Towards an efficient, integrated and cost-effective net-zero energy system in 2050

The role of cogeneration
Agenda

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   - Methodology & key assumptions
   - Key results

3. System focus
   - Methodology & key assumptions
   - Results

4. Key conclusions & recommendations
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The **European Green Deal** aims to raise the EU decarbonisation ambitions, and to deliver a net-zero emissions economy by 2050, in a cost efficient and secure way.

The **key enablers** of a net-zero economy include energy efficiency, energy system integration, as well as the direct and indirect electrification of a number of end-uses.

Various **policy initiatives** are being taken to ensure the EU can achieve these objectives (e.g. Energy System Integration Strategy, Hydrogen Strategy, Renovation Wave, revision of EE/RES directives, etc.)
Objectives of the study

BACKGROUND

Energy efficiency and energy systems integration are key to reaching carbon neutrality by 2050.

So far, EU scenarios have not fully captured the benefits of efficiently combining heat and power as an enabling solution to move to a net-zero integrated energy system.

This study pursues three objectives

1. **Explore the potential** of further integrating Europe’s energy system in an efficient way to reach a carbon-neutral economy cost-efficiently.

2. **Assess the role of cogeneration**, building on the EC’s Long-Term Decarbonisation Strategy (LTS).

3. **Provide recommendations** to better reap the benefits of efficient and local system integration solutions in policy-making and modelling.

Artelys is a consulting and software edition company specialised in energy systems modelling and decision-support.

In this assignment, the **Artelys Crystal Super Grid** model has been used with European-wide integrated gas, heat and electricity scenarios, capturing key aspects of the energy transition, with a focus on sector integration.
OVERVIEW
The study proceeds in two steps: first considering the point of view of a user, then the wider system.

USER FOCUS
Identify Cost-competitive CHP Applications
Micro-economic assessment of heat generation solutions (with/without CHP) in different use-cases using various:

- Heat demand profiles
- Technologies
- Energy sources
- Archetypal countries

SYSTEM FOCUS
Explore CHP Benefits for the Energy System
Scenario-based assessment of 2050 European energy mix featuring:

- Benefits for the whole energy system; and
- Cost-optimal high efficiency CHP deployment across 1.5TECH* & Integrated Energy Systems (IES) decarbonisation pathways.

*derived from the EC Long-Term Strategy 1.5TECH scenario and additional assumptions, referred to as 1.5TECH* in this study for simplicity.
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Comparison between two configurations (with CHP, without CHP), in seven use-cases

- The use-cases cover applications in the residential, industrial and district heating sectors
- The different use-cases differ via their heat demand profiles and the price of energy
- The situation “without” CHP and the characteristics of the CHP are adapted to the end-use
- Hourly simulations are performed over one year in 3 EU archetypal countries (ES, PL, SE)
- Key indicator: cost of heat provision

User focus: an analysis of various use-cases

Use-case comparison

Without CHP (benchmark) vs With CHP
## User focus: 7 different configurations

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<tr>
<td>Fuel Cell mCHP for residential power and heating + heat storage and electric boiler</td>
<td>Green gas engine CHP for hospital micro-grid + heat storage and gas boiler</td>
<td>Green gas engine CHP for district heating + heat storage and gas boiler</td>
<td>Green gas turbine CHP for district heating + heat storage</td>
<td>Green gas engine CHP + heat storage for medium-temperature industrial heat</td>
<td>Green gas turbine CHP for high-temperature industrial heat + power and thermal storage</td>
<td>Biomass fluidized bubbling bed CHP for industrial heat and municipal district heating</td>
</tr>
<tr>
<td><strong>Benchmark:</strong> Power markets (retail) – Heat Pump + heat storage + H2 boiler</td>
<td><strong>Benchmark:</strong> Power markets – Heat Pump + heat storage + gas boiler</td>
<td><strong>Benchmark:</strong> Power markets – Gas boiler</td>
<td><strong>Benchmark:</strong> Power markets – Biomass boiler</td>
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<tr>
<td><strong>Sensitivity analysis on H2 prices</strong></td>
<td><strong>Sensitivity analysis on H2 prices</strong></td>
<td><strong>Sensitivity analysis on fuel prices to cover different potential fuels (biomass, waste, etc.)</strong></td>
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**CHP operation:** Power-driven CHP, heat as side-product valued as avoided heating costs from heating system (HP + heat storage + gas boiler)

**CHP operation:** Heat-driven, power as side-product consumed locally or injected on networks
User focus: Modelling approach (2/2)

**Benchmark configuration**
(example)

- Heating demand
- Heat storage
- Heat Pump
- Boiler
- Power markets
- Carbon-neutral energy

**CHP configuration**
(example)

- Heating demand
- Heat storage
- Heat Pump
- Boiler
- CHP
- Power markets
- Carbon-neutral energy

**Levelised Cost Of Heat (LCOH)**

\[
LCOH = \frac{CAPEX + OPEX}{heating\ demand}
\]

**LCOH**

\[
LCOH = \frac{CAPEX + OPEX - \text{Power sales revenues}}{heating\ demand}
\]
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4. **Key conclusions & recommendations**
In almost all the considered use-cases, installing a CHP can be beneficial to the user from a cost perspective (excluding benefits from network tariffs and tax avoidance by own consumption).

The benefits can vary depending on the use-case, country, fuel prices, technology cost and characteristics.

- **District Heating**
  - 0.4–3M€ for 500 GWh

- **Hospital (high-temperature)**
  - 6–52k€ for 8 GWh

- **Industry (medium-temperature)**
  - 3–10M€ for 684 GWh

- **Industry (using residual waste and biomass)**
  - 1.5–7.1M€ for 500 GWh

- **Industry & city district heat**
  - 0.9–16M€* for 700 GWh

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*This use-case depends strongly on biomass price, for this range prices between 40 and 60 €/MWh were considered*
The benefits shown in the previous slide are system-level benefits that do not include additional benefits that end-users can capture: avoided taxes/levies and network tariffs.

When considering the entire consumer bill, CHPs can become even more competitive than alternative technologies, and in more uses-cases.

For example, fuel cells are found to be competitive in the residential sector from a final user point of view, in particular in countries that face high electricity prices in wintertime and high levels of taxes/tariffs.
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### System focus: Methodology (1/3)

#### Scenario Definition
Configuration of the power and heat model in two scenarios

- Assumptions on heat demand by sector based on the LTS 1.5TECH scenario

- Definition of maximum heat demand that can be supplied by CHP

<table>
<thead>
<tr>
<th>Sector 1</th>
<th>Sector 2</th>
<th>Sector 3</th>
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<tbody>
<tr>
<td>Heat demand</td>
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<tbody>
<tr>
<td>Increased CHP</td>
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#### Scenario Economic Optimisation
Economic optimisation of the heat and electricity generation from a systemic point of view

- Trade-off between investment costs and operational costs to optimise the integrated power and heat generation mix for each scenario

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<thead>
<tr>
<th>Sector 1</th>
<th>Sector 2</th>
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<th>Sector 4</th>
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</thead>
<tbody>
<tr>
<td>CHP CAPEX</td>
<td>CHP OPEX</td>
<td>CHP OPEX</td>
<td>CHP CAPEX</td>
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<tr>
<td>Pure heat CAPEX</td>
<td>Pure heat OPEX</td>
<td>Pure heat OPEX</td>
<td>Pure heat CAPEX</td>
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<td>Pure elec. CAPEX</td>
<td>Pure elec. OPEX</td>
<td>Pure elec. OPEX</td>
<td>Pure elec. CAPEX</td>
</tr>
</tbody>
</table>

- CHPs are installed in each sector only when economical

#### Scenario Result Comparison
Comparison of the costs and deployment of CHPs in both scenarios

- Conclusions at EU level in terms of deployment, costs, GHG emissions, etc.

#### Scenario Result Comparison
Comparison of the costs and deployment of CHPs in both scenarios

- Sectoral analysis

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<th>Sector 1</th>
<th>Sector 2</th>
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<tbody>
<tr>
<td>Share of CHPs in each sector</td>
<td>Share of CHPs in each sector</td>
<td>Share of CHPs in each sector</td>
<td>Share of CHPs in each sector</td>
</tr>
</tbody>
</table>

- Increased CHP | Increased CHP | Increased CHP | Increased CHP |

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Artelys SOLUTIONS EN OPTIMISATION
Electricity generation assets are aggregated by technology for each country.

Consumption is modelled by sector with advanced modelling of flexibility solutions (EVs, electricity and heat storage).

Supply and demand are balanced for heat and electricity at each node for each hour.

Pan-European heat and power model in Artelys Crystal Super Grid
System focus: an analysis of optimal deployment (3/3)

- Energy consumption, heat supply in each sector, levels of energy efficiency and electrification
- Installed capacities of variable RES, hydropower and nuclear
- The rest of the electricity generation mix (biomass, biogas, natural gas, hydrogen) is optimised

European-wide integrated heat and power scenarios modelled in Artelys Crystal Super Grid based on the following characteristics of the EC LTS 1.5TECH scenario

- Optimisation performed with **hourly time resolution** and **country granularity**, for EU27, Balkans, Switzerland, Norway and UK
- **Technical constraints** of each technology are taken into account: ramping rate, minimum generation for thermal fleets, seasonal hydro management, etc.
- **Reduction of grid losses** and **avoidance of network reinforcements** are implicitly considered in the efficiencies and capital costs of CHP technologies
- Optimisation of CHP deployment in sectors that are not electrified (i.e. the deployment of heat pumps is not optimised) to **minimise total system costs**

The investments in heat and power generation and system operations are **jointly optimised** to meet 2050 energy demand
System focus: Scenarios

The analysis is performed from two starting points:

1.5TECH*
Energy system derived from EC LTS 1.5TECH scenario

Integrated Energy Systems (IES)
Higher shares of green gases, incl. P2X & H2, reflecting an increased focus on system integration

Economic Optimisation of Thermal Heat & Power (Optimised CHP)

More CHP installed compared to EC LTS 1.5TECH, resulting in a more efficient use of energy and reduced energy system costs.

CHP brings higher system benefits by efficiently replacing a large share of less-efficient non-CHP thermal generation in the energy mix.

CHP DEPLOYMENT POTENTIAL
LOW

High

In total, 4 scenarios are compared:

1.5TECH*: Baseline vs Optimised CHPs
IES: Baseline vs Optimised CHPs

*Artelys’ understanding and modelling of EC Long-Term Strategy 1.5 TECH scenario that combines all technologies and relies heavily on biomass and CCS, referred to as 1.5 TECH* in this study for simplicity.
1.5TECH* relies on publicly available assumptions of the 1.5TECH scenario of the EC Long-Term Strategy (LTS)

- Between 2015 and 2050, the fossil fuel consumption reduces drastically as the role of electricity increases and bioenergy and e-fuels develop.
- The 1.5TECH scenario considers an important system electrification, especially of transport and heat, and significant energy efficiency efforts (high number of renovations, important technological improvements)

![Power capacity mix - EU28 (GW)](chart1)

![Final energy consumption by energy carrier - EU28 (TWh)](chart2)

*Source: EU Long Term Strategy
System focus: Heat sector assumptions

The heating sector is modelled jointly with the electricity system:

- 4 sectors are modelled: 1. district heating for industries, 2. district heating for buildings (residential/tertiary), 3. on-site heat generation for industries, 4. on-site heat generation in buildings (collective heat or individual heat)
- The share of each energy source in each sector is an input from the 1.5TECH scenario
- The generation of heat in each sector is optimized between CHP and separated heat generation with a limitation on the maximal share for CHP*.
- Waste heat recovery on industrial furnaces for electricity generation is also optimised.

* We consider that in any case, the separated heat generation remains in the heat generation mix. CHP is installed only if its energy savings (in both systems) offsets its additional investment costs.
System focus: Integrated Energy Systems scenario variant

In addition to the 1.5 TECH* scenario, the Integrated Energy System (IES) scenario variant was designed to account for the emerging systems integration paradigm.

- An increase of the share of thermal generation (biomass, biogas+, syngas, or natural gas with CCS).
- A steady nuclear capacity installation rate comparable to current nuclear increase rate (based on the 1990-2020 period), resulting in a capacity of 50 GW in 2050, compared to the 120 GW in EU in the 1.5TECH* scenario (-58%)
- A larger share of biogas-based heat demand in DH for buildings, in line with increased biogas-based power generation.
- Demand levels, electrification rates and share of variable RES is maintained as in 1.5TECH*
- Like 1.5TECH, it meets a net-zero emissions objective

* Biogas uptake is increased so that natural gas consumption is the same in both scenarios
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CHP multiple benefits for net-zero in 2050

- €4-8 Bn: Costs for energy system
- 150–220 TWh: Primary energy savings across the energy system
- 4-5 MtCO2: Reduction of CO2 emissions
- 13-16%*: of total electricity
- 19-27%**: of total heat
- and 30-36% of flexible thermally generated power to complement variable RES and to cover peak demand
- and 52-100***% of thermal heat in buildings, industry & district heating

* excluding offgrid RES for P2X generation
** excluding furnaces.
*** excluding furnaces; DHC for industry is 100% CHP.
Energy system savings

The additional capital cost in CHPs is more than compensated for by energy and CO2 savings at the European level:

- The addition of CHP in the system reduce system costs by **4.1 - 8.2 B€/year overall at EU level**
Increasing the CHP share in all sectors leads to a reduction of primary energy consumption at system level:

- Reduction of the generation of electricity from natural gas-fired units thanks to a better use of fuels
- Primary energy use is reduced by 154 - 221 TWh per year
Installing CHPs in all sectors leads to an overall CO2 emissions reduction:

- **3.8 – 5.5 Mt** of CO2 emissions saved annually thanks to the reduced use of natural gas in CCS plants (assuming a 90% CO2 capture rate)
- In comparison (on the right), 600 Mt eq-CO2 are emitted and captured (either with CCS or natural sinks) in the LTS 1.5TECH scenario, with net emissions of 26 Mt CO2.
- Potential to reduce circa one fifth of the remaining 26 Mt CO2 emissions in 2050
Overall, 86 – 96 GW of CHP capacity is added to the mix compared to the 1.5 TECH* scenario:

- Adding CHP helps replacing investments in gas-fired boilers and electricity-only generation capacity, which, in combination, are less efficient and more CO2 intensive.

- The additional investment costs in optimised CHP scenarios (2.5-3.3 B€) are compensated for by the primary energy savings and CO2 emissions reduction.
The optimisation of the power and heat generation mix leads to an increase of the share of CHP in thermal heat generation in all sectors:

- The system sees value in increasing the share of CHP in the heat generation: + 236 TWh of heat covered by CHP
- CHP are installed in all sectors. They deliver more than 40% of fuel-based heat demand in most sectors, corresponding to 541 TWh of heat supply.
In the IES scenario, the uptake is even higher, given the larger role of thermal technologies in both heat and power.

- CHP share of thermal heat reaches

81% in industries and 70% in buildings
CHP operations combine flexibility & efficiency

In 1.5TECH, the heat demand is electrified by between 34% and 70% depending on the sector.

Optimised CHP can contribute by 50 to 100% to the supply of the the heat demand that cannot be electrified.

In **summer**, back-up boilers are used because electricity prices are low and fuel-based power generation is not often required (nuclear and RES generation are sufficient to cover the demand for most hours)

In **winter**, CHPs can operate at maximum load, complemented by boilers to cover peak demand

In **summer**, CHPs ramp down in response to lower electricity prices and lower demand

In **winter**, CHPs operate at maximum load ramping up to cover higher demand and capturing higher electricity prices

**CHP hourly operation – example for a thermosensitive heat demand (district heat for buildings)**

CHP Boiler Demand
The dynamic operational management of CHPs is simulated with Artelys Crystal Super Grid. CHPs adopt a virtuous behaviour by only generating when it is cost-effective for the joint electricity and heat system.

In particular, CHPs, with a flexible price-driven operational mode, do not compete with, but **complements** variable renewable generation to meet seasonal peak demand due to high shares of electrified heat.

CHPs (orange) run as base load during low wind and sun periods, covering a high share of the peak demand.

CHP stops producing when variable renewable generation is sufficient to cover demand, and covers evening peaks.
CHPs function most of the time but reduce generation when solar production increases.

Peakers (grey) reduce their generation in the high wind period, while CHP continue producing.
Focus on power: Generation by technology

Optimising CHP production results in an increase of its share in thermal generation from **18% in 1.5 TECH** to **30%-36% in Optimised CHP (equivalent to 13-16% of total power generation)**

This leads to:

- a reduction of non-CHP, less efficient and more polluting thermal electricity generation.
- more efficiently using available renewable gases, not requiring additional gas production (notably e-gas).

* In the simulations, in order to match the results of production by technology of the Long Term Strategy, the assumption is made that a large share of offshore wind, onshore wind and PV are connected to P2G installations and do not participate into the electricity market.
Optimal CHP deployment

Optimising CHP leads to a total CHP capacity of 142 – 154 GWₑ in the 1.5TECH* & IES scenarios respectively, compared to 117 GWₑ in 2018 and 56 GWₑ in the 1.5 TECH scenario.

- **On-site building and industry** account for the largest potential for further CHP deployment.

- **Further CHP uptake to supply DHC for buildings** is identified as cost-effective beyond 1.5 TECH*

- From a system point of view, investing in industrial waste heat recovery is cost-effective in all scenarios.
Focus on heat: CHP delivering efficient heat

### ALL SECTORS IN THE EU

<table>
<thead>
<tr>
<th>Buildings</th>
<th>TOTAL HEAT</th>
<th>THERMAL HEAT</th>
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<tbody>
<tr>
<td>Micro-CHP empowering householders</td>
<td>26%</td>
<td>52%</td>
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<tr>
<td>In a mix with electric &amp; district heating</td>
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<tr>
<td>Key technologies: fuel cells &amp; engines</td>
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<tr>
<th>Industry &amp; SMEs</th>
<th>TOTAL HEAT</th>
<th>THERMAL HEAT</th>
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<tbody>
<tr>
<td>CHP boosting competitiveness</td>
<td>26%*</td>
<td>84%**</td>
</tr>
<tr>
<td>Delivering medium and high temperature heat on-site or via DHC</td>
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<tr>
<td>Optimising waste heat recovery</td>
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<tr>
<td>Key technologies: engines, turbines &amp; fuel cells</td>
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<th>Cities</th>
<th>TOTAL HEAT</th>
<th>THERMAL HEAT</th>
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<tr>
<td>CHP supplying local and affordable heat</td>
<td>40%</td>
<td>91%</td>
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<tr>
<td>Complementing waste heat &amp; heat pumps</td>
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<tr>
<td>Key technologies: engines &amp; turbines</td>
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*excluding furnaces.
**excluding furnaces; DHC for industry is 100% CHP.
Recap of key figures

154 – 221 TWh
PRIMAR ENERGY SAVINGS
OR
2.5 x annual electricity consumption of Belgium*

3.8 – 5.5Mt
AVOIED CO₂ EMISSIONS
OR
The annual CO2 emission of 3 million petrol cars

4.1 – 8.2 Bn €
SAVED YEARLY
OR
9.5x of LIFE Climate Action Funding

* IEA 2019 statistics
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CHP is found to be an efficient enabler for reaching carbon neutrality by 2050

- There is cost-effective potential for further CHP deployment to support a highly electrified and low demand energy system compared to 1.5 TECH LTS scenario.

- In a scenario with a higher uptake of bioenergy sources, CHP uptake is even more relevant, fostering the efficient use of these fuels.

- Optimised CHP deployment leads to a system cost reduction of 4.1-8.2 B€ compared with a solution with a lower CHP deployment, and allows to reduce CO2 emissions by 4-5 MtCO2 annually.

- CHP can displace less efficient power-only and heat-only generation technologies, up to 30-36% of thermal power and 50-100% of thermal heat production in 2050.

- CHP can be optimised to maximise system energy/resource efficiency and flexibility, complementing high variable RES electricity generation technologies.

- CHP is relevant in all sectors of the economy: buildings and industry either on-site or when connected to district heating.
Identified barriers to CHP efficient deployment

This study demonstrates the benefits of CHP uptake beyond what is considered in the European Commission’s Long-Term Strategy in 2050, in different carbon neutral scenarios, at both user- and system-levels, across different geographies and in all sectors.

The barriers that may prevent the cost-competitive potential for CHPs to materialise in 2050 include:

- The market structure and the national/European regulatory context do not necessarily allow CHP to capture the all value they bring to the heat and power systems (which impacts distribution, generation and capacity).
- The revenues CHP can get scattered across different markets, some of which being country-specific.
- Taxes and tariffs may not always provide the appropriate price signals to projects that are cost-effective from a system point of view.
- In many cases, the value CHP brings to networks (avoidance of electricity network reinforcement costs) cannot be captured by the CHP owner.
- While CHP production contribute to peak load, they do not necessarily get a capacity remuneration (contribution to reducing the needs for peak capacity).
Recommendations on modelling

The study shows that a refined modelling of electricity-heat interlinkages is essential to assess the cost-effective potential for CHPs, in the context of the EU Green Deal in highly decarbonised contexts.

In particular, several recommendations emerge from this study:

- Prospective studies should simultaneously consider the power system and heat sector with an adequate level of detail.
- CHP operation should be modelled to complement renewable variable generation by adopting a cost-efficient operational management approach. Market models such as METIS could be used for this purpose.
- Heat consumption should be modelled with sufficient detail in each country, by heat sector (buildings, industrial, district heat) and heat temperature levels.
- The diversity of heat supply solutions should be accounted for in each sector. The use cases studied highlight many relevant applications for CHPs with a large range of fuels in the different sectors.
- Studies and modelling exercises should aim at capturing the benefits of distributed electricity generation in terms of avoided distribution network reinforcement costs and avoided electricity losses.
Thank you for your attention

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Annex 1: CHP technology survey outcome
User focus: CHP technology survey

- Identifies existing and upcoming CHP technologies considering different
  - carbon-neutral fuels
  - applications (industry, district heating networks, decentralised heating in buildings)

- Describes the main techno-economic parameters for each technology and their likely evolution until 2050
  - Parameters compared across different sources
  - Technology comparison for similar applications
  - Integration of feedback from CHP industry

- Survey outcome available in the annexes

Key parameters covered
- Capital expenditures (CAPEX)
- Operational expenditures (OPEX)
- Lifetime
- Conversion efficiency
- Heat-power ratio
- Heat output temperature
- Start-up time / ramping gradients

CHP technologies covered
- Open cycle turbines
  - Gas turbines
  - Steam turbines
- Combined cycle
- Engines
- Organic Rankine Cycle
- Fuel cells
  - PEM
  - SOFC
CHP technology survey: Sources

- **Covered sources (non-exhaustive list)**
  - JRC (2018): Cost development of low carbon energy technologies
  - Asset project (2018): Technology pathways in decarbonisation scenarios
  - Artelys (2018): METIS study S9
  - JRC (2017) - Large: Long term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU
  - JRC (2017) - Small: Techno-economic projections until 2050 for smaller heating and cooling technologies in the residential and tertiary sectors in the EU
  - Roland Berger (2015): Advancing Europe's energy systems: Stationary fuel cells in distributed generation
  - Energy Brainpool: study *Flexibility needs and options for Europe’s future electricity system*
  - Imperial College: Benefits of Widespread Deployment of Fuel Cell Micro CHP
  - Manufacturers documentation (Eugine, Wartsila, GE)
  - Mollenhauer et al. (2016): Evaluation of combined heat and power plants
  - Thilak Raj (2011): A review of renewable energy based cogeneration technologies

*Used as data sources in this study*
The most exhaustive source is the **Long-term projection from the JRC (JRC – Large, 2017)**.

The other sources provide partial information and deal with a limited range of technologies and fuels.

<table>
<thead>
<tr>
<th><strong>JRC 2018</strong></th>
<th><strong>ASSET 2018</strong></th>
<th><strong>JRC – Large 2017</strong></th>
<th><strong>JRC Small 2017</strong></th>
<th><strong>Roland Berger 2015</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td>Steam turbines, ORC, Gasification</td>
<td>Fuel cells, Gas engines, µCC Turbines, OC Turbines</td>
<td>Steam turbines, OC/CC Turbines, Gas engines, ORC, Fuel cells</td>
<td>Gas engines, Fuel cells</td>
</tr>
<tr>
<td><strong>OPEX</strong></td>
<td>Steam turbines, ORC, Gasification</td>
<td>OC Turbines</td>
<td>Steam turbines, OC/CC Turbines, Gas engine, ORC, Fuel cells</td>
<td>Gas engines, Fuel cells</td>
</tr>
<tr>
<td><strong>Lifespan</strong></td>
<td>OC Turbines</td>
<td>Steam turbines, OC/CC Turbines, Gas engine, ORC, Fuel cells</td>
<td>Fuel cells</td>
<td>Fuel cells</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Fuel cells, Gas engines, µCC Turbines</td>
<td>Steam turbines, OC/CC Turbines, Gas engine, ORC, Fuel cells</td>
<td>Gas engines, Fuel cells</td>
<td>Fuel cells</td>
</tr>
<tr>
<td><strong>Power:heat ratio</strong></td>
<td></td>
<td>Steam turbines, OC/CC Turbines, Gas engine, ORC, Fuel cells</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Decentralized heating application size

District heating & Industrial steam application size
- Gas turbines, combined cycles and gas engines currently are the prevalent technologies for industrial CHP
- Electrical efficiency is expected to increase (especially for gas engine/turbines and fuel cell).
- Total efficiency is likely to remain stable
- Lifetime is expected to increase by 5 to 10 years for most technologies
CHP technology prospective

- **Engines** feature high power efficiencies, very flexible operations and investment costs reduction towards 2050.

- **Gas/steam turbines** can be used for high capacities plants. Mature technologies which are not expected to experience major technological breakthroughs.

- While **ORC** plants allow to convert low-temperature heat to power, the capital costs are found to be higher than steam/gas turbines for common application cases (high/medium temperature heat recovery).

- Expectations of **fuel cell** CHP learning potential is very high: both CAPEX and lifetime are expected to improve significantly.
CAPEX-Performance overview for gas-fueled CHP

- Different technologies have different techno-economic profiles

- **Fuel cells** could be interesting in a 2050 context involving high penetrations of hydrogen and well distributed access to it.

- **Internal combustion engines** can be an efficient solution for district heating or industrial applications.

- **Gas turbines** with heat recovery can be better suited to large (industrial) plants as they can provide higher capacities and higher power-to-heat ratios.
While this study fully integrates the CHP flexibility value within timeframes from 1h to 1 year, technologies like gas engines can also compete with batteries, hydro storage and demand-side management to provide even shorter flexibility services (e.g. ancillary services).

However, the ability to provide short-term flexibility may depend on the CHP applications (heat or power driven).

Source: Flexibility needs and options for Europe’s future electricity system, Energy Brainpool
Flexibility of CHP technologies (2/2)

Ramp rate of GE Turbines (%/min)

<table>
<thead>
<tr>
<th>FL/min</th>
<th>CCGT</th>
<th>CCGT</th>
<th>ICE</th>
<th>ICE CC</th>
<th>Hard coal</th>
<th>Lignite</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>40%</td>
<td>50%</td>
<td>60%</td>
</tr>
<tr>
<td>Hours</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: IEA

Source: General Electric
Annex 2:
Complementary assumptions for the user focus
Hydrogen price projections (IEA, 2019)

Hydrogen production costs for different technology options, 2030

Future levelised cost of hydrogen production by operating hour for different electrolyser investment costs (left) and electricity costs (right)

Notes: WACC = weighted average cost of capital. Assumptions refer to Europe in 2030. Renewable electricity price = USD 40/MWh at 4,000 full load hours at best locations; sensitivity analysis based on +/-30% variation in CAPEX, OPEX and fuel costs; +/-3% change in default WACC of 8%; and a variation in default CO₂ price of USD 40/CO₂ to USD 80/CO₂ and USD 100/CO₂. More information on the underlying assumptions is available at www.iea.org/hydrogen2030.

Source: IEA 2019. All rights reserved.

With increasing full load hours, the impact of CAPEX on hydrogen costs declines and the electricity becomes the main cost component for water electrolysis.
METIS S1 2050 scenario

- METIS S1 2050 scenario was used as a basis to derive electricity prices in 2050 in the “user focus”
- Main characteristics of the scenario
  - EU annual generation is 4800 TWh
  - PV and WP accounts for 62% of the EU power production (less RES than in 1.5TECH)
  - Overall RES share exceeds 80%
  - 260 TWh (HHV) of biogas consumed / 44 TWh de synthetic CH4 (much less P2G than in 1.5TECH)
  - ≈100% decarbonised power mix
Annex 3:

Use cases – detailed results
Use case 1: Fuel Cell mCHP for residential power and heating

- This use case focuses on a domestic consumer equipped with a fuel cell mCHP that aims at minimizing its total heat and power bill, accounting for taxes. All of its electricity production is self-consumed, therefore avoiding taxes and transportation costs on the electricity.
- The LCOH presented below includes these avoided taxes, assumed to be twice the average wholesale price.
- This LCOH is computed for a large range of values for hydrogen prices given their uncertainty.

The result shows that FC can be competitive from the perspective of a user minimizing its energy bill.

The competition with other solutions depends on hydrogen prices. As an illustration, the Gas Decarbonisation Pathways 2020-2050 report (Gas for Climate, 2020) expects production costs in 2050 to be around 52 €/MWh (excl. transport/distribution, storage taxes)

FC will be more competitive in countries where power prices are high in winter, i.e. in countries where the decrease of temperature is significant in winter and who do not have significant flexibilities.

As a distributed technology, FCs enable self-consumption and can help a consumer lower his total energy bill.

The competitiveness of FC is dependent on H2 end-use prices, which can be affected by many factors (electricity and gas prices, H2 penetration, H2 infrastructure, CCS costs and potential), and on the level of tax in each country.

*Fuel cell end consumer assumptions: CAPEX 4692 €/kWe, fixed OPEX 143 €/kWe/y, lifetime 20 years, thermal efficiency 46%, electrical efficiency 57%, LHV
Use case 2: Gas engines CHP for a hospital micro-grid

Use case 2.1

<table>
<thead>
<tr>
<th>Heat demand type</th>
<th>Hospital microgrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>ChP configuration</td>
<td>Gas-engines CHP</td>
</tr>
<tr>
<td></td>
<td>Heat-Pump</td>
</tr>
<tr>
<td></td>
<td>Gas boiler</td>
</tr>
<tr>
<td></td>
<td>Heat storage (8h / hot water)</td>
</tr>
<tr>
<td>Operations</td>
<td>Power driven</td>
</tr>
<tr>
<td>CHP plant sizing</td>
<td>Optimized in Artelys (cost-minimizing) model</td>
</tr>
<tr>
<td>Other elements sizing</td>
<td>Fixed at pure-heating-configuration sizing</td>
</tr>
<tr>
<td>Pure heating configuration</td>
<td>Heat-Pump</td>
</tr>
<tr>
<td></td>
<td>Gas boiler</td>
</tr>
<tr>
<td></td>
<td>Heat storage (8h / hot water)</td>
</tr>
</tbody>
</table>

**Sizing**

- Optimized in Artelys (cost-minimizing) model

- In a **power driven** configuration, the CHP plant can value the generated power and the heat recovery as avoided heat variable generation costs.

- The optimized CHP configurations lead to a gain of **0.7 – 6.3 €/MWh of heat**

![LCOH breakdown charts](image)
Use case 3: Gas engines CHP for district heating

**Heat demand type**
- District heating - residential

**CHP configuration**
- Gas-engines CHP
- Heat-Pump
- Gas boiler
- Heat storage (8h / hot water)

**Operations**
- Optimized in Artelys (cost-minimizing) model
- Power driven

**Sizing**
- Optimized in Artelys (cost-minimizing) model

- In a power driven configuration, the CHP plant can value the generated power and the heat recovery as avoided heat variable generation costs
- The optimized CHP configurations lead to a gain of 0.6 - 4.5 €/MWh of heat
Use case 4: Gas turbine CHP for district heating

- **Heat demand type**: District heating - residential
- **CHP configuration**:
  - Gas turbine CHP
  - Heat pump
  - Gas boiler
  - Heat storage (8h / hot water)
- **Operations**
  - CHP plant sizing
  - Other elements sizing
    - Heat driven
    - Jointly optimized in Artelys modelling
- **Pure heating configuration**:
  - Heat pump
  - Gas boiler
  - Heat storage (8h / hot water)
- **Sizing**
  - Optimized in Artelys (cost-minimizing) model

- **In a heat driven configuration**, CHP can displace other heating technologies, avoiding investment costs.
- The optimized CHP configurations lead to a gain of **0.7 – 6.7 €/MWh of heat**.
Use case 5: Gas engine CHP and heat storage for medium-temperature industrial heat

For some industrial applications, electrical heating is not possible and **CHP is the main option for sector coupling** and multi-energy synergies.

The economic relevance of a CHP is sensitive to electricity prices.

The optimized CHP configurations lead to a gain of **3.1 – 14.3 €/MWh of heat**.
Use case 6: Gas turbine CHP for high-temperature industrial heat – chemical industry

- In the high temperature heat industry, storage development for demand shifting purposes remains moderate due to high capacity costs.
- Results are highly similar over the demand profiles of the different industries, except for flatter profiles that decrease capacity needs.
- The optimized CHP configurations lead to a gain of $3.2 – 14.9 \text{ €/MWh}$ of heat.

<table>
<thead>
<tr>
<th>Use case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat demand type</strong></td>
</tr>
<tr>
<td><strong>CHP configuration</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Operations</strong></td>
</tr>
<tr>
<td><strong>CHP plant sizing</strong></td>
</tr>
<tr>
<td><strong>Other elements sizing</strong></td>
</tr>
<tr>
<td><strong>Pure heating configuration</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Sizing</strong></td>
</tr>
</tbody>
</table>
Use case 4:

**Heat demand type**: Industrial – High temperature

**CHP configuration**
- Gas turbines CHP
- Gas boiler
- Heat storage (12h)

**Operations**
- CHP plant sizing
- Other elements sizing
- Heat driven
- Optimized in Artelys modelling

**Pure heating configuration**
- Gas boiler
- Heat storage (12h)

**Sizing**
- Optimized in Artelys (cost-minimizing) model

- In the high temperature heat industry, storage development for demand shifting purposes remains moderate due to high capacity costs.
- Results are highly similar over the demand profiles of the different industries, except for flatter profiles that decrease capacity needs.
- The optimized CHP configurations lead to a gain of 3.7 – 14.1 €/MWh of heat.
Use case 6: Gas turbine CHP for high temperature industrial heat – generic industrial profile

- **Heat demand type**: Industrial – High temperature
- **CHP configuration**:
  - Gas turbines CHP
  - Gas boiler
  - Heat storage (12h)
- **Operations**:
  - Pure heating
- **Other elements**:
  - Sizing Optimized in Artelys (cost-minimizing) model

- **In the high temperature heat industry**, storage development for demand shifting purposes remains moderate due to high capacity costs.
- **Results are highly similar** over the demand profiles of the different industries, except for flatter profiles that decrease capacity needs.
- **The optimized CHP configurations lead to a gain of 3.7 – 13.8 €/MWh of heat**.
Use case 6: Heat demand type

Industry + municipal DH

CHP configuration
Bubbling Fluidized Bed Boiler
CHP (biomass)
Biomass boiler
Heat storage (8h / hot water)

Operations
CHP plant sizing
Jointly optimized in Artelys modelling
Other elements sizing

Heat storage (8h / hot water)

Pure heating configuration
Biomass boiler
Heat storage (8h / hot water)

Sizing
Optimized in Artelys (cost-minimizing) model

- In this use case different fuel prices were considered to cover various fuel types (different types of biomass and waste).

- In a 2050 decarbonized power system, biomass-fired CHP technologies can be competitive with gas-to-power on power markets:
  - Most CCGTs would be running on green gas, which can be more expensive than biomass energy crops or residues
  - Biomass-fired CHP has a higher overall efficiency than power-only gas turbines

- Consequently, using biomass or waste in CHP applications can result in greater benefits than only supplying local heat.

Use case 7: Biomass fluidized bubbling bed CHP for industrial heat and municipal district heating

- In this use case different fuel prices were considered to cover various fuel types (different types of biomass and waste).

- In a 2050 decarbonized power system, biomass-fired CHP technologies can be competitive with gas-to-power on power markets:
  - Most CCGTs would be running on green gas, which can be more expensive than biomass energy crops or residues
  - Biomass-fired CHP has a higher overall efficiency than power-only gas turbines

- Consequently, using biomass or waste in CHP applications can result in greater benefits than only supplying local heat.
Annex 4:
Appendix to system focus
Appendix - Techno-economic parameters

### Electricity generation

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>CAPEX (k€/MW/y)</th>
<th>Fixed O&amp;M costs (k€/MW/y)</th>
<th>Variable O&amp;M costs (€/MWh)</th>
<th>Electrical efficiency (LHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass power plant</td>
<td>138</td>
<td>38</td>
<td>3.6</td>
<td>40%</td>
</tr>
<tr>
<td>Biomass power plant w. CCS</td>
<td>244</td>
<td>61</td>
<td>5.8</td>
<td>32%</td>
</tr>
<tr>
<td>Gas power plant – high efficiency</td>
<td>64</td>
<td>15</td>
<td>1.7</td>
<td>63%</td>
</tr>
<tr>
<td>Gas power plant – low efficiency</td>
<td>47</td>
<td>17</td>
<td>11.0</td>
<td>42%</td>
</tr>
<tr>
<td>Hydrogen power plant</td>
<td>74</td>
<td>17</td>
<td>1.7</td>
<td>63%</td>
</tr>
<tr>
<td>Gas power plant w. CCS</td>
<td>129</td>
<td>34</td>
<td>2.8</td>
<td>49%</td>
</tr>
</tbody>
</table>

### Combined heat and power

<table>
<thead>
<tr>
<th>CHP</th>
<th>CAPEX* (k€/MW/y)</th>
<th>Fixed O&amp;M costs (k€/MW/y)</th>
<th>Variable O&amp;M costs (€/MWh)</th>
<th>Electrical efficiency (LHV)</th>
<th>Thermal efficiency (LHV)</th>
<th>Equivalent electrical efficiency (avoided losses)</th>
<th>Primary energy savings***</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP biomass –</td>
<td>172</td>
<td>20</td>
<td>0.6</td>
<td>32%</td>
<td>63%</td>
<td>34%</td>
<td>14%</td>
</tr>
<tr>
<td>District heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP biomass –</td>
<td>172</td>
<td>20</td>
<td>0.6</td>
<td>32%</td>
<td>63%</td>
<td>34%</td>
<td>14%</td>
</tr>
<tr>
<td>On-site industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP gas –</td>
<td>76</td>
<td>8</td>
<td>5.3</td>
<td>39%</td>
<td>53%</td>
<td>42%</td>
<td>14%</td>
</tr>
<tr>
<td>On-site industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP gas –</td>
<td>112</td>
<td>9</td>
<td>10.1</td>
<td>46%</td>
<td>48%</td>
<td>52%</td>
<td>22%</td>
</tr>
<tr>
<td>On-site buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP Hydrogen –</td>
<td>88</td>
<td>9</td>
<td>5.3</td>
<td>40%</td>
<td>55%</td>
<td>43%</td>
<td>14%</td>
</tr>
<tr>
<td>On-site industry**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP Hydrogen –</td>
<td>450</td>
<td>143</td>
<td>0.0</td>
<td>57%</td>
<td>46%</td>
<td>63%</td>
<td>29%</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*CHP CAPEX includes grid reinforcement cost savings from distributed generation

**CAPEX for on-site industry hydrogen-based CHPs are based on CAPEX of engines or turbines. They are derived from gas-based engines or turbines, considering a 15% cost-increase due to hydrogen technical specificities.

***CHPs allow for 14% to 29% of primary energy savings compared to separate heat and power production, thus ensuring high efficiency CHPs are considered (PES higher than 10%).

### Heat generation

<table>
<thead>
<tr>
<th>Heat Generation Type</th>
<th>CAPEX (k€/MW/y)</th>
<th>Fixed O&amp;M costs (k€/MW/y)</th>
<th>Variable O&amp;M costs (€/MWh)</th>
<th>Thermal efficiency (LHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump</td>
<td>49</td>
<td>2</td>
<td>1.6</td>
<td>381%</td>
</tr>
<tr>
<td>Gas boiler</td>
<td>8</td>
<td>2</td>
<td>0.2</td>
<td>105%</td>
</tr>
<tr>
<td>Biomass boiler</td>
<td>23</td>
<td>4</td>
<td>0.2</td>
<td>100%</td>
</tr>
<tr>
<td>Hydrogen boiler</td>
<td>9</td>
<td>2</td>
<td>0.2</td>
<td>112%</td>
</tr>
</tbody>
</table>

### Heat storage

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Capacity CAPEX (k€/MW/y)</th>
<th>Storage CAPEX (€/MWh/y)</th>
<th>Discharge time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Storage – Large</td>
<td>8.3</td>
<td>1.0</td>
<td>8</td>
</tr>
<tr>
<td>Heat Storage – Small</td>
<td>22.8</td>
<td>1.9</td>
<td>12</td>
</tr>
</tbody>
</table>

Data sources:
- JRC, datasheet key indicators for large scale heating and cooling technologies, 2017
- COGEN members

Appendix - Assumptions for avoided grid losses

The methodology for taking into account “avoided grid losses” is to consider that a MWh produced at a lower level of the grid has more value than one produced at a higher level of the grid. Self consumption also avoids energy flows in the network and reduces losses even further.

To take this into account, we use the official Journal of the European Union* which provides correction factors for avoided grid losses.

Correction factors for avoided grid losses for the application of the harmonised efficiency reference values for separate production of electricity (referred to in Article 2(2))

<table>
<thead>
<tr>
<th>Connection voltage level</th>
<th>Correction factor (Off-site)</th>
<th>Correction factor (On-site)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 345 kV</td>
<td>1</td>
<td>0,976</td>
</tr>
<tr>
<td>≥ 200 - &lt; 345 kV</td>
<td>0,972</td>
<td>0,963</td>
</tr>
<tr>
<td>≥ 100 - &lt; 200 kV</td>
<td>0,963</td>
<td>0,951</td>
</tr>
<tr>
<td>≥ 50 - &lt; 100 kV</td>
<td>0,952</td>
<td>0,936</td>
</tr>
<tr>
<td>≥ 12 - &lt; 50 kV</td>
<td>0,935</td>
<td>0,914</td>
</tr>
<tr>
<td>≥ 0,45 - &lt; 12 kV</td>
<td>0,918</td>
<td>0,891</td>
</tr>
<tr>
<td>&lt; 0,45 kV</td>
<td>0,888</td>
<td>0,851</td>
</tr>
</tbody>
</table>

For instance, 1 MWh produced at a connection voltage level between 0,45 and 12kV and self-consumed at 80% is equivalent to

\[
\frac{1}{0.918 \times 20\% + 0.891 \times 80\%} = 1,116 \text{ MWh produced at 345kV}
\]

To compute the corresponding “equivalent increase in power output”, we specify below average connection levels and average self-consumption for each heat consumption sector modelled.

Note that self-consumption corresponds here to the amount of electricity that is not injected to higher voltage levels (electricity could be consumed by neighbours, in the same part of the grid)

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>District heating (industry, buildings)</strong></td>
<td></td>
</tr>
<tr>
<td>Average connection level</td>
<td>Average self-consumption in 2050</td>
</tr>
<tr>
<td>[50 kV ; 100 kV] 20% + 5.4%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>On-site industry</strong></td>
<td></td>
</tr>
<tr>
<td>[50 kV ; 100 kV] 20% + 5.4%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>On-site buildings</strong></td>
<td></td>
</tr>
<tr>
<td>[0.45 kV ; 12 kV] 80%</td>
<td>80%</td>
</tr>
</tbody>
</table>

This increase in power output will be applied in the modelling to the different technologies of each sector. For instance, for small CHP in buildings (electric efficiency of 43%), equivalent efficiencies while taking into account the avoided grid losses is: 43% * (1 + 11.6%) = 47.7%
Appendix – Assumptions for fuel and CO2 costs and bio-fuels potentials

- Fossil fuel and CO2 prices are provided by the Long Term Strategy.
- Biomass and biogas prices are determined endogenously based on the optimization of the consumption of their limited supply (provided in the Long Term Strategy).

<table>
<thead>
<tr>
<th></th>
<th>Natural gas</th>
<th>CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>39,6 €/MWh</td>
<td>350 €/t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Biomass</th>
<th>Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5TECH scenario</td>
<td>1 261 TWh</td>
<td>570 TWh</td>
</tr>
<tr>
<td>IES scenario*</td>
<td></td>
<td>1 150 TWh</td>
</tr>
</tbody>
</table>

* Biogas potential is increased so that natural gas consumption is the same in both scenarios (approx. 300 TWh)
Appendix – Assumptions for on-site industrial heat assumptions

- The LTS does not provide data about on-site CHP deployment.
- The disaggregation by end-use and carrier of the industrial fuel consumption from 1.5 TECH based on complementary sources* shows that 280 TWh of fuel is used for space heating and steam/hot water production. This heat can be provided by CHPs (as displayed in red).
- According to the Long Term Strategy, 210 TWh of distributed heat are provided to industries and produced by CHPs (in orange).
- In addition, waste heat recovery modules are assumed to be installed in the “furnaces” end-use (in green). In this case, it would represent an additional electricity generation that would come at no cost, as waste heat is assumed to be recovered from furnaces.

*additional source: ISI Industrial scenario published in the LTS
Appendix – Assumptions for on-site industrial CHP assumptions

- In more details, the **280 TWh** of fuel consumed for heat generation (low to high temperature) are the following*:

  ![Graph showing final gas and biomass demand for on-site heat generation (TWh)]

- Based on this data, we consider the following assumptions:

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>1.5TECH* and IES</th>
<th>Optimised CHP scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>CHP can cover up to 50% of the heat/steam consumption (if economically relevant)</td>
<td>CHP can cover up to 100% of the heat/steam consumption (if economically relevant)</td>
</tr>
<tr>
<td>Biogas</td>
<td>No CHP</td>
<td></td>
</tr>
<tr>
<td>E-gas</td>
<td>No CHP</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>No CHP</td>
<td></td>
</tr>
</tbody>
</table>

*repartition by fuel based on the fuel consumption from industry (excluding electricity) from the LTS 1.5TECH scenario

Fully accessible to CHPs in the increased CHP scenario (if economically relevant from a system perspective)
Appendix – Assumptions for on-site heat generation in buildings

- The fuel consumption of building is of 825 TWh according to the 1.5TECH scenario (including district heating, excluding electricity). These fuels are mostly used for space heating, hot water and cooking.
- 340 TWh are from biogas, e-gas and hydrogen, of which 84% (286 TWh) are used for heating purposes (space and water heating).
Appendix – Assumptions for on-site heat generation in buildings

Assumptions for scenarios:

1.5TECH* and IES scenarios

- The LTS 1.5TECH scenario does not mention CHP as an individual or small heating technology.
- Consequently, this scenario assumes there are no CHP in buildings (excluding from district heat).

Optimised CHP scenarios

- This scenario goes beyond what is proposed by the LTS 1.5TECH scenario
- Biogas, e-gas and hydrogen CHP capacities are optimized up to the full share of heat covered with these carriers in buildings (i.e. up to 286 TWh of fuel consumption)

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Comparison of results with 2017

CHP capacities in both scenarios are comparable to current ones, despite important direct electrification and energy efficiency (renovation, reduction of heat needs) at EU level.

- CHP potential as foreseen in the Long Term Strategy 1.5TECH may be underestimated
- Its deployment is larger when not bounded to LTS assumptions
- In IES, which includes lower nuclear energy capacities, CHP heat and power production increases significantly. The capacity increases relatively less.

![Graph showing comparison of gas consumption per gas type, non-electricity fuel consumption in buildings, and total final energy consumption in industry by scenario compared to 2015.](Image)

Source: Eurostar (2015), PRIMES

Source: PRIMES

Source: PRIMES
Annex 5:
Appendix to system focus results
The cost-efficient operation of CHP also depends on the electricity system:

- CHP are used as a mid-merit technology.
Hourly power supply-demand equilibrium

The cost-efficient operation of CHP also depends on the electricity system:

- CHP are used as a mid-merit technology. They stop producing when renewables and nuclear generation are sufficient to cover the demand.
- Therefore, CHP do not displace variable renewables or nuclear power.
The cost-efficient operation of CHP also depends on the electricity system:

- CHP are used as a mid-merit technology. They stop producing when renewables and nuclear generation are sufficient to cover the demand.
- Therefore, CHP do not displace variable renewables or nuclear power.
- Thermal electricity-only generation (OCTs/CCGTs) are still required for peak hours.

CHPs adapt to renewables to match power demand

CHPs are stopped at times of excess RES/nuclear generation, backup boiler covers heat demand

Biogas/hydrogen turbines provide peak generation