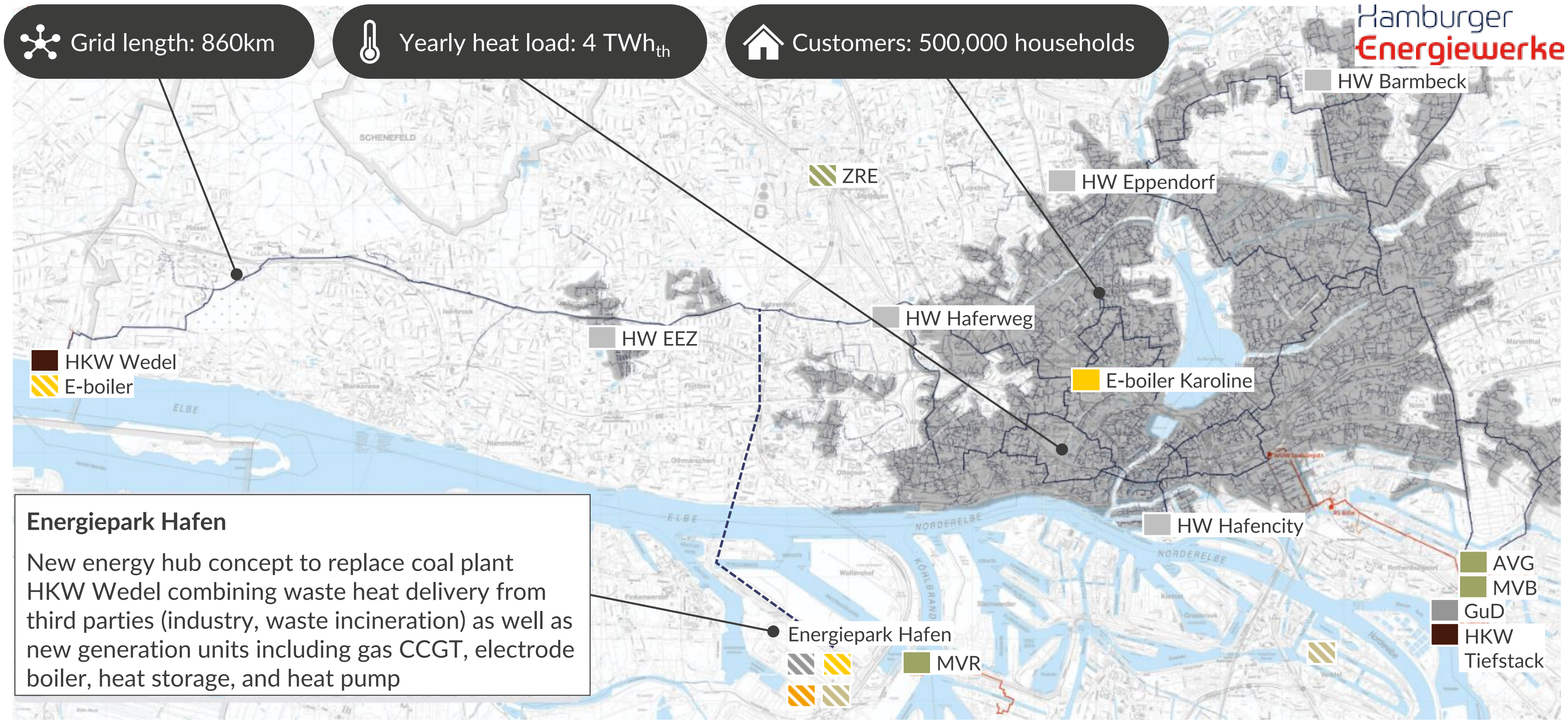
Hamburger Energiewerke's heat capacity mix[1] and grid extent

GW_{th}





Energiepark Hafen

New energy hub concept to replace coal plant HKW Wedel combining waste heat delivery from third parties (industry, waste incineration) as well as new generation units including gas CCGT, electrode boiler, heat storage, and heat pump

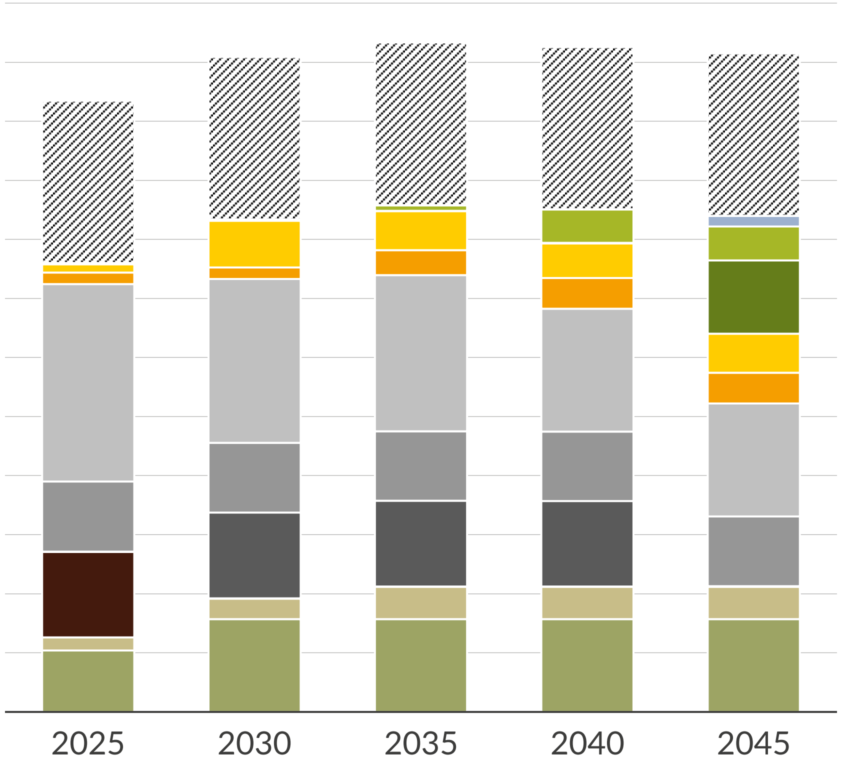
Electrode boilers | Heat pumps | Gas HoB | CCGT | Industrial waste heat | Waste incineration | Coal CHP | planned

1) Including backup capacity

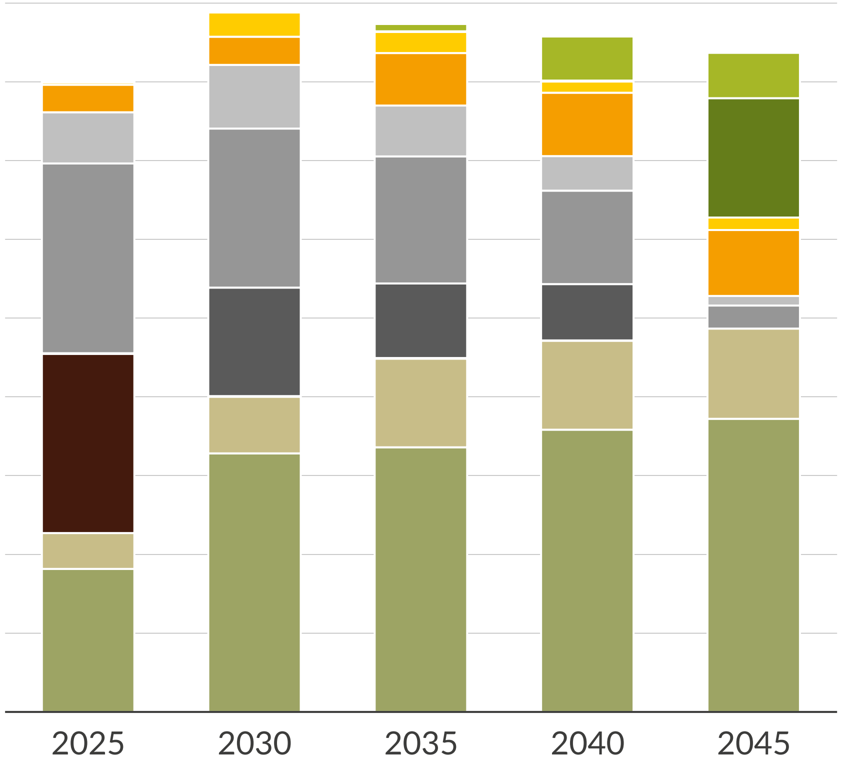
Sources: Aurora Energy Research, Hamburger Energiewerke

Decarbonised portfolio could rely on waste heat, power-to-heat, biomass, and hydrogen – where gas acts as a bridging technology

Capacity
GW_{th}



Generation
TWh_{th}



Waste incineration | Industrial waste heat | CHP Coal | CHP Gas[1] | CHP Gas CCGT[1] | HoB Gas[1] | Heat pump | Electrode boiler | CHP Biomass | HoB Biomass | HoB Hydrogen | Backup capacity[2]

Comments

- Waste incineration and industrial waste heat as baseload technologies could supply almost half of the total heat demand in 2045
- Coal CHP converts to gas and later to biomass due to higher fuel costs for carbon neutral biogas, operating mid load
- New built heat pumps would serve base/mid load
- Biomass CHP and heat-only boilers (HoB) support in the mid- to peak load
- Existing electrode boilers not utilised much before 2030, mostly dispatch in the mid/peak range when power prices are low
- Gas & hydrogen HoB only used for peak load and to top up temperature levels

1) Assumes that for Net Zero after 2045 only biogas (or other molecular equivalent gas) could be used in the asset for a higher price, but without incurring conversion costs 2) Backup capacity is not part of the economic optimisation, but needed for extreme weather events or to cover for outages of individual units (N-1)

Source: Aurora Energy Research

In a decarbonised system, waste heat and heat pumps could provide baseload, complemented by biomass CHP and hydrogen HoB

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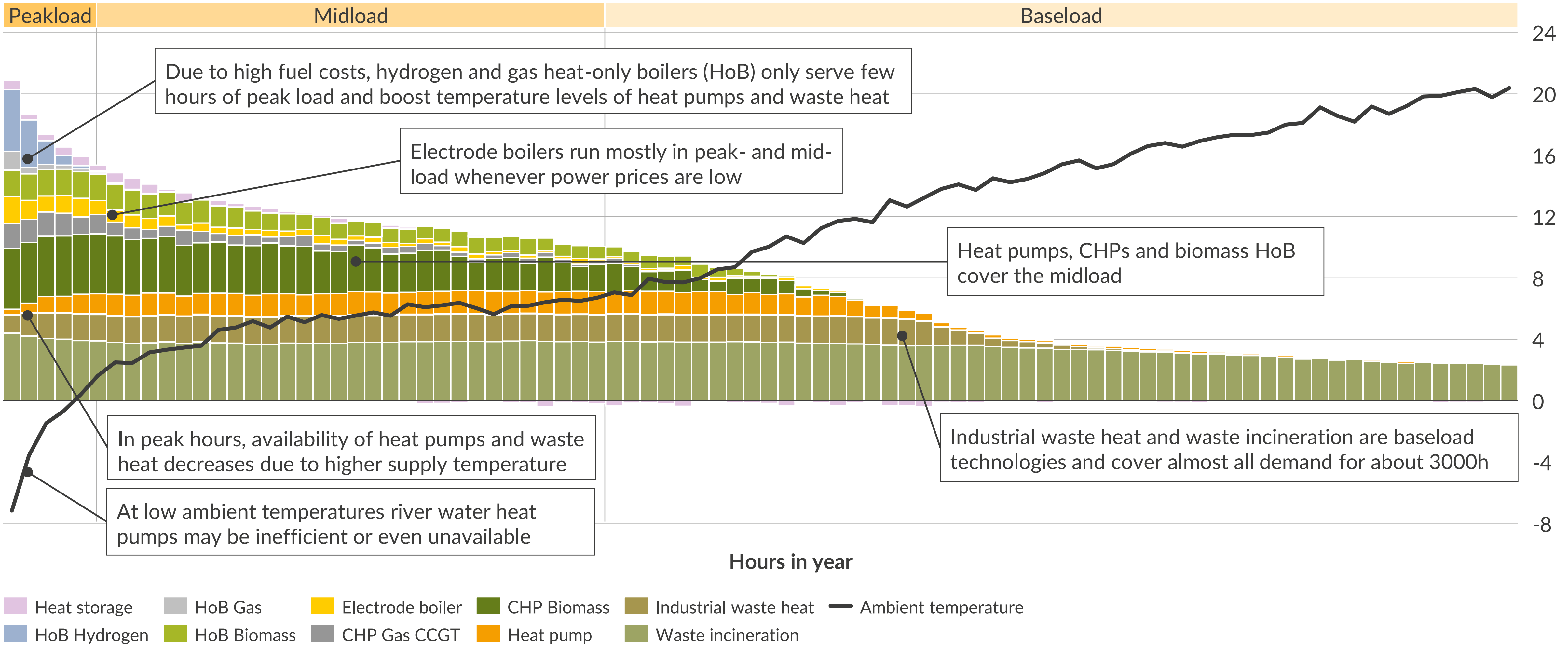
Average heat generation grouped and sorted by heat load vs. ambient temperature in 2050

MW_{th}, °C

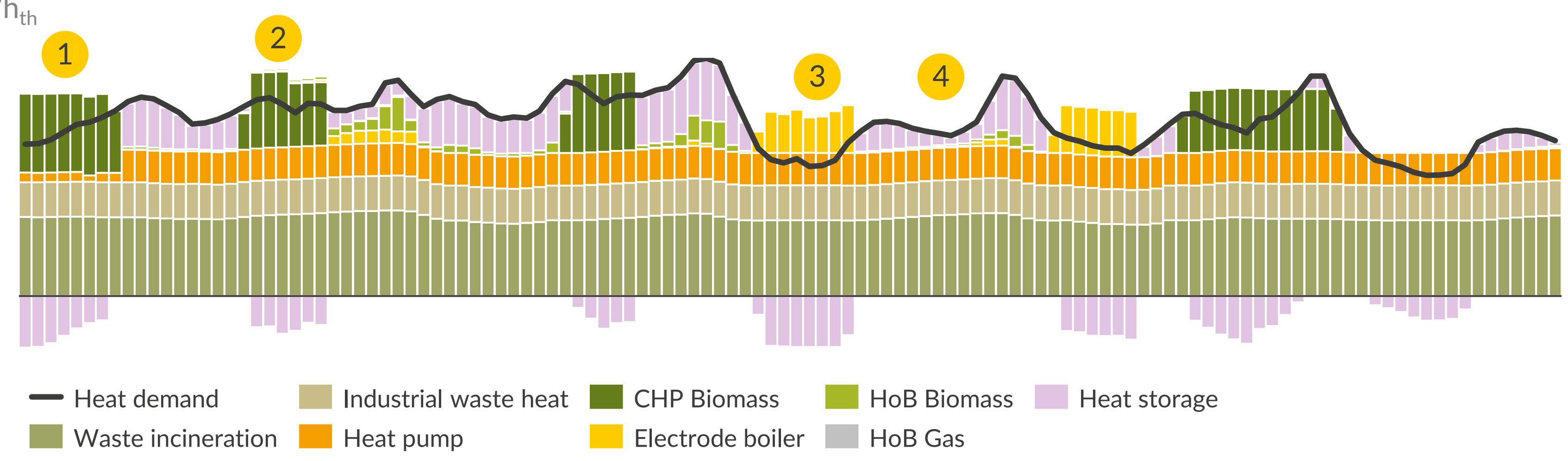


Source: Aurora Energy Research

Sector coupling between heat and power is most efficient when storage can absorb surplus heat when power prices are attractive

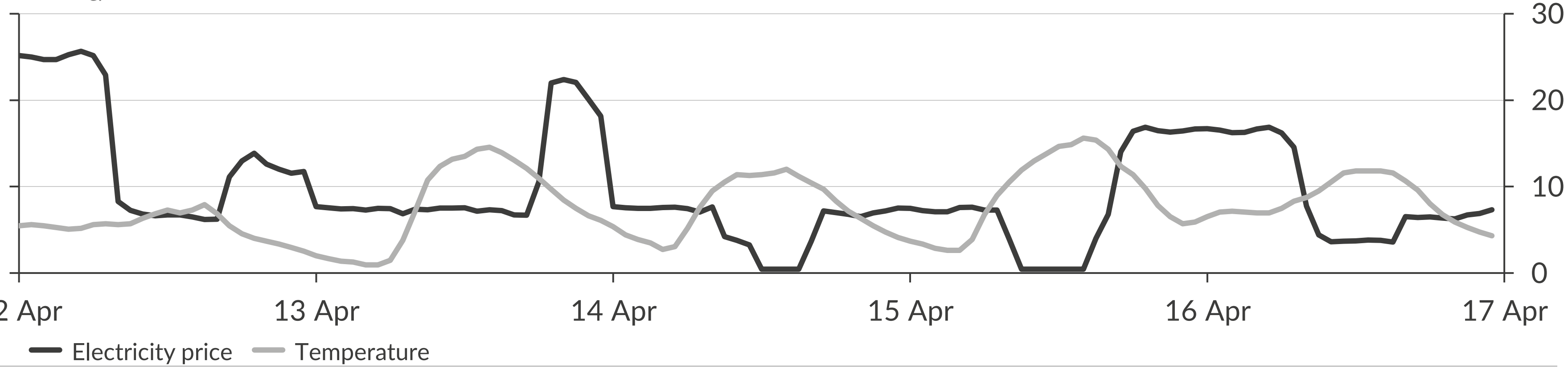
Hourly heat demand and dispatch by technology for 5 sample days

MWh_{th}



Power prices and ambient temperatures for 5 sample days

EUR/MWh_{el}, °C



Source: Aurora Energy Research

Comments

- Storage can absorb surplus heat energy when electricity markets are attractive for CHPs or electrode boilers:
  1. When power prices are high, CHP displaces other mid/baseload technologies like heat pumps
  2. At medium power prices midload technologies as biomass HoB are replaced
  3. Electrode boilers dispatch when power prices are very low
  4. Stored heat can be dispatched at low power prices when neither CHPs nor electrode boilers provide cheap heat
- CHPs, electrode boilers and short-term storage form a highly flexible system in times of medium heat demand and volatile power prices

We check the robustness of our reference case by testing individual assumptions on infrastructure and regulation in sensitivities

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Default assumptions

1. Reference case

- Capacity timelines and plans were aligned with the client
- However, the model can decide to mothball or convert assets endogenously
- Local potentials and technical limits for each technology buildout and conversion option are specified for individual locations

- Implicit switch for all gas assets to carbon-neutral biogas by 2045 at a higher price, but without incurring any conversion costs

- Heat pump subsidies according to BEW: 7 ct/kWh$_{th}$, but capped at 90% electricity costs for the first 10 years
- Implementation for model buildout as 45% subsidy for all 20 years of project lifetime

- CO_2-budget according to reduction targets city climate plan

Sensitivities

These scenarios test individual or implicit assumptions of the reference case by considering some extremes

2. Cyclical economy

- Waste incineration phased out 2035-45

3. Unconstrained electrification

- Lifted build restrictions on electrode boilers and heat pumps to assess economic potential

4. No biogas

- Cannot utilise gas generation units beyond 2045 unless they are converted to hydrogen

5. No heat pump subsidies

- Heat pumps bear the full electricity costs

6. Accelerated decarbonisation

- Tighter CO2 budget, especially in 2035-2045

Common assumptions across all scenarios

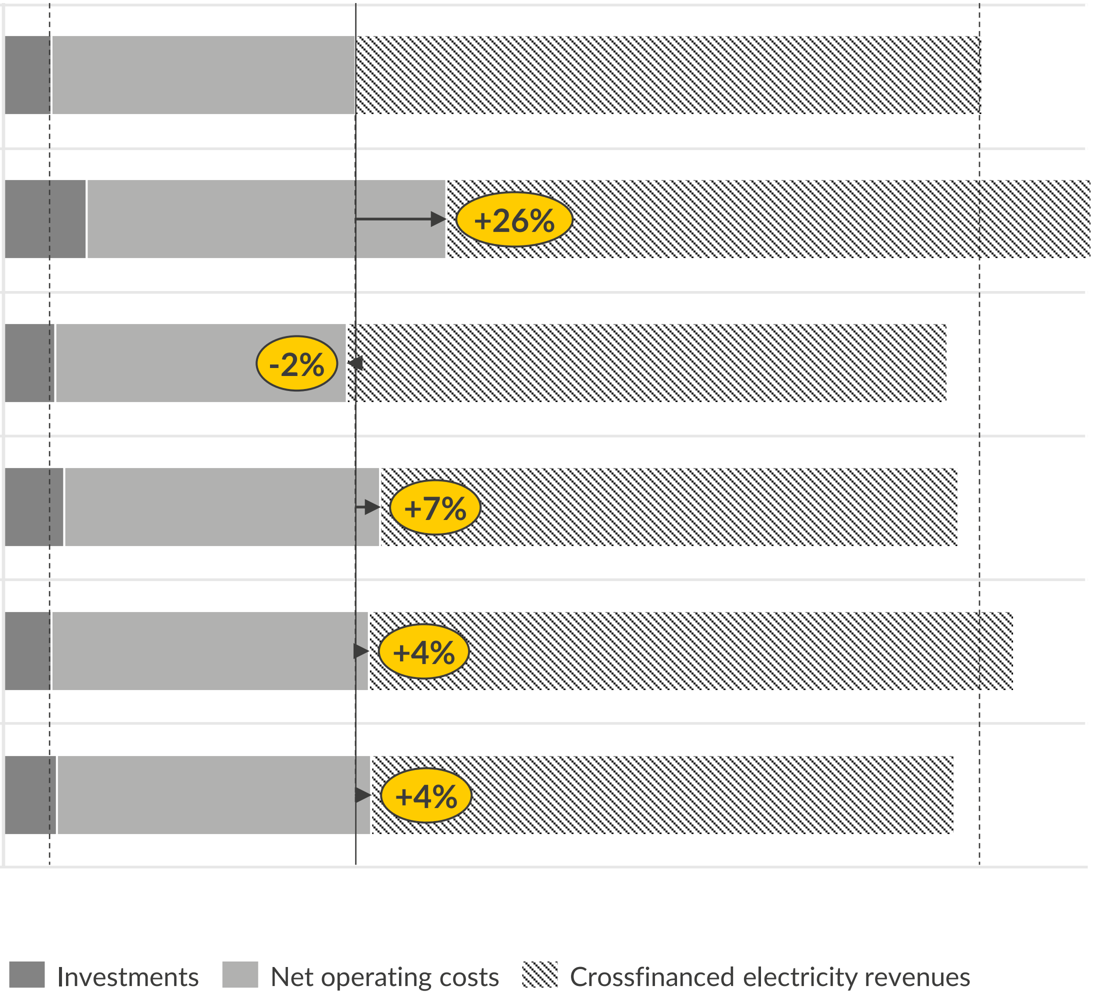
- Aurora Net Zero Oct 2021 commodity and power prices
- Techno-economic parameters of decarbonisation options based on research
- Demand projections
- Grid structure and flow constraints

Sources: Aurora Energy Research

Without waste incineration as a cheap baseload heat source, costs would increase by 26% whereas technology mix can balance out other factors

Scenario	Key features and differences
1. Reference case	▪ CHP Coal-to-Gas conversion 2030, 2045 to biomass ▪ HoB Gas-to-hydrogen conversion ▪ New build heat pumps and biomass HoB
2. Cyclical economy	▪ Additional heat pumps and geothermal to replace waste incineration as baseload ▪ Higher investment and operating costs
3. Unconstrained electrification	▪ Overall lower costs due to additional heat pumps buildout with low operating costs ▪ Slightly higher investment costs for heat pumps
4. No biogas	▪ Additional electric boilers replace biogas peak capacity ▪ Earlier hydrogen conversion of HoB, but without biogas CCGT, less cogeneration electricity revenues
5. No more heat pump subsidies	▪ Less heat pump capacity buildout and operation ▪ Instead more biomass, electric boilers, and geothermal which are more expensive to build and operate
6. Accelerated decarbonisation	▪ Similar decarbonisation mix but pulled forward; i.e. converting and operating an almost decarbonised system earlier increases costs due to discounting

Full cost of heat[1)]
Mio EUR



1) Net present value in 2025 discounted at 6%, where 2050 cashflows (without investment) are extrapolated until 2100

Source: Aurora Energy Research

German Power Market Service: Key market analyses and forecasts for all participants in the German power market

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Quarterly data and market reports to assess business models

- Yearly forecasts of **wholesale market prices along 4 scenarios** (Central, High, Low and Net Zero) until 2050
- **Price distributions**, capture spark spreads, peak prices
- **Capacity development**, generation mix, interconnector capacity, capacity buildout, exports
- **Capture prices** of technologies (CCGT, coal, onshore wind, offshore wind, solar PV)
- **Analysis of key sensitivities** (coal closures, Climate Action Plan target)
- EU-ETS carbon price forecasts
- ***Global Energy Market Forecasts***

Group Meetings and Strategic Insight Reports

- **In-depth thematic reports** on topical issues
- **Four multi-client roundtable discussions** per year in Berlin to discuss reports with actors across the German power market
- Past and future topics include
  - *Reserve market and business models for batteries*
  - *Coal exit auctions*
  - *Security of supply and weather risks*

Interaction through workshops and ongoing support

- **Bilateral workshops** at your office to discuss specific issues on the German market
- **Ongoing availability** (calls, access to market experts, modellers) to address any questions across European power markets
- Invitation to all Aurora events and discounted invitations to Aurora's annual **Spring Forum**

All intelligence for a successful business, based on bankable price forecasts

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Decarbonising heat and power takes centre stage at Aurora's Group Meetings in Germany over the next year

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With the German Net Zero target set for 2045, not only decarbonising the power but also the heating sector becomes ever more pressing. While this is uncontested, it is unclear and highly disputed which role different heating technologies and fuels will play in a climate-neutral energy system and how a path towards it could like.

To equip our subscribers with the necessary analytical background for their strategic decisions, we will focus on analysing the different options of decarbonising heat with all its complexities, as well as its implications on the German power market and policy over the course of the next year

Preliminary research agenda[1]

December 2021

Decarbonizing municipal district heating systems:

Options, their comparative advantages and a case study

February 2022

CHPs, hydrogen or heat pumps?

Pathways to decarbonize the heating sector and their impact on the power market

Summer 2022

Market Design

Review of 2021 and outlook on the German power market and its interplay with EU market integration

End of 2022

To be determined

1) This research agenda is preliminary and could be subject to change e.g. if other topics become topical due to market or regulatory changes.

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