Is Germany Ready for Hydrogen? Outlook on New Reliable Capacity

Public Report

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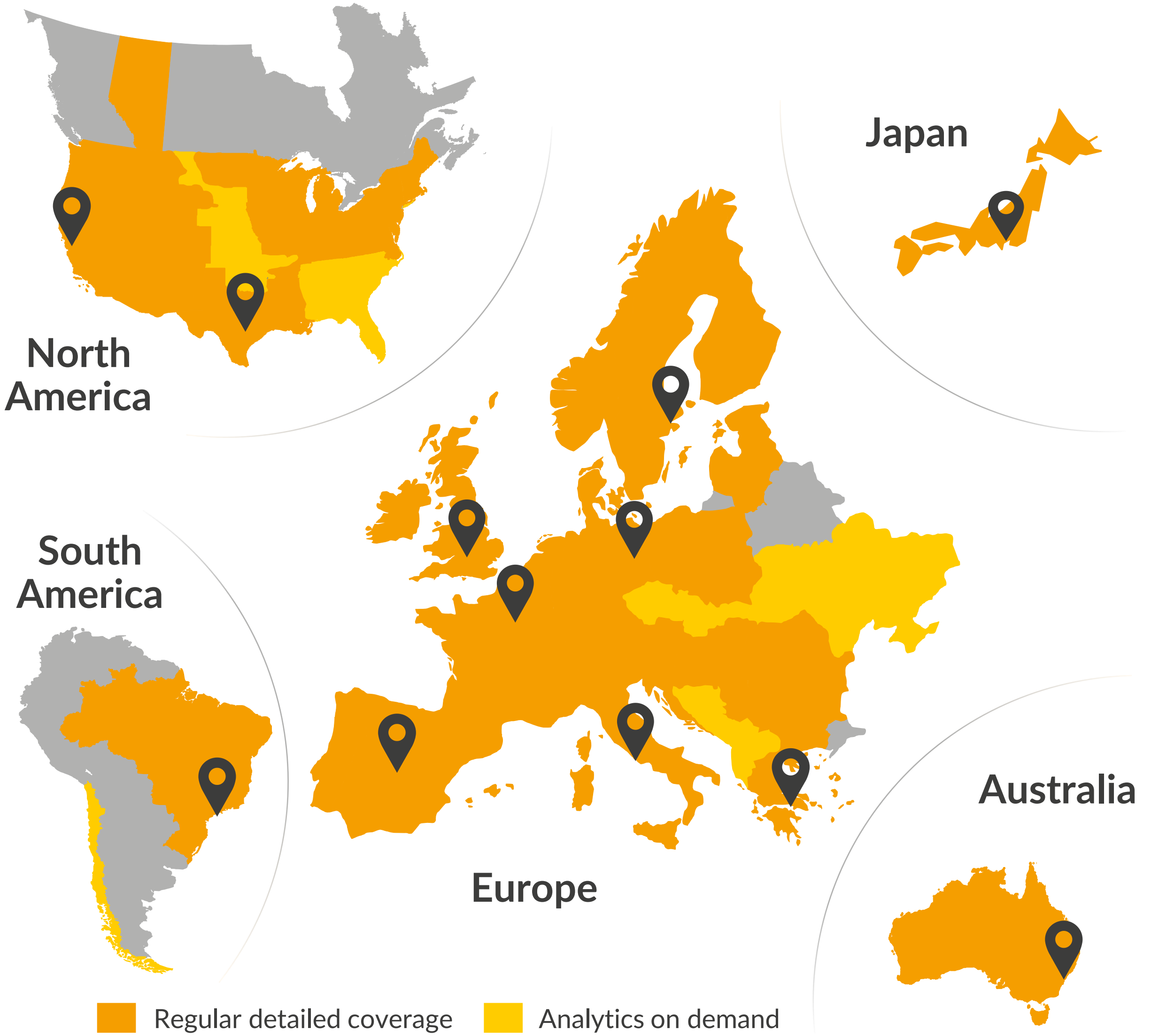

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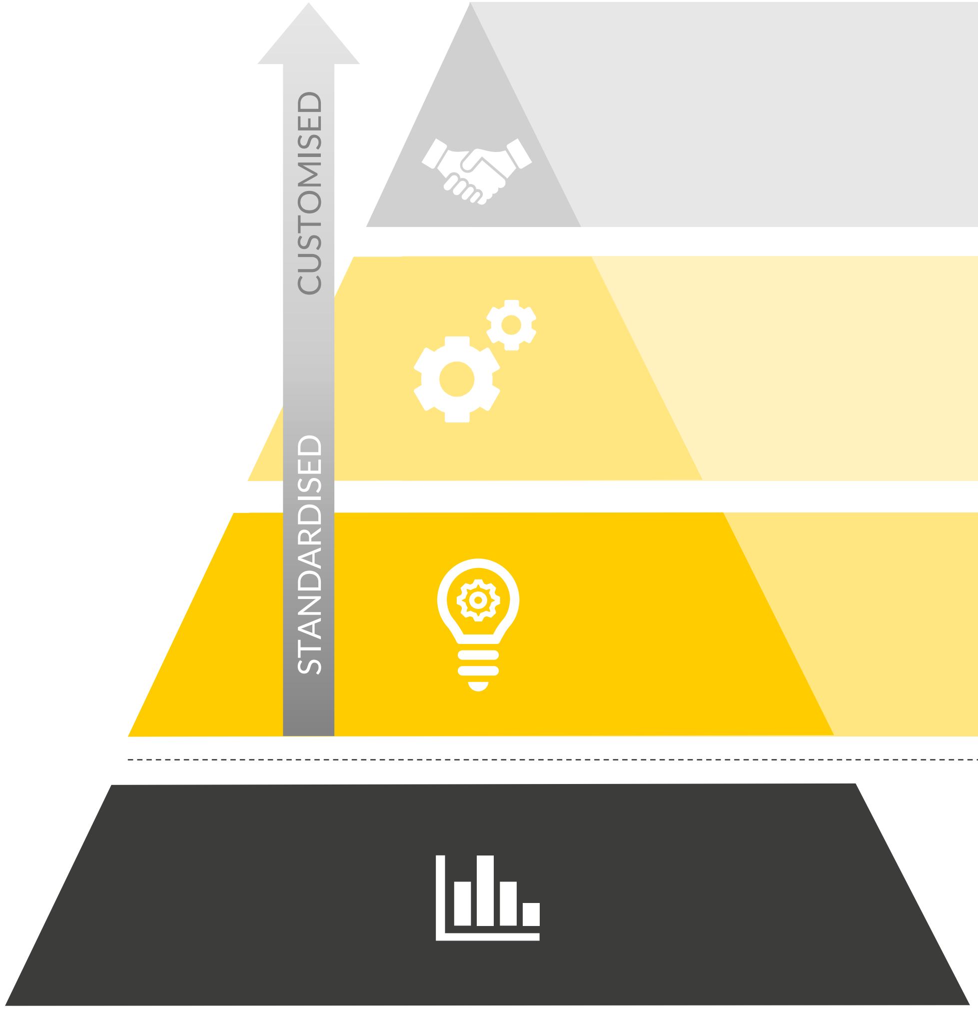

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> *"With its capabilities, intellect and with its credibility Aurora plays an essential role bringing the dialogue [in the global energy transition] to a different plane"*
>
> Ben van Beurden, CEO, Shell

> *"Aurora analysis and the provision of reliance was crucial for our debt funding. Their ability to explain market logics and revenue streams was vital for this successful financing."*
>
> Jeremy Taylor, Director, Green Frog Power

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Source: Aurora Energy Research

Agenda

Without additional dispatchable capacity, Germany might face a capacity gap of 10 GW in its power system by 2030

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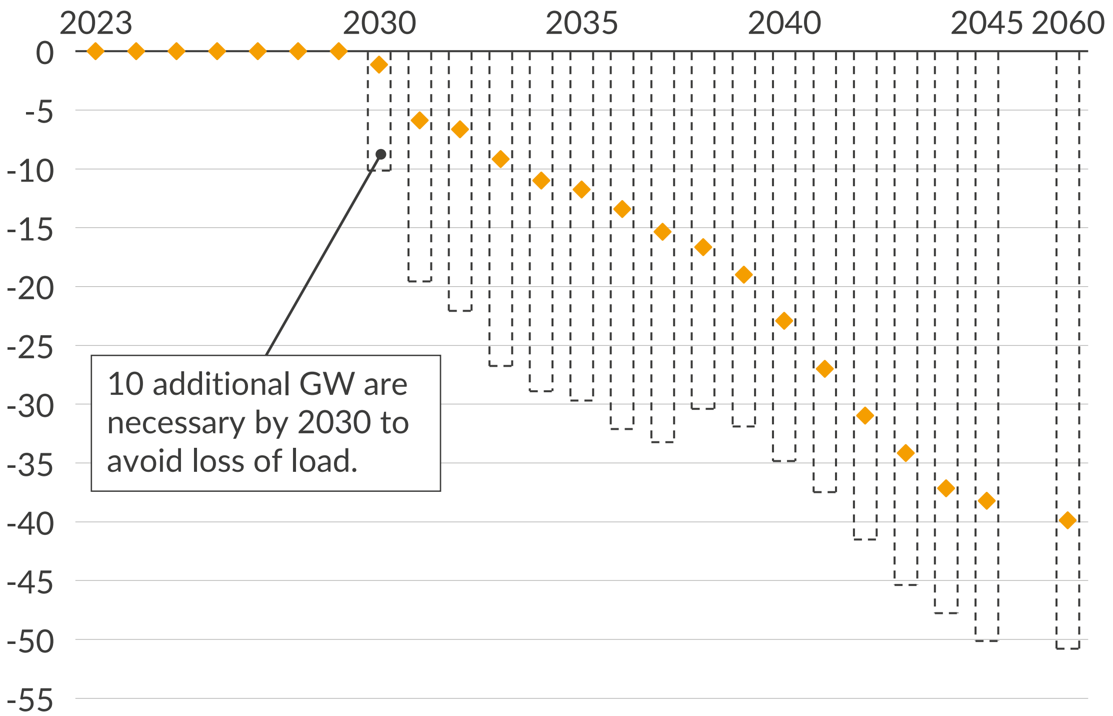
The National Resource Adequacy Assessment[1] assesses that security of supply is ensured in the period between 2025 and 2031.

Key assumptions/outcomes	BNetzA adequacy assessment	Aurora Net Zero + 2030 coal exit
Meeting governmental buildout targets for renewables, grid, and interconnector availabilities	✓ (Included)	✓ (Included)
Early coal exit in 2030	✓ (Included)	✓ (Included)
Sufficient day-ahead market price peaks for peaker buildout	✓ (Included)	✓ (Partially included)
Full realisation of demand flexibility potentials and emergency power systems	✓ (Included)	✓ (Partially included)
Missing capacity in 2030	0 GW	10 GW

✓ Included ✓ Partially included

Capacity gap without newbuilds in Aurora Net Zero incl. 2030 coal exit
GW



Insufficient price signals from the energy-only market (EOM) necessitate a support strategy to close this gap.

◆ Average across weather years (2006-2015) [ ] Tightest weather year

1) Versorgungssicherheitsmonitoring.

Sources: Aurora Energy Research, Bundesnetzagentur

Closing the capacity gap with CO_2-free flexibility is expensive and will require subsidies under the current energy-only market design

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Technological options for providing reliable CO_2-free flexibility are limited in Germany

+ CCS	+ CCS		
Natural gas & CCS	**Biomass & CCS**	**Long-duration energy storage**	**H_2 (-ready) plants**
CCS not feasible under existing German regulation	CCS not feasible under existing German regulation + limited availability of biomass	Missing technological market readiness, but with potential to provide system stability in the future	Facing a profitability gap that can be bridged with subsidies

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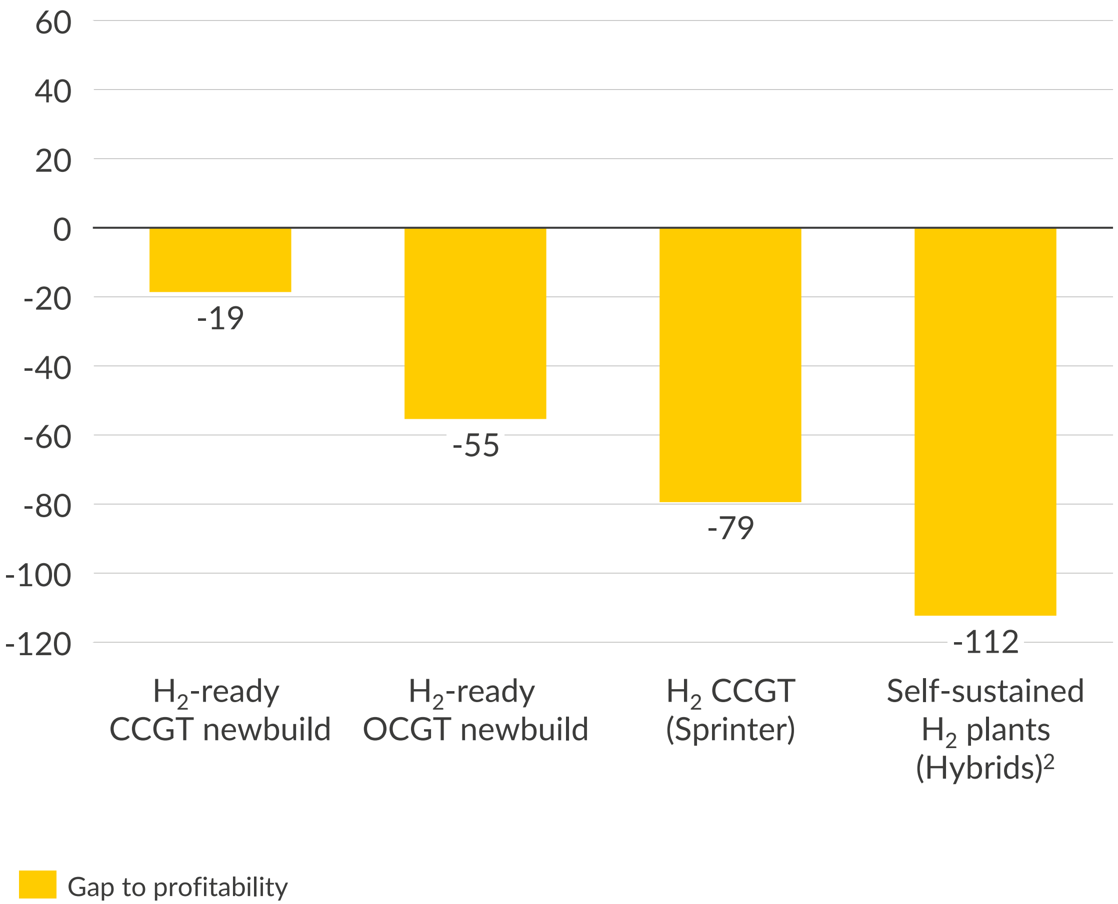
benjamin.latrobe@auroraer.com

Focus of this report

Feasible hydrogen plant technologies for the German market face a profitability gap

Average annual gap to profitability over lifetime, COD 2030[1]
k€/MW * a (real 2022)



1) Assumes switch to hydrogen for conversion plants in 2036. 2) Hybrid plants cannot be fully counted as firm capacity with current suggestion of 24 – 72h storage duration.

Source: Aurora Energy Research

By 2028, the BMWK proposes to tender 23.8GW of dispatchable hydrogen-based capacity to replace retiring baseload plants and ensure security of supply

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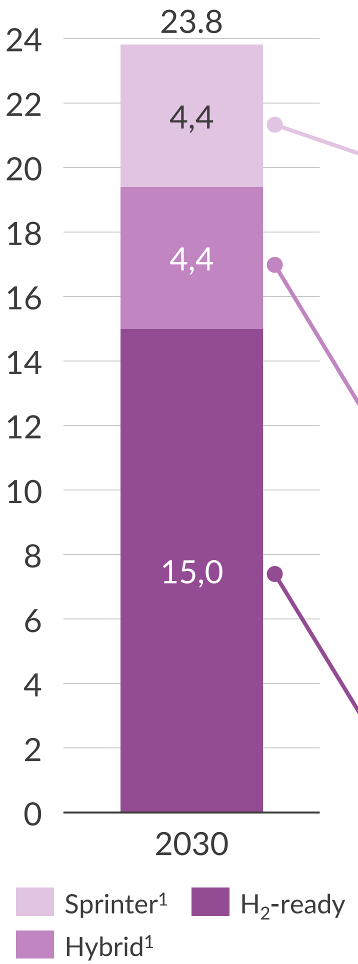
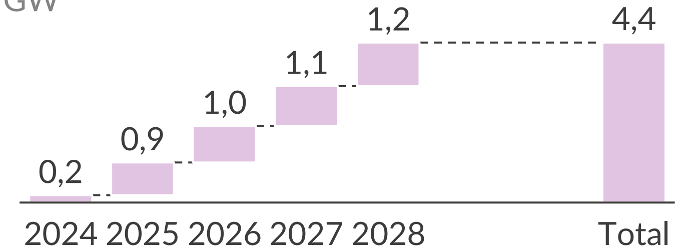
Dispatchable capacity
GW



Planned tenders	Technology	Subsidy	Constraints

Sprinter

Green hydrogen Sprinters[2]
GW



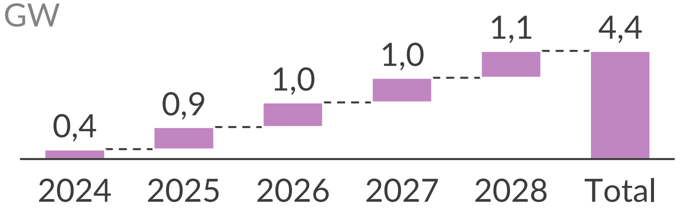
Technology
- **CCGT**[3] or OCGT[4]
- **New build** or retrofit

Subsidy
- CAPEX and OPEX subsidies with multiple options[5]
- 10-year subsidy phase

Constraints
- OPEX support restricted to 1,000 full load hours per year

Hybrids

Hybrid hydrogen plants[2]
GW



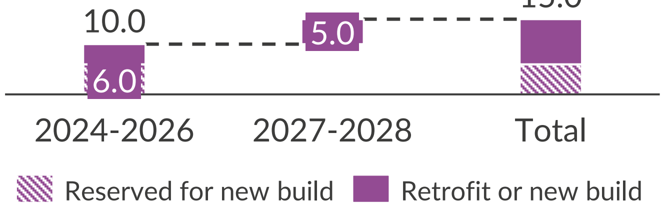
Technology
- **OCGT** or CCGT
- **New build**

Subsidy
- Fixed share of CAPEX is subsidised
- Market premium for hydrogen-based electricity subject to auction
- Renewables market premium[6]
- 10-year subsidy phase

Constraints
- OPEX support restricted to 200 to 250 full load hours per year

H_2-ready

H_2-ready plants
GW



Technology
- **CCGT** or OCGT
- **New build** or retrofit

Subsidy
- CAPEX subsidy subject to auction
- OPEX: fuel price CfD
- 10-year subsidy phase after conversion

Constraints
- Up to 1,000 full load hours per year
- Strong restrictions for retrofits[7]

1) Both Sprinter and Hybrid assets are purely hydrogen-fuelled plants. 2) Tendered under the EEG. 3) Combined cycle gas turbine. 4) Open cycle gas turbine. 5) Details on the different proposed subsidy options on page 17. 6) The average strike price of latest two renewables auctions will be the support level for the renewables power fed into the grid directly. 7) A plant would only be eligible to subsidy payments if the CAPEX of a retrofit exceed 80% of newbuild costs (compare page 12).

Sources: Aurora Energy Research, BMWK

We analyse the prospect of the different asset types in our Aurora Net Zero scenario

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Aurora Net Zero scenario – including *Kraftwerksstrategie* (KWS)

Net Zero 2045

- Supporting a Net Zero economy by 2045.
- Governmental buildout targets for renewables are met.

KWS plants included

- Buildout of all 23.8 GW of hydrogen(-ready) plants as outlined in the *Kraftwerksstrategie*.
- Plants receive CAPEX + CfD/market premium support.
- Additional thermal capacity buildout after 2040, assuming capacity payments.

High power demand

- Increased demand from electrification of heat, transport and industry, as well as from subsidised hydrogen electrolysers lead to a demand of 745 TWh by 2030 and 1108 TWh by 2045.

Central hydrogen price

- Assuming the introduction of a functioning international hydrogen market.
- Prices are outcomes of our in-house hydrogen market model and the same as in our Central scenario.

We invite you to join our study on the Kraftwerksstrategie and the future of the German gas fleet. **Check out slide 25 for more info!**

Source: Aurora Energy Research

Agenda

H_2-ready

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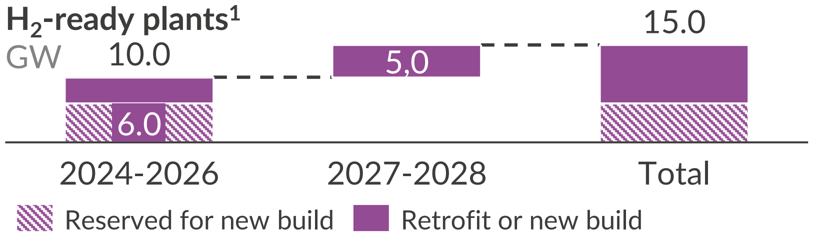
H_2-ready: power plants that can convert to burning hydrogen once connected to the hydrogen core grid

Plant-specific subsidy scheme under current KWS proposal

Planned tenders



Technology

- Newbuilds and retrofits
- Minimum size: 10 MW
- Fuels: (green) hydrogen or (green) ammonia

Subsidy

- One-off investment subsidy, up to 100% (subject to bidding process)
- OPEX-CfD, subsidizing cost difference between hydrogen and clean gas price

Constraints

- Subsidies limited to 10,000 total and 1,000 FLH[2] per year
- **Backstop rule:** Only eligible for support while power price is above coal or gas SRMC[3]
- **Retrofits are only eligible if conversion costs are at least 80% of newbuild costs**
- Newbuild must be built in proximity of the H_2 core grid

Aurora model implementation and asset parameters

Commencing operation	2028 - 2032	
Technology	CCGT[4]	
Lifetime	30	years
Year of conversion	2036	
Efficiency at maximum load (HHV)	57	%

Learn more about Aurora power market modelling capabilities from **Benjamin La Trobe, Commercial Associate**

benjamin.latrobe@auroraer.com

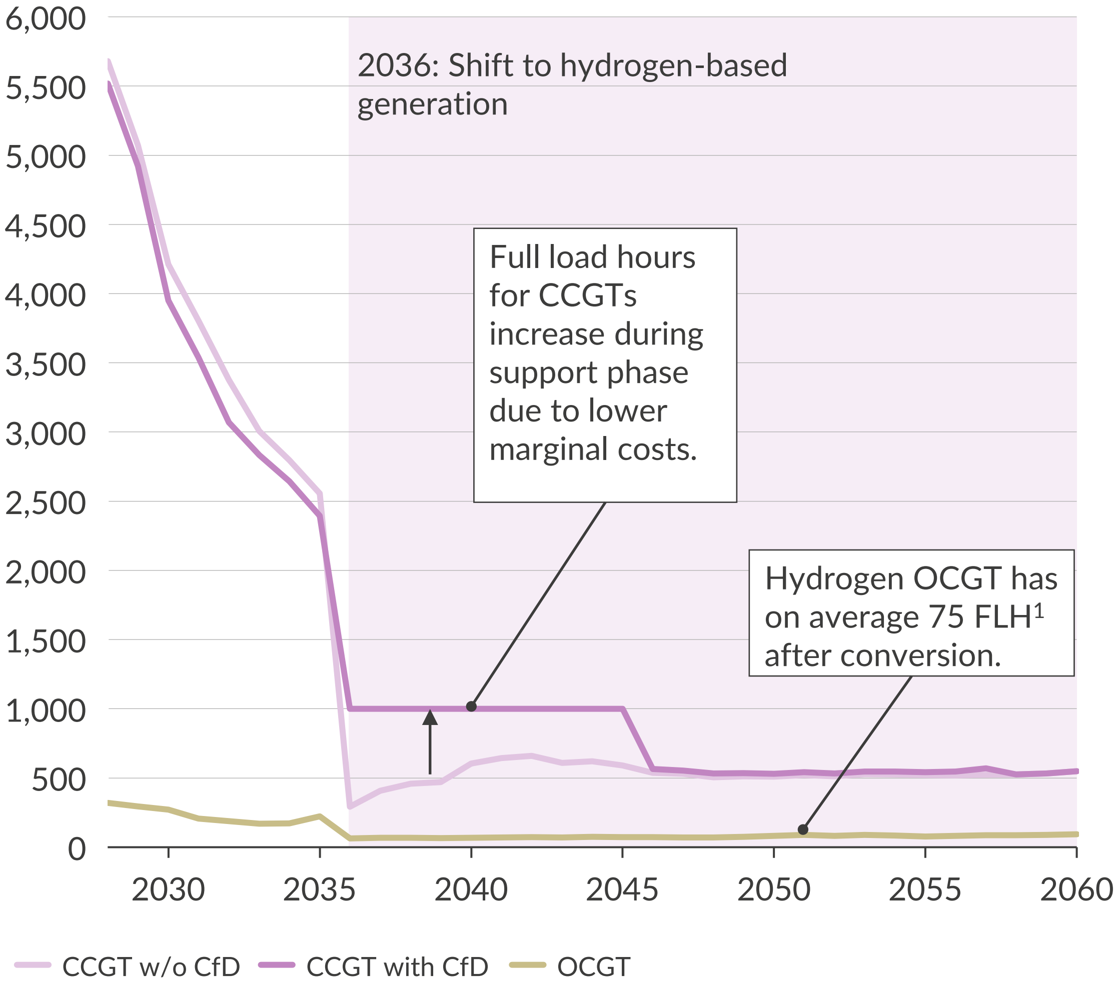
1) Tendered under the EEG. 2) Full load hours. 3) Short-run marginal costs. 4) For simplicity we only consider CCGTs here, while our modelling also allows for OCGTs as conversion plants.

Source: Aurora Energy Research

Shifting from natural gas to hydrogen as a fuel entails a significant decrease in utilisation for H_2-ready plants

Annual full load hours for subsidised vs. unsubsidised CCGTs and OCGTs

hours



CCGT vs. OCGT

- Full load hours for CCGTs decrease to below 3,000 hours until 2035 as increasing generation from renewables and CO_2 prices reduce the utilisation rate of thermal assets.
- The switch to hydrogen-based generation marks a collapse in full load hours for conversion plants.
- Due to their lower efficiency and thus higher marginal costs, OCGTs have an even lower full load hours.[2]
- OCGTs experience a similar decrease in full load hours upon the switch to hydrogen, with full load hours remaining below 100.

Full load hours for CCGTs

- The Kraftwerksstrategie allows a maximum of 1,000 subsidised full load hours per year for a period of 10 years.
- Operating under natural gas SRMC due to the OPEX-CfD, H_2-ready plants reach this upper limit in each of the 10 years.

1) Full load hours. 2) Here we only consider operation on the day-ahead market.

Source: Aurora Energy Research

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Sprinter: Power plants that purely run on hydrogen and thus need a reliable hydrogen supply from the beginning

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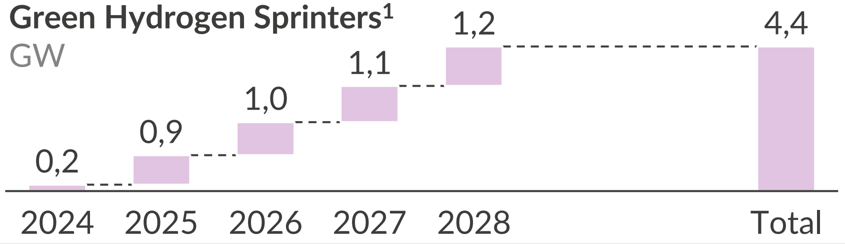
Plant-specific subsidy scheme under current KWS proposal

Planned tenders

Green Hydrogen Sprinters[1]
GW



Technology

- Newbuilds and retrofits
- Minimum size: 1MW
- Fuels: (green) hydrogen or (green) ammonia

Subsidy

Option 1 (preferred by BMWK)

- Market premium for hydrogen-based power generation (subject to bidding process)
- Investment subsidy: 50-80% of investment cost, paid out over 10 years

Option 2

- One-off investment subsidy of up to 100% (subject to bidding process)
- OPEX-CfD subsidizing cost difference between H_2 and clean gas price

Constraints

- Limited to 10,000 FLH total and 1,000 FLH per year
- **Backstop rule:** Only eligible for support while power price is above coal or gas SRMC[2]

Aurora model implementation and asset parameters

Commencing operation	2029 - 2034	
Technology	CCGT	
Lifetime	30	years
Efficiency at maximum load (HHV)	56	%

1) Tendered under the EEG. 2) Short-run marginal costs.

Source: Aurora Energy Research

Sprinter

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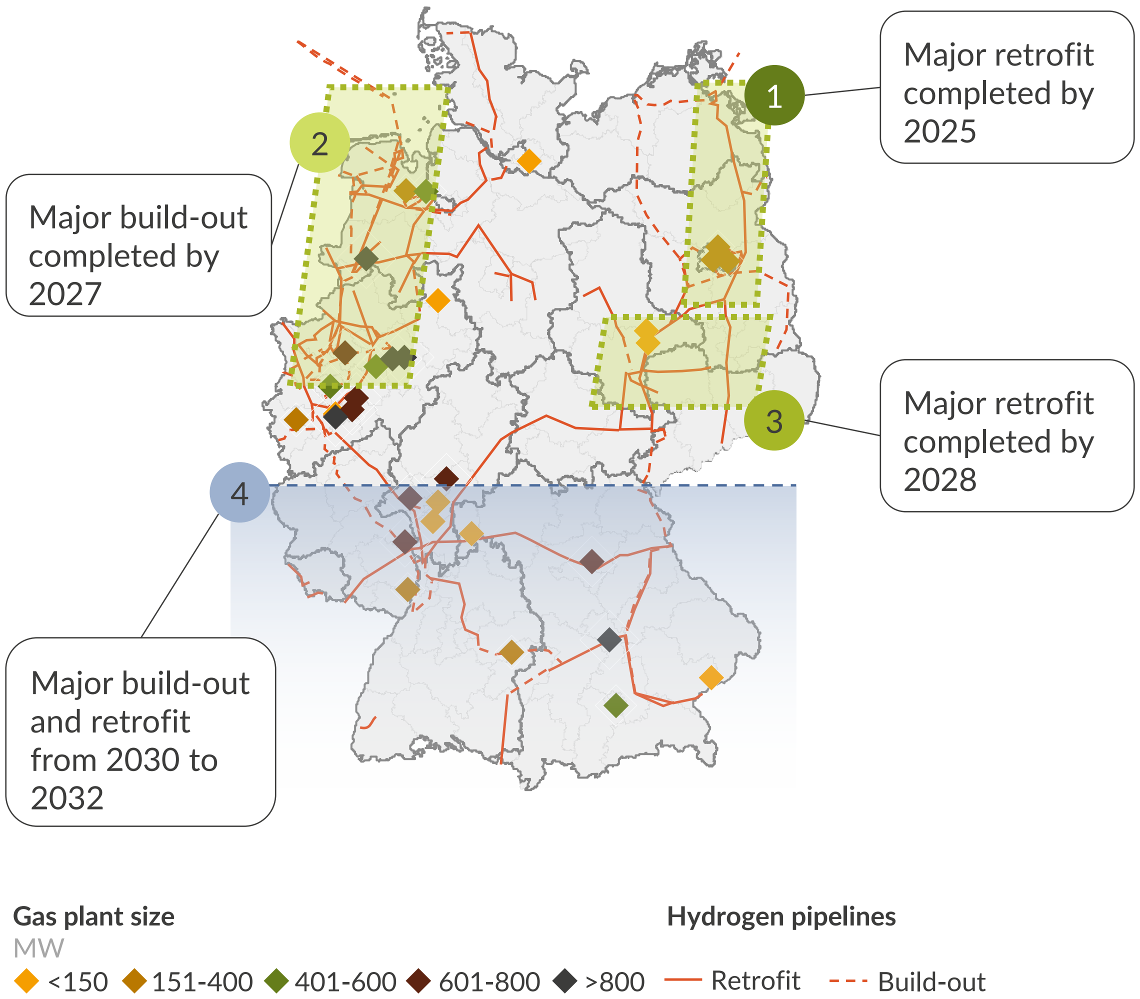
Earlier availability of a reliable hydrogen supply in northern Germany restricts the system-friendly allocation of these plants

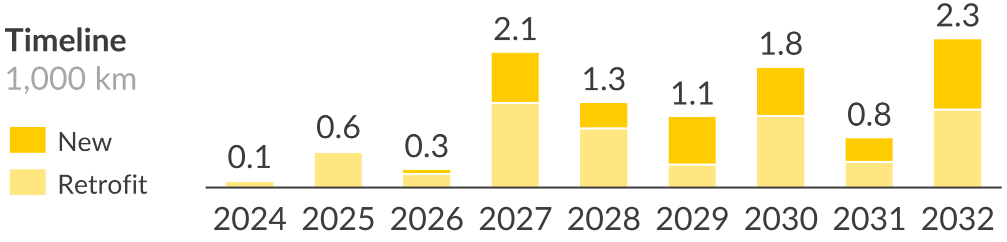
Hydrogen core grid plan and existing gas plants[1]



Overview of the planned development of the hydrogen core grid

		Retrofit	Build-out (new)	Total
Total length	km	5,630 (58%)	4,091 (42%)	9,721
Total costs	bn€	3.3	16.5	19.8

Timeline
1,000 km



- Burning hydrogen from start of operation requires Sprinter plants to have access to the hydrogen core grid.
- Sprinter plants that participate in the first auctions will have to locate in the Northwest or East of Germany to secure hydrogen supply.
- A fast buildout is essential to enable system-friendly allocation in southern Germany.

1) Only includes gas plants > 100 MW.

Sources: Aurora Energy Research, Bundesnetzagentur, FNB

Agenda

I. Introduction: The new *Kraftwerksstrategie*

II. Outlook for hydrogen-based flexible assets

1) An analysis of H_2-ready gas plants
2) Sprinter plants and their dependency on hydrogen
3) Hybrid, but highly expensive: The case of Hybrid hydrogen plants

III. How does it all fit together?—Total costs and power price impact

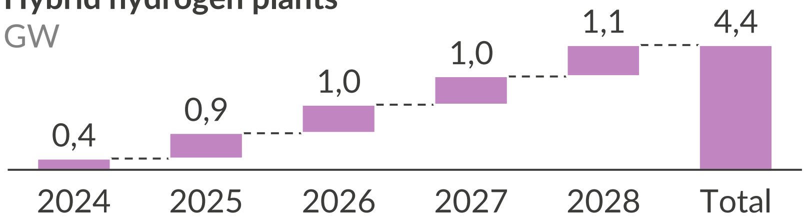
IV. Key takeaways

Hybrid plants: Asset combinations producing and reconverting hydrogen into electricity

Plant-specific subsidy scheme under current KWS proposal

Planned tenders

Hybrid hydrogen plants[1]
GW



Technology

- Newbuilds
- Fuel: (green) hydrogen

Subsidy

1. Market premium for renewable power generation fed into the grid (**not** subject to bidding process – average bids from two previous EEG auctions serve as reference value)
2. Market premium for hydrogen-based power generation (subject to bidding process)
3. Investment subsidy: 50-80% of all hydrogen-related components, paid out over 10 years

Constraints

- Limited to 2,500 full load hours (of the hydrogen plant) in total; per year: min 200 & max 250 full load hours
- **Backstop rule:** Only eligible for support while power price is above coal or gas SRMC[2]

Aurora model implementation and asset parameters

Commencing operation	2029 - 2034	
Technology	OCGT	
Lifetime	25	years
Efficiency at maximum load (HHV)	36% - OCGT 25% - round-trip efficiency[4]	

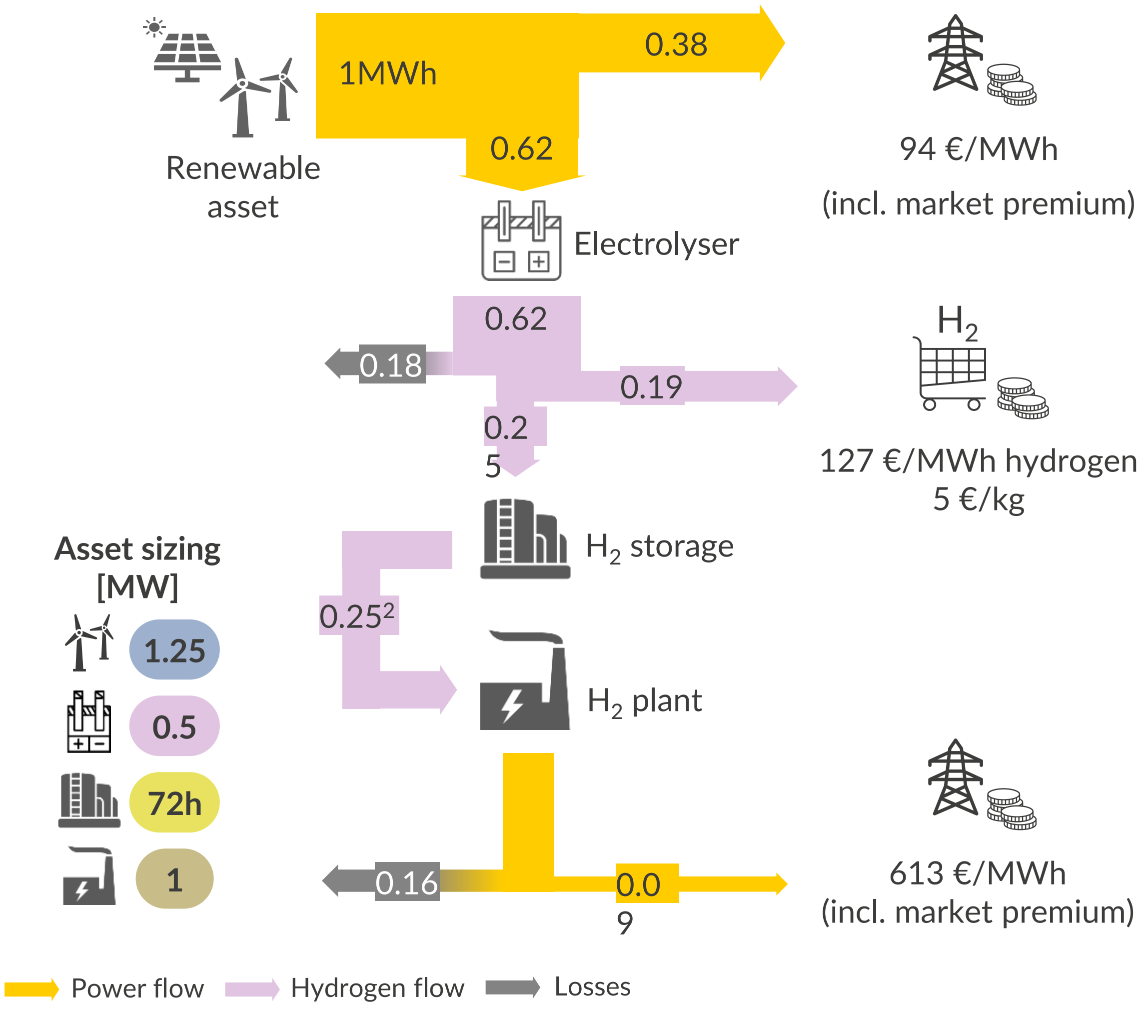
1) Tendered under the EEG. 2) Short-run marginal costs. 3) Commercial operation date. 4) Round-trip refers to process from hydrogen production to re-electrification.

Source: Aurora Energy Research

Set-up of Hybrid hydrogen plants consists of renewables assets, electrolysers, hydrogen storage and hydrogen power plants

Component		Operation and requirements
	Renewables assets Produces electricity with wind, solar or a combination of both.	▪ Power can be either sold directly on wholesale market (with market premium) or used in the electrolyser.
	Electrolysers Power is consumed from the RES asset or grid (in case of curtailment or negative price hours).	▪ Producing hydrogen for power plant or selling directly without subsidies. ▪ Size requirement > 50% of power plant capacity.
	Hydrogen storage Stores hydrogen for selling or reconversion to power.	▪ Requires enough storage capacity to power the plant for 24 to 72 hours. ▪ Could be a tank or cavern
	Hydrogen power plants Produces power from stored hydrogen.	▪ Full load hours restricted to 200-250 per year using locally produced green hydrogen. ▪ Power is sold on wholesale market (with market premium).

Set up of an exemplary Hybrid plant, energy flows, and revenues in 2030[1]
MWh



1) Onshore wind with a load factor of 21%, electrolyser efficiency of 71%, hydrogen power plant efficiency of 36%. 2) We assume no storage losses.

Source: Aurora Energy Research

Hybrids

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Various LDES technologies are currently being developed and could challenge Hybrid plants in technology-neutral auctions

Overview of Long Duration Energy Storage (LDES) technologies

	Iron Air Battery	Liquid Air Energy Storage (LAES)	Compressed Air Energy Storage (CAES)	Hybrid hydrogen plants
Storage duration	1 to 15MW[1] 1 to 100h	5 to 650MW 2 to 24h	100 to 500MW 8 to 72h	1 to 400MW 24 to 72h
Levelized cost of storage in 2030[2] in €/MWh (real 2022)	656	1.012	862	995
Commercial maturity[3]				
Efficiency				

1) The first commercialised pilot facility with a capacity of 1MW will be commissioned this year. Its producer, Form Energy, is planning on building another facility with the capacity of 15MW. 2) Assuming a lifetime of 25 years, a WACC of 9% , 24h storage duration, 250 discharge hours per year and Aurora Net Zero scenario wholesale power prices from October 2023. 3) Based on technology readiness level (TRL).

Sources: Aurora Energy Research, Fraunhofer ISI, Schmidt et al. 2019

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The *Kraftwerksstrategie* reduces baseload prices but comes at a cost of 41bn €; 15 bn € above the costs of a capacity market solution

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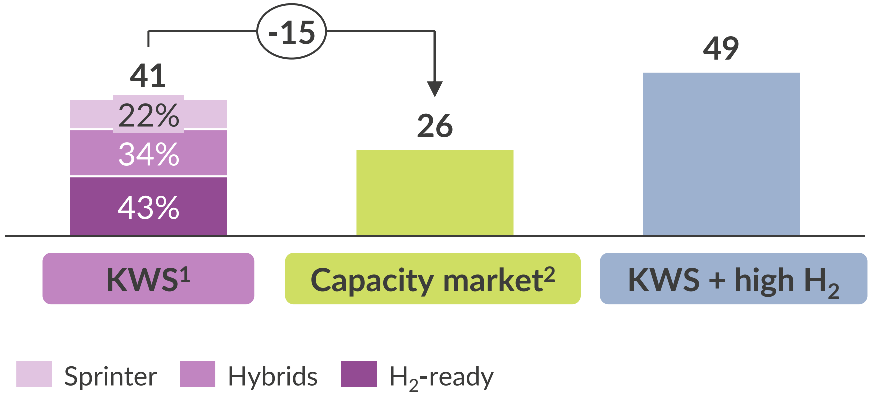
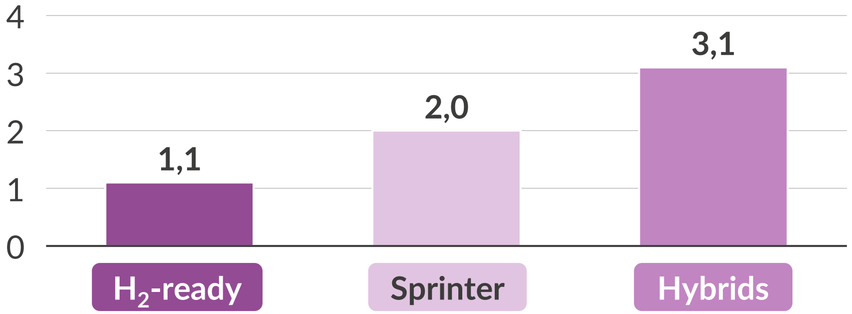
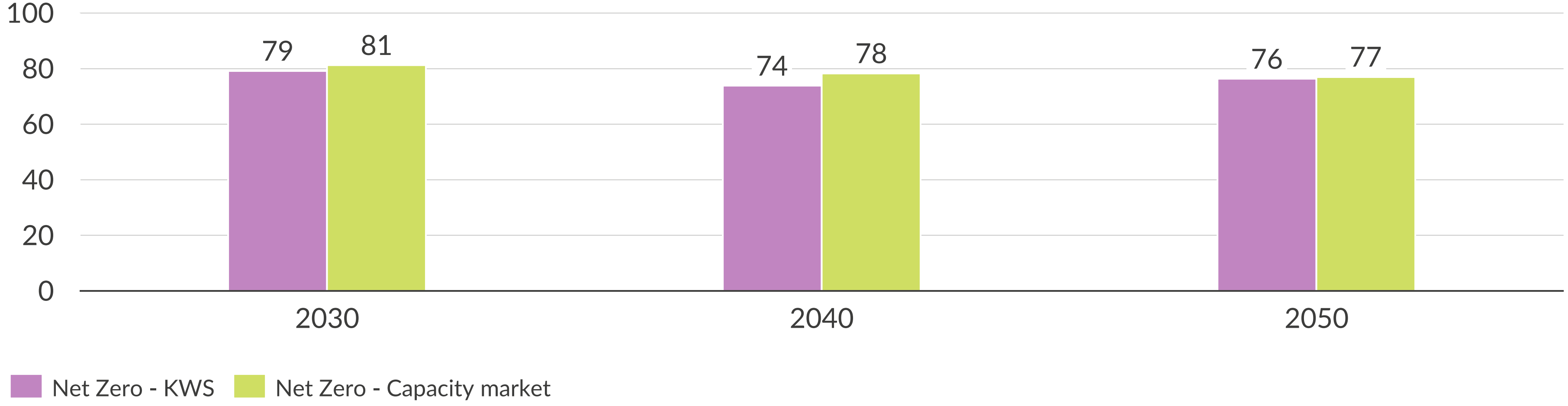
Cost for KWS and capacity market only scenarios 2025 – 2050[2]
bn€ (real 2022)



KWS support costs break down by technology
bn€/GW (real 2022)



Baseload electricity prices in KWS scenario and capacity market scenario[3]
€/MWh (real 2022)



1) Includes 2GW additional capacity market build-out. 2) Includes CAPEX and OPEX support costs for capacities laid out in the Kraftwerksstrategie draft. Not including costs arising from higher power prices. 3) Capacity market scenario realises capacity buildout via a capacity market and does not include any OPEX subsidies.
Source: Aurora Energy Research

State spending sensitivities

- Acquiring reliable capacity buildout through a capacity market would cost only 26 bn€ because of higher cost-effectiveness and later buildout of assets.
- The planned OPEX-CfDs for H_2-ready plants are the most important driver of the 8 bn € cost increase in the high hydrogen price sensitivity scenario.

OPEX subsidy impact on power prices

- More expensive oil and gas peakers are priced out of the market by subsidised KWS plants more often, leading to a reduction in the baseload price.
- Capacity market payments on the other hand, do not impact bidding behaviour as they do not impact marginal costs of the hydrogen plants

In the long run, other sources of flexibility besides thermal assets have a high potential to help ensuring security of supply

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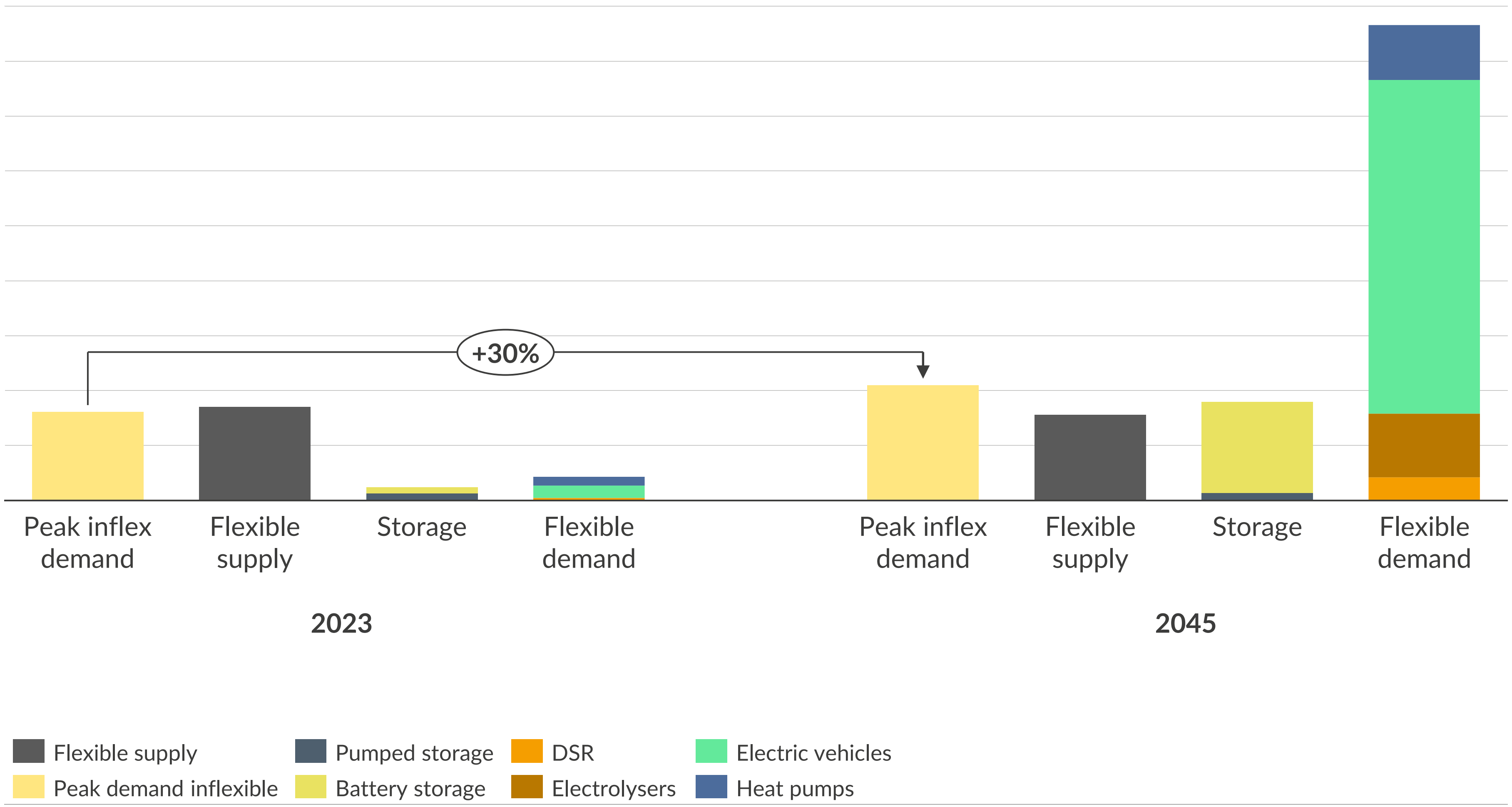
Installed capacity and peak of inflexible demand
GW



- Incentivising inflexible demand to react to price signals could reduce the need to build new flexible thermal assets.
- Although total demand more than doubles between 2023 and 2045, the peak of inflexible demand (maximum residual load) increases by just 30%.
- This increase could be easily (over-)compensated. For example, by vehicle to grid appliances that reach a very high potential for charging/discharging power by 2045.

Source: Aurora Energy Research

Agenda

Key takeaways

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1 Germany needs **10GW of additional reliable capacity to enable a coal exit by 2030**, while ensuring security of supply. The BMWK has proposed a power plant strategy (*Kraftwerksstrategie*) to address this capacity gap, which proposes **three new hydrogen-based asset** types: H_2-ready, Sprinter and Hybrid plants.

2 Each of these technologies faces a **gap to profitability**, as price peaks in the energy-only market do not provide sufficient revenue opportunities. Based on the Aurora Net Zero scenario, the average missing money per year for plants commissioning in 2030 is:

- H_2-ready CCGT: 19 k€/MW/year
- Hydrogen CCGT plants (Sprinter): 79 k€/MW/year
- Self-sustained hydrogen plants (Hybrids): 112 k€/MW/year

3 According to our estimates, to bridge the profitability gap, **a total subsidy amount of 41 bn€ until 2050** in the form of CAPEX and OPEX support under the *Kraftwerksstrategie* is needed. In the alternative capacity market scenario, costs are lower (26 bn€) because of the assumed higher cost-effectiveness and later buildout of assets.

4 We see the following necessities/opportunities to improve the *Kraftwerksstrategie*:

- Existing **gas plants have low incentives to convert** to hydrogen in 2030s, possibly leading to a fossil lock-in.
- Planned tenders for Hybrids could be exchanged **with technology-neutral tenders** for assets with storage durations of 24 – 72h.
- The *Kraftwerksstrategie* could be made more cost-effective by allocating **more capacity to H_2-ready and less to Sprinter/Hybrids plants**.
- To reduce reliance on hydrogen created by *Kraftwerksstrategie*, **power demand flexibilization and new sources of storage will be key**.

Source: Aurora Energy Research

We invite you to join our study on the Kraftwerksstrategie and the future of the German gas fleet

Answering key questions via a study

- We will answer the most important questions on the Kraftwerksstrategie and the future of the German gas fleet. For doing so, we offer you to **join our study.** This allows us to create a **comprehensive analysis at an affordable rate,** while simultaneously **bringing the relevant parties and their ideas together** to the table. Main questions to be answered are:
  - How does the final version of the Kraftwerksstrategie (KWS) look and what is it trying to achieve?
  - Does a profitable business case for commercial gas power plants exit, or is further policy support needed?
  - What are costs and barriers for plant conversion?
  - Which plants are likely to convert first, given planned hydrogen infrastructure?
  - What are the economics of new-built plants versus converted ones? What is the missing money and how does the KWS help to close the gap?
  - What are considerations for bidding in future auctions?
- With this study, we are **inviting players along the value chain for gas assets in Germany, covering generators and plant owners, network operators, utilities, investors, and policy makers** to understand the impact of the *Kraftwerksstrategie* on gas assets in Germany. With input from the stakeholder group, we also aim to publish a policy note on the study outcomes.
  - We will start the study early 2024 once final details on the KWS are clear and expect the work to finish 2 months later.
  - The Aurora team will drive the analysis, topics and results will be discussed in two extensive workshops.

Deliverables

1 Final report	2 Four-hour workshops	1 Public insights report
Compiling all work and feedback.	Discuss in a collaborative format.	To provide insights for policy makers.

Source: Aurora Energy Research

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Credentials

Aurora has a strong track record working in the German power market and with the decarbonisation of thermal assets.

Throughout Europe we have advised utilities, financial institutions and asset owners on the impact of system-wide changes on power markets.

Aurora's price outlooks are regularly tested by a large subscriber base when it comes to financing investment decisions.

We would be delighted to welcome you as a participant!

Contact **Benjamin La Trobe, Commercial Associate,** to join our study.

benjamin.latrobe@auroraer.com

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- **Guarantees of Origin (GOO)** market statistics and price forecast

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Details and disclaimer

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