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ENERGY RESEARCH

CO_2-free flexible generation in the Dutch energy mix

Aurora Public Webinar

3 February 2022

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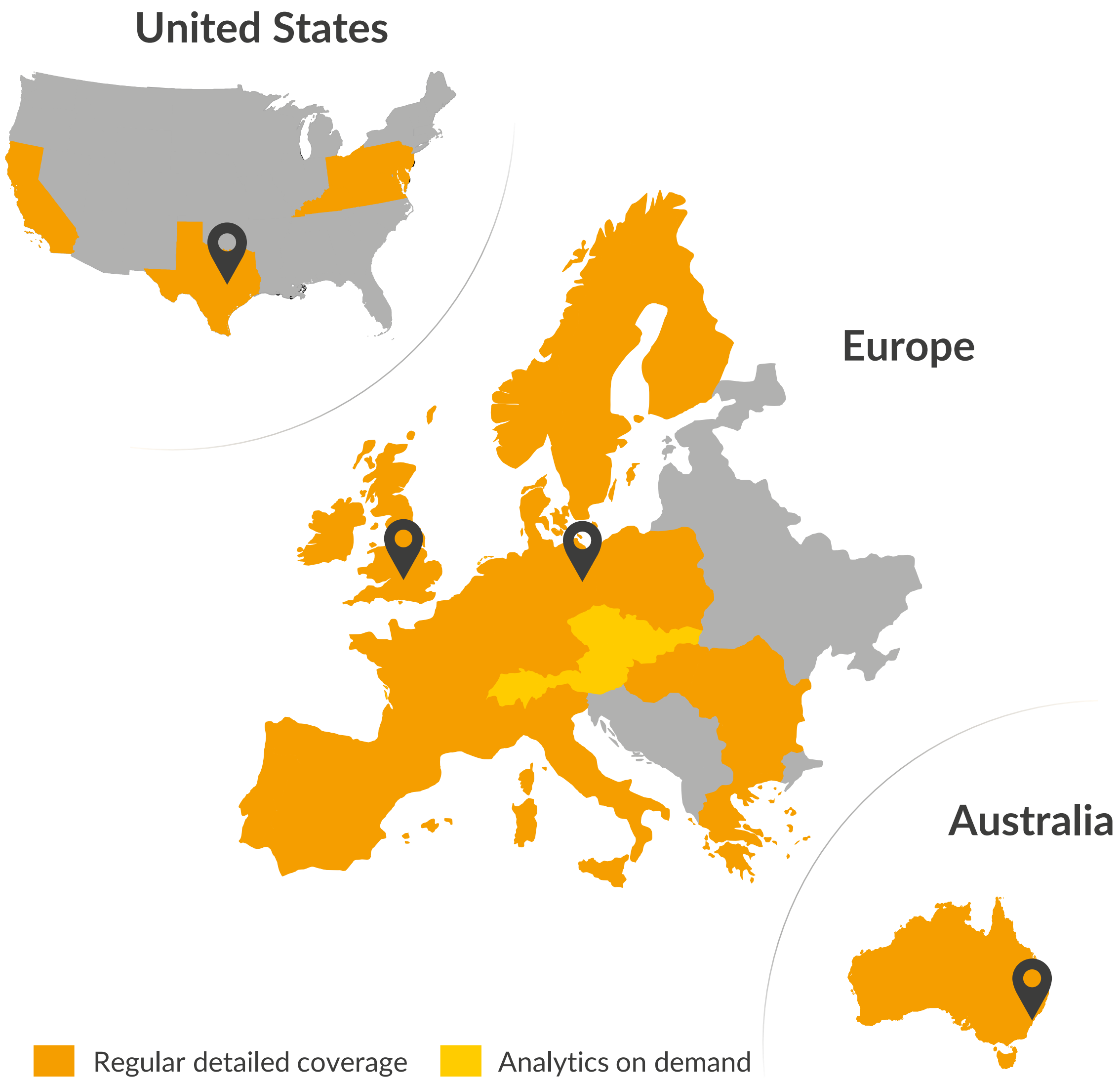
- Power markets
- Renewables
- Storage
- Electric vehicles
- Hydrogen (H_2)
- Carbon (CO_2)
- Natural gas



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Source: Aurora Energy Research

Aurora brings a sophisticated approach to the provision of analysis and insight to the energy industry

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- Industry-standard market outlook reports and bankable price forecasts for power, gas, carbon and hydrogen markets
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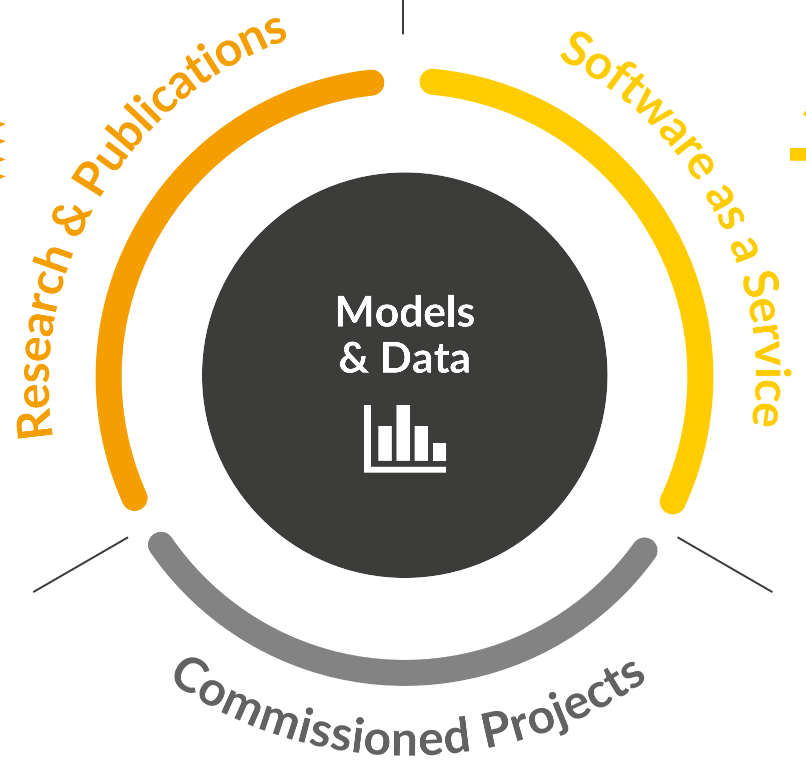
- Out-of-the-box SaaS solutions, combining cutting-edge sophistication with unparalleled ease of use
- *Origin* provides cloud-based access to Aurora's market model, pre-populated with our data
- *Amun* automates asset-specific wind farm valuations for over 30 leading funds, developers and utilities



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- Bespoke analysis, drawing upon our models and data
- Trusted advice for all major market participants proven in 500+ projects: transaction support, valuations, strategy & policy engagement

Models & Data

- Market-leading long-term models for power, gas, hydrogen carbon, oil and coal markets
- Continuous model improvements to reflect policy and market developments

Source: Aurora Energy Research

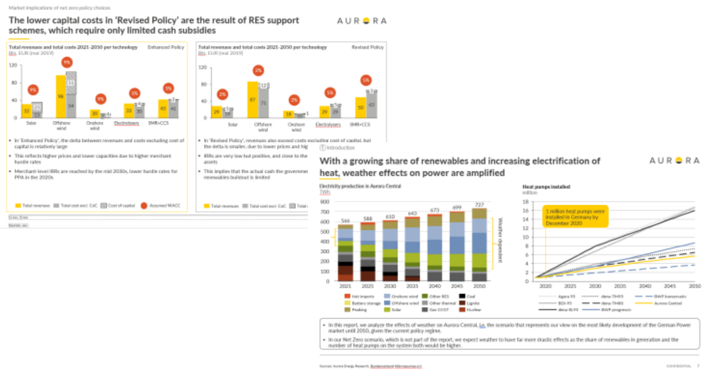
Dutch Power Market and Renewables Service: Key market analyses and forecasts for all participants in the Dutch power market

Quarterly data and bi-annual market reports to assess business models

- **Yearly forecasts of wholesale market prices** until 2050 in three scenarios: central, high and low
- **Net Zero scenario until 2050** detailing capacity mix, generation mix, capture prices and wholesale market prices
- **Price distributions**, dark and spark spreads
- **Capacity development**, generation mix, interconnector capacity, capacity buildout, exports
- **Capture prices** of key technologies (onshore, offshore, solar) in three scenarios: central, high and low
- **Imbalance costs & Guarantee of Origin forecast**
- **Utilisation rates** of key thermal technologies along different efficiencies
- EU-ETS carbon price forecasts

Group Meetings and Strategic Insight Reports

- **In-depth thematic reports** on topical issues
- **Three multi-client roundtable discussions** per year in Amsterdam to discuss reports with actors across the Dutch power market (utilities, developer, investors, project finance, government, regulation)



Interaction through workshops and ongoing support

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

Interested? Contact: Felipe van de Kerkhof (Felipe.vandeKerkhof@auroraer.com), +49 30 166 39 728

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Summary

The economics of flexibility options in 2030

i. Levelised Cost of Electricity

ii. Model Results on Profitability

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i. Analysis of Required Flexibility

ii. Technology Mixes

Non-financial hurdles

Executive Summary

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1. Overview of technologies offering CO2-free flexibility to the system

- Dispatchable Production Technologies (e.g. hydrogen power plant), Storage Technologies (e.g. Li-ion battery), Demand Flexibility Technologies (e.g. electric boilers, EVs) and Other Technologies (i.e. wind, solar and interconnection)

2. Evaluation of the business cases of the various flexibility options in 2030

- From a cost perspective:
  - Retrofitted biomass, biogas and H_2 power plants are best for short periods (1500 h/year)
  - Gas and biomass plants with CCS perform slightly better for longer periods (4500 h/year)
  - Of Storage Technologies, lithium-ion batteries have the lowest cost
- When testing the assets in the energy system of 2030:
  - Almost none of the assessed technologies have a positive business case by 2030
  - The best performing flexibility assets have low investment costs, like e-methane, biogas and hydrogen CCGTs

Executive Summary

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3. Quantification of the need for flexibility and determination of the cost-efficient path to CO2-free security of supply by 2050

- Demand Flexibility Technologies (up to 58 GW) reduce the need for additional capacity in the system towards 2050
  - However, the Dutch gas fleet cannot be phased out without additional CO_2-free production and storage post 2030
- With high security of supply margins, flex technologies will struggle to generate enough revenue to break-even
- In a tighter system with less back-up flexibility would lead to sufficient high-price hours for technologies to be profitable
- Retrofitted BECCS and H_2 CCGTs are best positioned to provide long-duration flexibility towards 2050
- Nuclear plants and Gas CCS will find it difficult to compete with BECCS and H_2 CCGT
- Back-up and short-duration flex capacity also require high-priced hours to operate economically

4. Overview of key non-financial hurdles to market entry and scale-up for CO_2 free technologies

- Lithium-ion batteries face high grid tariffs and scarcity issues on material use
- For Demand Flexibility Technologies, most hurdles stem from lacking incentives to flexibilize demand (e.g. fixed prices for households)
- Biofuels may be difficult to source sustainably in sufficient quantities
- Carbon-free hydrogen and e-methane are as of yet only available in small quantities; production requires scale-up
- For nuclear fission plants, long construction times and potential delays risk stalling CO_2 abatement. High CAPEX and long lifetimes risk large write-offs in later years, when more than expected RES capacities or other competing technologies are built
- Furthermore, a number of overarching uncertainties and infrastructural prerequisites would benefit from national coordination. For instance, power grid reinforcement and RES build-out need to happen fast for increased electrification, which is a prerequisite for decarbonisation and the deployment of many of the flexible technologies analysed in this report

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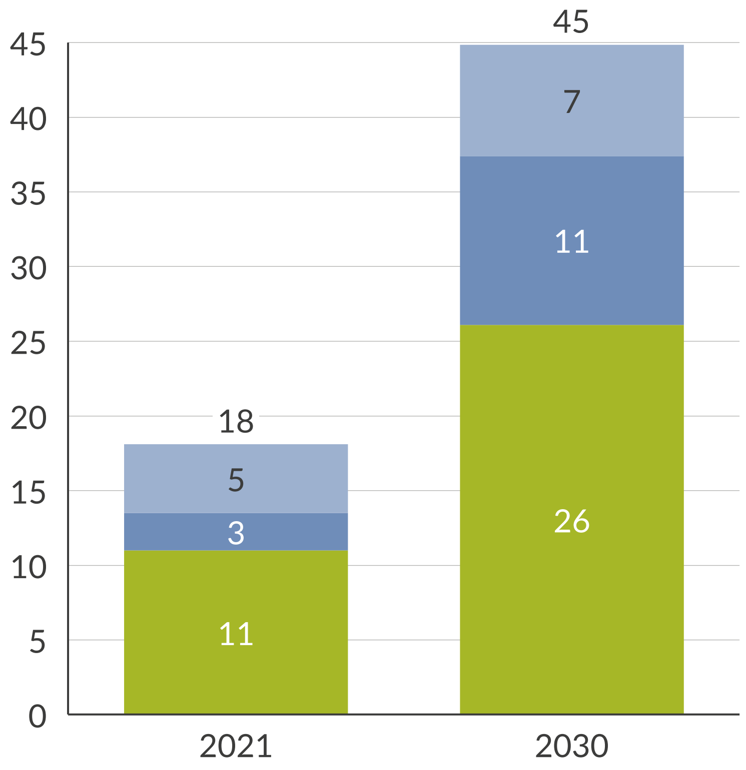
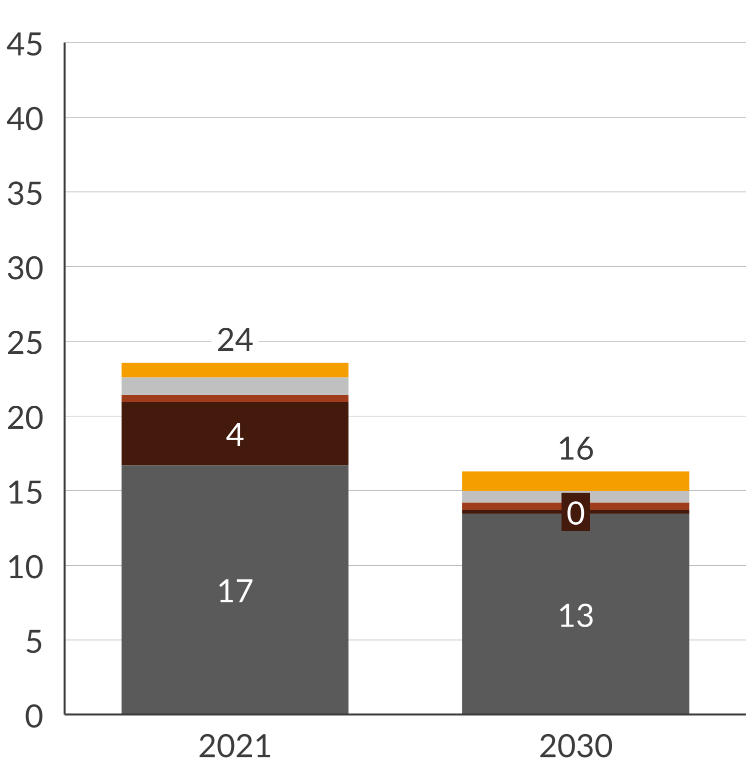
Towards 2030, renewable capacity is expected to more than double, whereas thermal capacity declines, leading to lower overall emissions

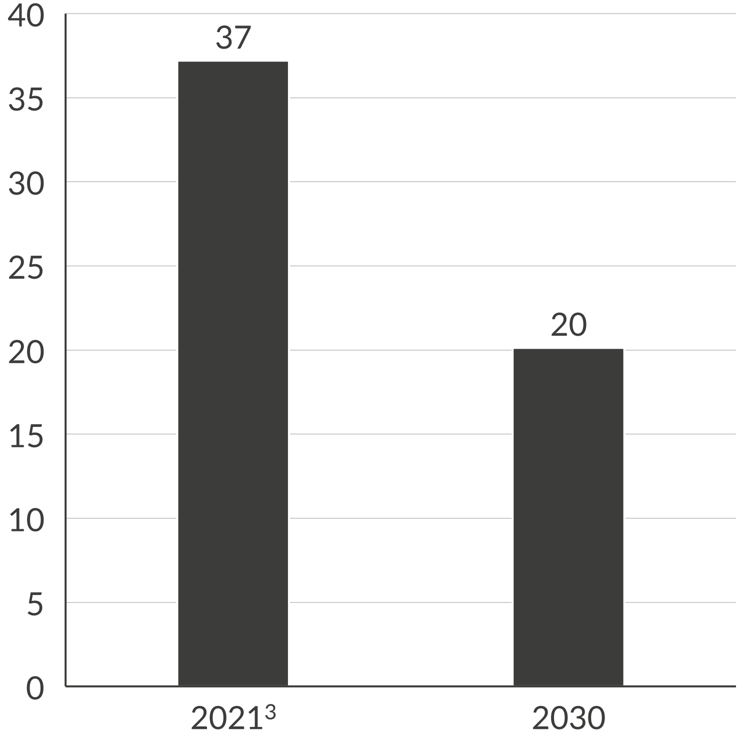
Renewable capacity
GW



Other capacity
GW



CO_2 emissions over time[1,2]
Mt



Onshore wind | Offshore wind | Solar | DSR[4] | Waste | Nuclear | Coal & biomass | Gas

Note: Base Case aligned with EZK and TenneT, based on KEV2020 and II3050. 1) Assumes waste incineration uses CCS starting 2030; 2) Includes emissions from heat produced by CHPs; 3) estimated based on standard weather year, no actual information available yet; 4) excludes demand response from electric boilers, electrolysers, EVs and heat pumps

Source: Aurora Energy Research

We assessed flexible technologies to further reduce emissions which differ in their economics and role in the power market

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A Dispatchable Prod. Technologies

- Technologies that can freely dispatch
- Characterized by their **levelised costs of electricity** (LCOE)
- **Financed** through the **wholesale market**

B Storage Technologies

- Technologies that buy in low price hours and sell at higher prices
- Assets are **financed** through the **wholesale market**
- Depend on the **spread between high and low-price hours**

C Demand flexibility Technologies

- Technologies do not supply electricity but can **adjust their demand**
- Investments mostly made for **diverse purposes** (e.g. heating)
- Assets **can contribute flexibility**

D Other Technologies

- Characterized by their **levelised costs of electricity** (LCOE)
- **Cannot freely dispatch power**

Technologies

A:
- *Biomass*
- *BECCS*
- *Biogas*
- *Gas CCS*
- *Hydrogen*
- *E-methane*
- *Metal fuels*
- *Nuclear energy*

B:
- *Batteries – Li-ion*
- *Batteries – Redox-Flow*
- *Compressed Air*
- *Vehicle to grid*

C:
- *Heat Pumps*
- *Hybrid Heat Pumps*
- *Electric Boilers*
- *EV Smart Charging*
- *Industrial DSR*
- *Electrolysers*

D:
- *Additional RES Capacity*
- *Interconnection*

Note: Plant efficiencies in this report are denoted in higher heating value (HHV), while in other publications for some types of plants lower heating value (LHV) might be used. Plant efficiencies expressed in LHV are higher than in HHV. This distinction does not impact our calculations, as we consistently apply HHV in the Aurora Power Market Model.

Source: Aurora Energy Research

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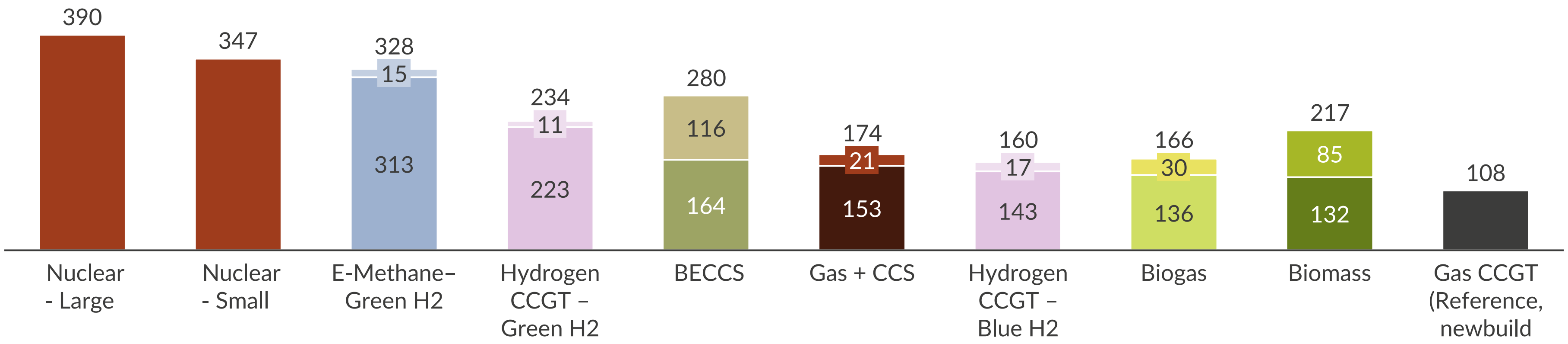
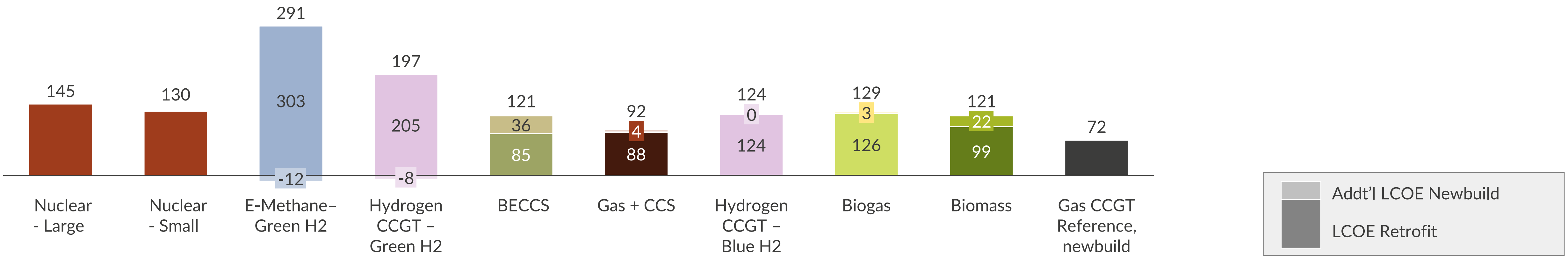
Levelised Cost of Electricity –
Dispatchable Production Technologies in Project Base Case 2030

LCOE in 2030, 1500 Full Load Hours (FLH)
€/MWh (real 2020)



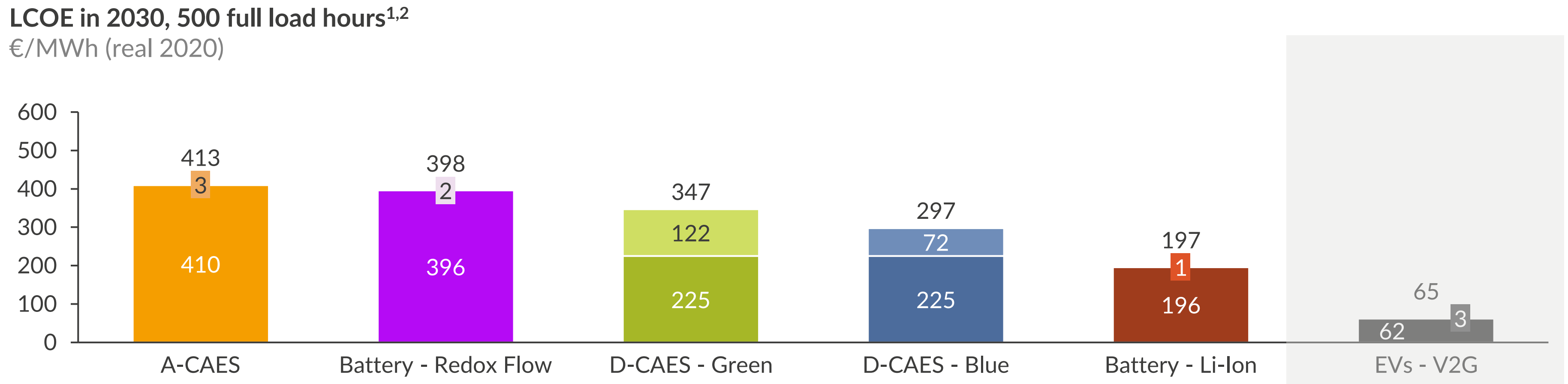
LCOE in 2030, 4500 Full Load Hours (FLH)
€/MWh (real 2020)

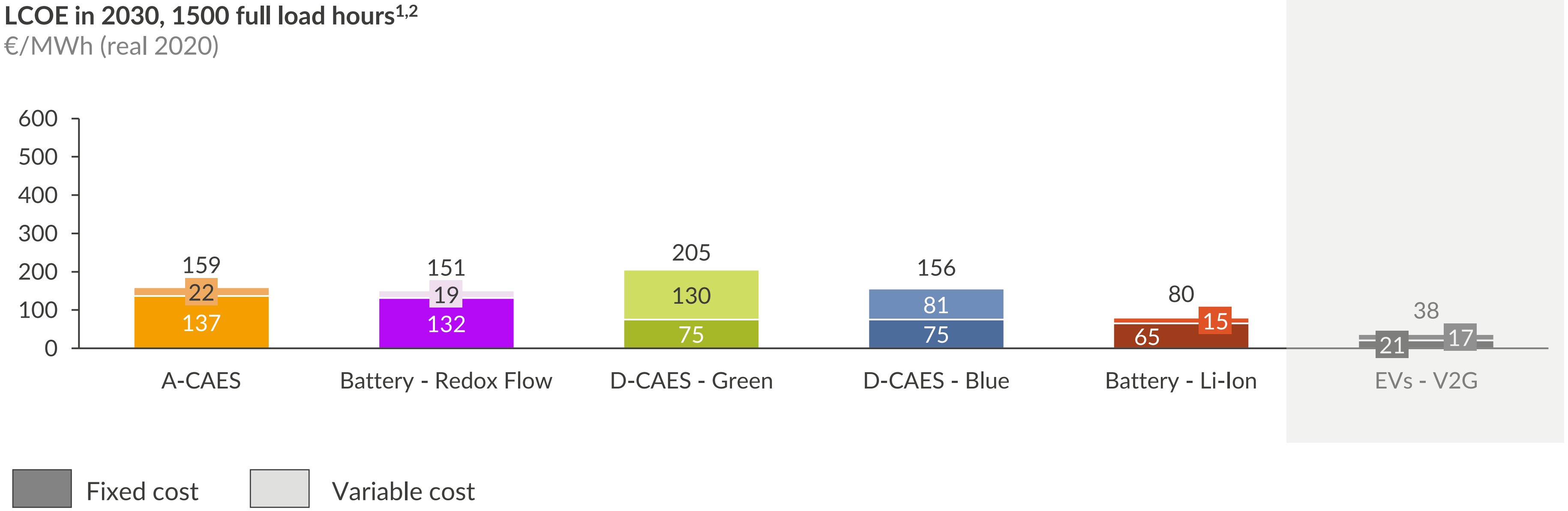


Note: We assume a cost of capital (WACC) of 9%; 1) Most gas CCGTS run 3,000 – 5,000 hours in 2030, 1,500 – 2,000 hours in 2040; 2) Ramping costs are excluded, as they depend on the exact running pattern of an asset.

Source: Aurora Energy Research

Levelised Cost of Electricity – Storage Technologies in Project Base Case 2030





Note: We assume a cost of capital (WACC) of 9%. 1) Does not include costs for ramping. 2) Discharging hours.

Source: Aurora Energy Research

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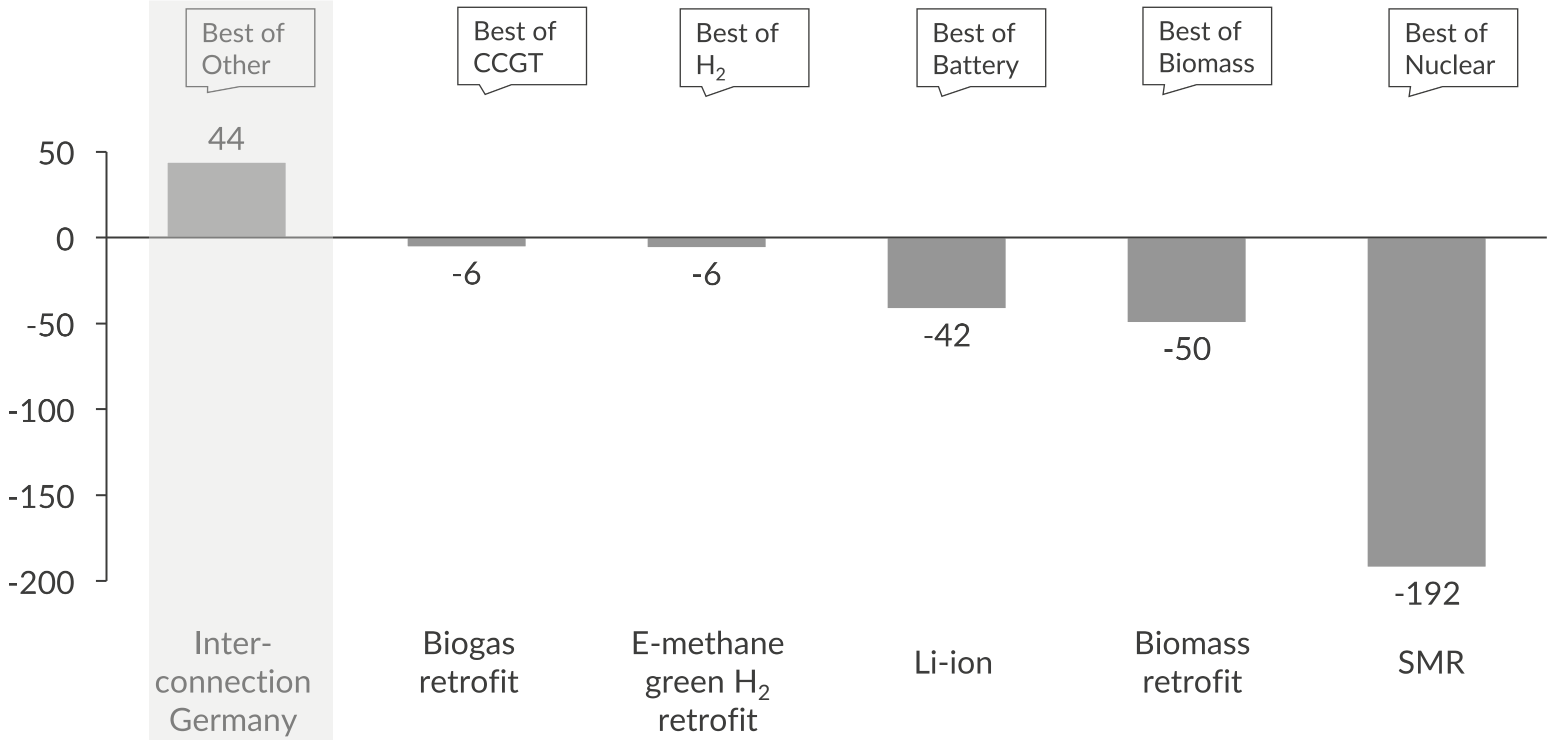
Gap to Profitability in Project Base Case 2030 – Best in class technologies

Gap to profitability 2030 – Best in class technologies
€/kW (real 2020)



	Inter-connection Germany	Biogas retrofit	E-methane green H_2 retrofit	Li-ion	Biomass retrofit	SMR
Run hours (h)	4,808	15	6	686	225	7,405
SRMC (€/MWh)	-	128	315	69	87	23

Note: We assume a cost of capital (WACC) of 9%. For simplification, we have clustered technologies: Other technologies (RES and Interconnection), CCGT-based technologies (Biogas, Gas CC, Hydrogen), Hydrogen-based technologies (Hydrogen, metal fuels, e-methane), Storage technologies (Li-ion, Redox Flow, CAES, V2G), Biomass-based technologies (Biomass, BECCS) and nuclear (Large III+ gen, SMR). We depict the most economical of each of these groups here. For details on each tech, see appendix.
Source: Aurora Energy Research

The price duration curve of the Base Case in 2030 explains the running hours and profitability of the technologies

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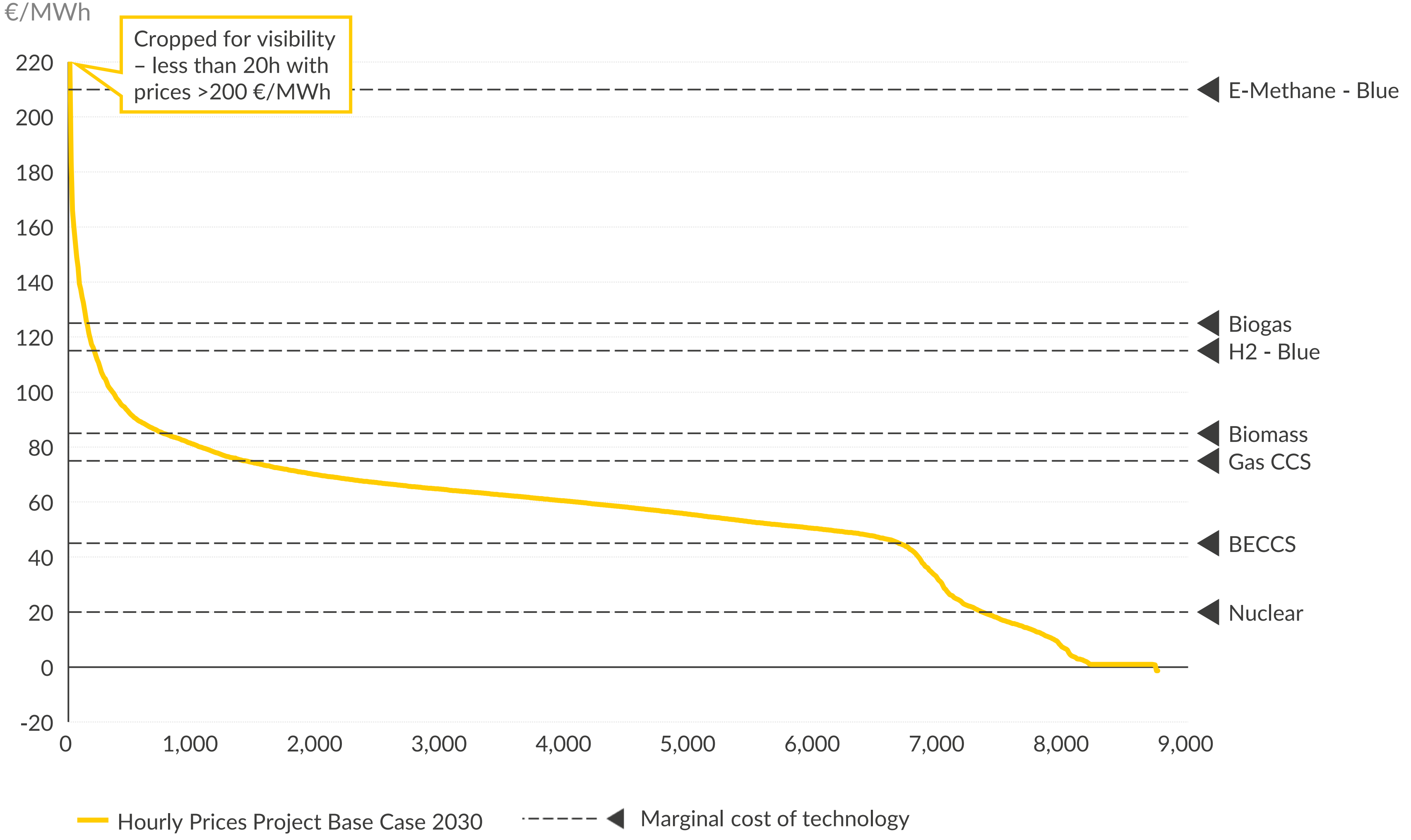
Price duration curve and Marginal Costs – Base Case, 2030



Note: While the intersection of marginal costs and price duration curve gives a rough indication of run hours, plants will additionally have to consider ramping in their decision to dispatch. I.e. they will not ramp up for one high price hour, but only if there are enough consecutive high price hours to recover ramping cost. Some technologies (e.g. metal fuels) have such high marginal costs, they are not plotted here.

Source: Aurora Energy Research

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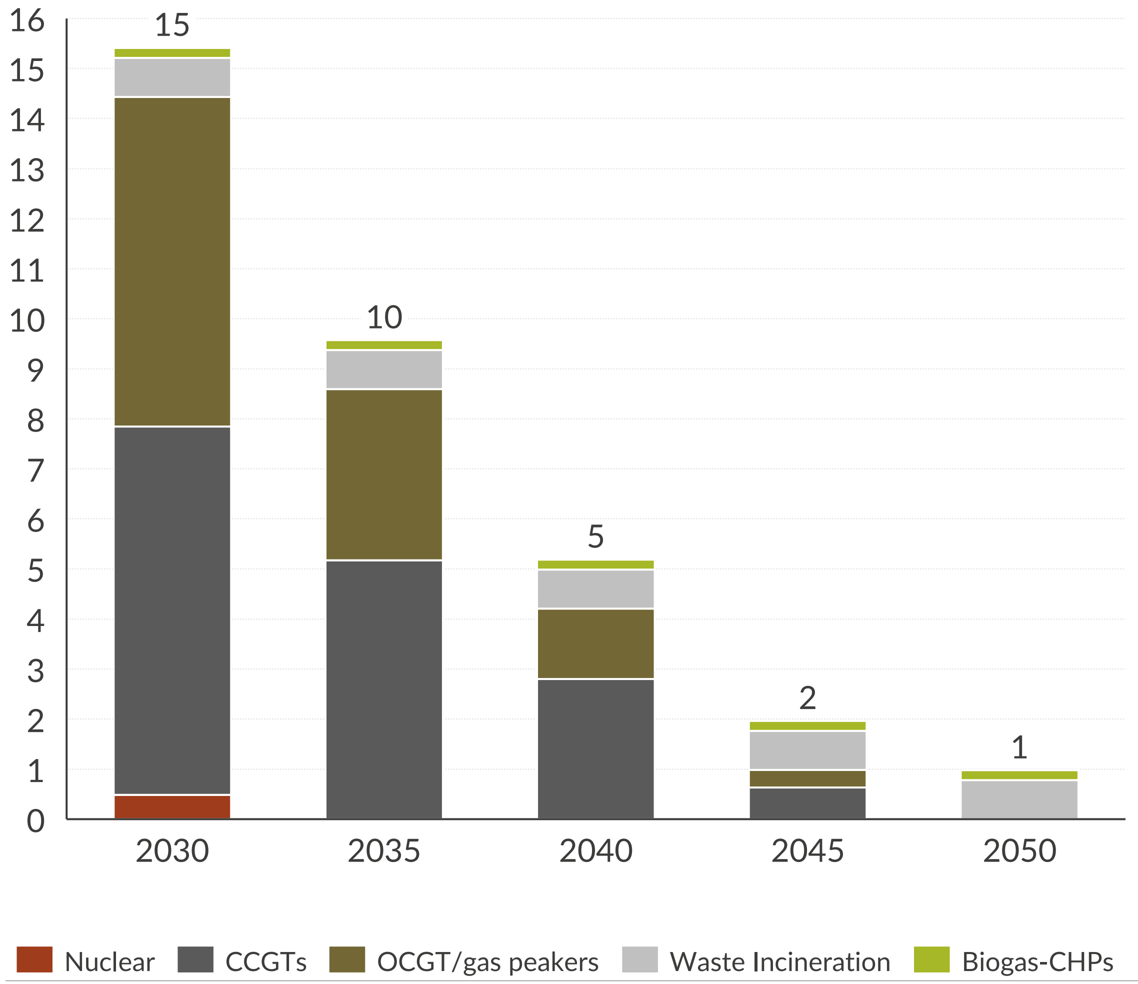
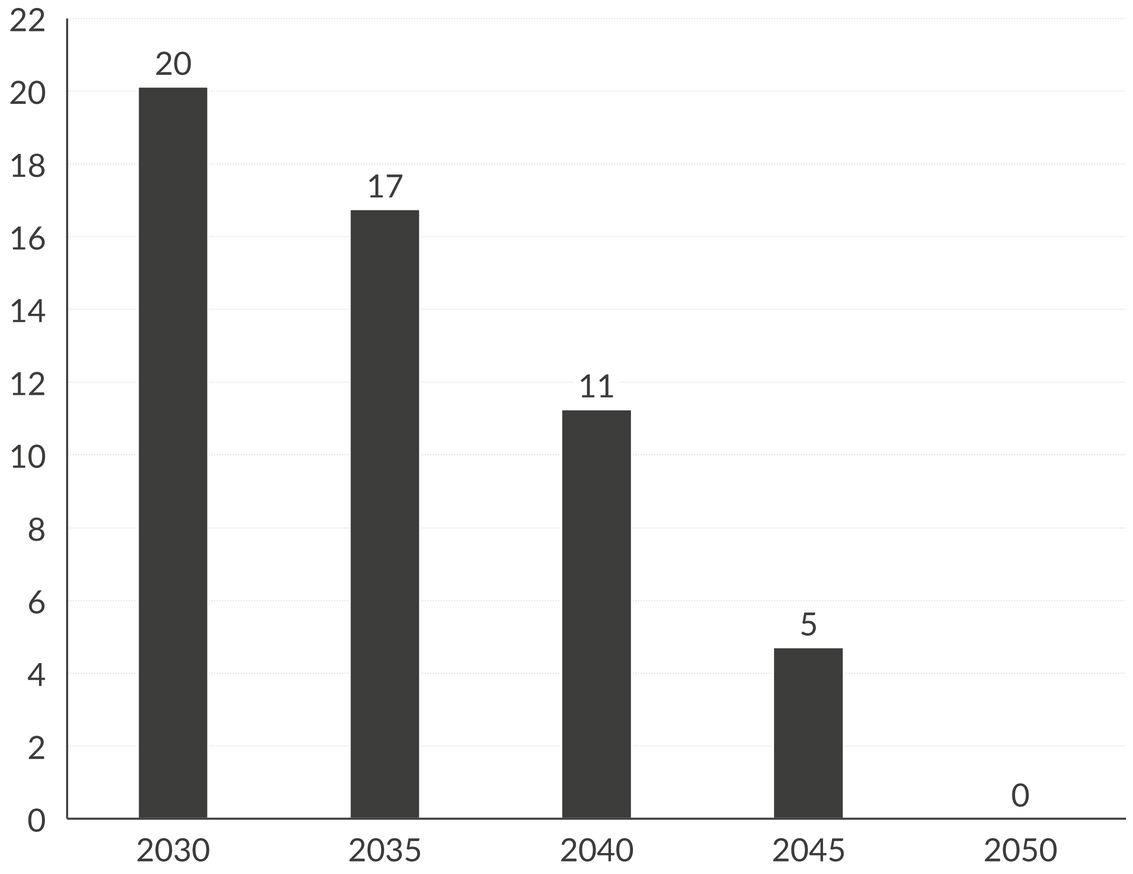
The phase out of thermal capacities towards 2050 in the aligned Base Case leads to an emissions-free power system in the Netherlands

Base Case - Thermal capacities over time
GW



CO_2 emissions over time[1,2]
Mt



Note: Base Case aligned with EZK and TenneT; 1) Assumes waste incineration uses CCS starting 2030; 2) Includes emissions from heat produced by CHPs; 3) This reduction can result from different factors. On the one hand, this could be due to market dynamics, should natural gas plants become unprofitable with rising carbon prices, on the other hand it could be due to market interventions. We do not specify the exact mechanism but outline what needs to happen to reach Net Zero by 2050.
Sources: Aurora Energy Research, PBL

Renewable capacity continues to increase post 2030 – similar development for flexible demand technologies

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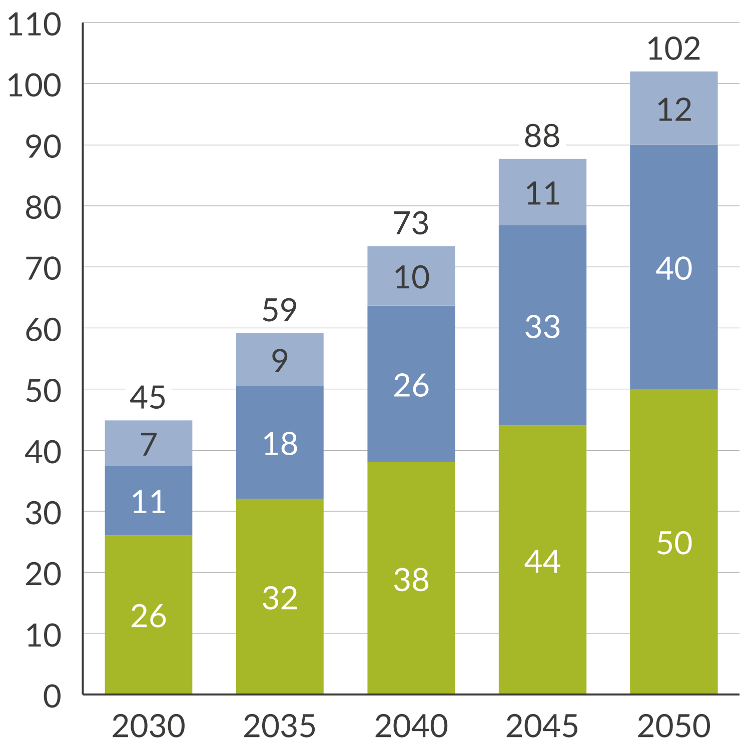
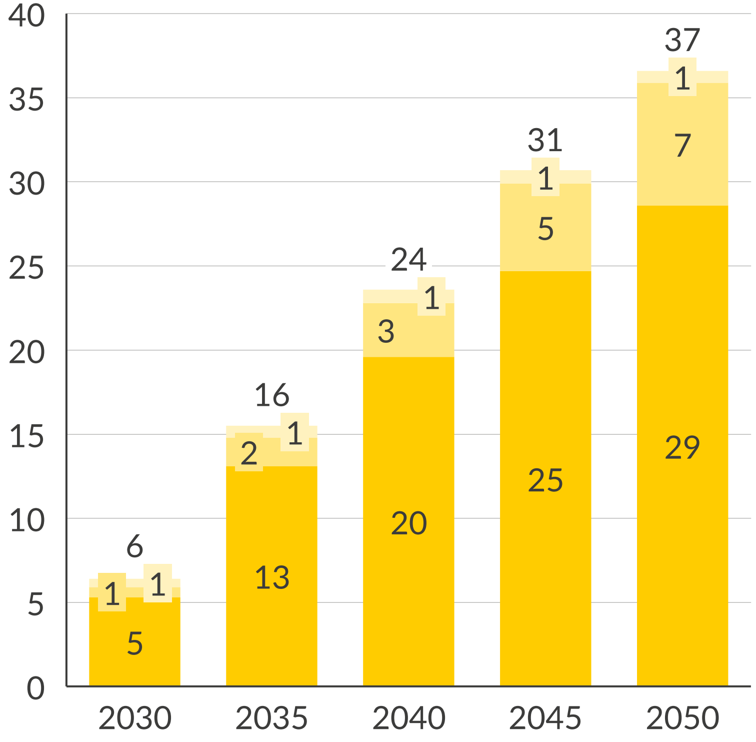
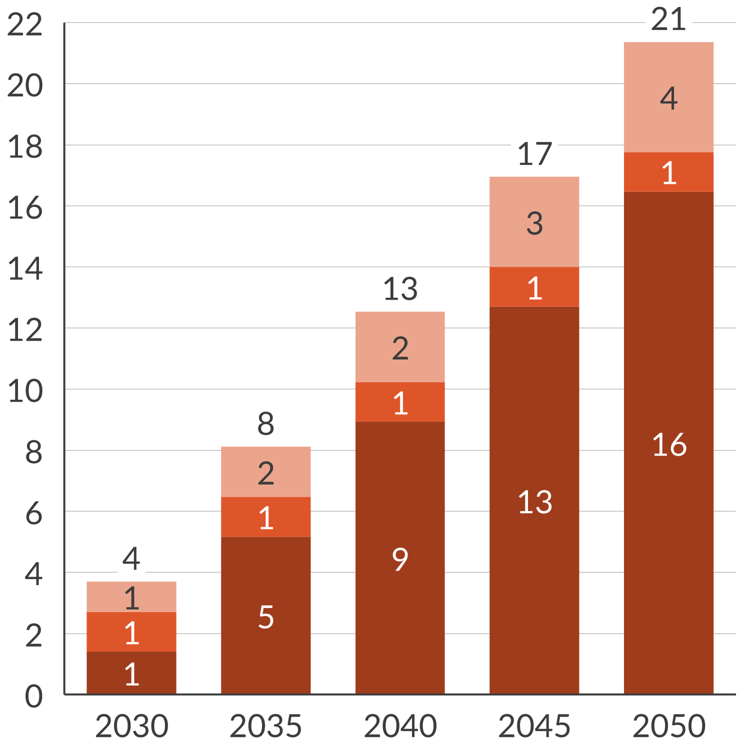
Renewable capacity
GW



Flexible EV & heat pump capacity
GW



Electrolyser, P2H & DSR capacity
GW



Onshore wind | Offshore wind | Solar | Smart EVs | Smart HPs | Hybrid HPs | Input electrolysers | DSR | E-Boilers

Note: Base Case aligned with EZK and TenneT, based on KEV2020 and II3050.

Source: Aurora Energy Research

Without additional flex capacity, average weather year with ~4 TWh of unmet demand by 2050

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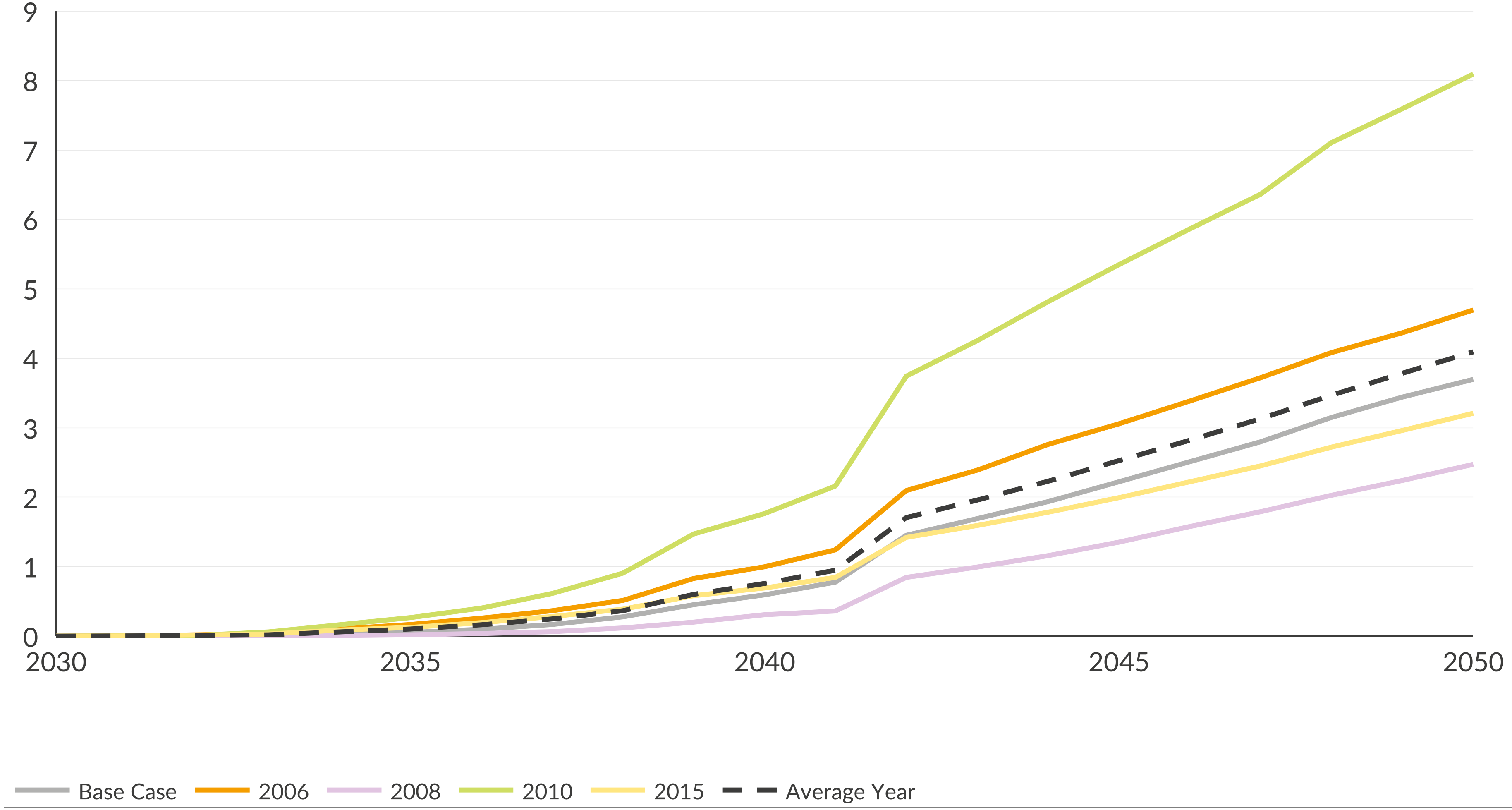
Loss of load depth
TWh



Source: Aurora Energy Research

While hours of extreme loss of load already occur in 2040, their number increases strongly within the ten years up to 2050

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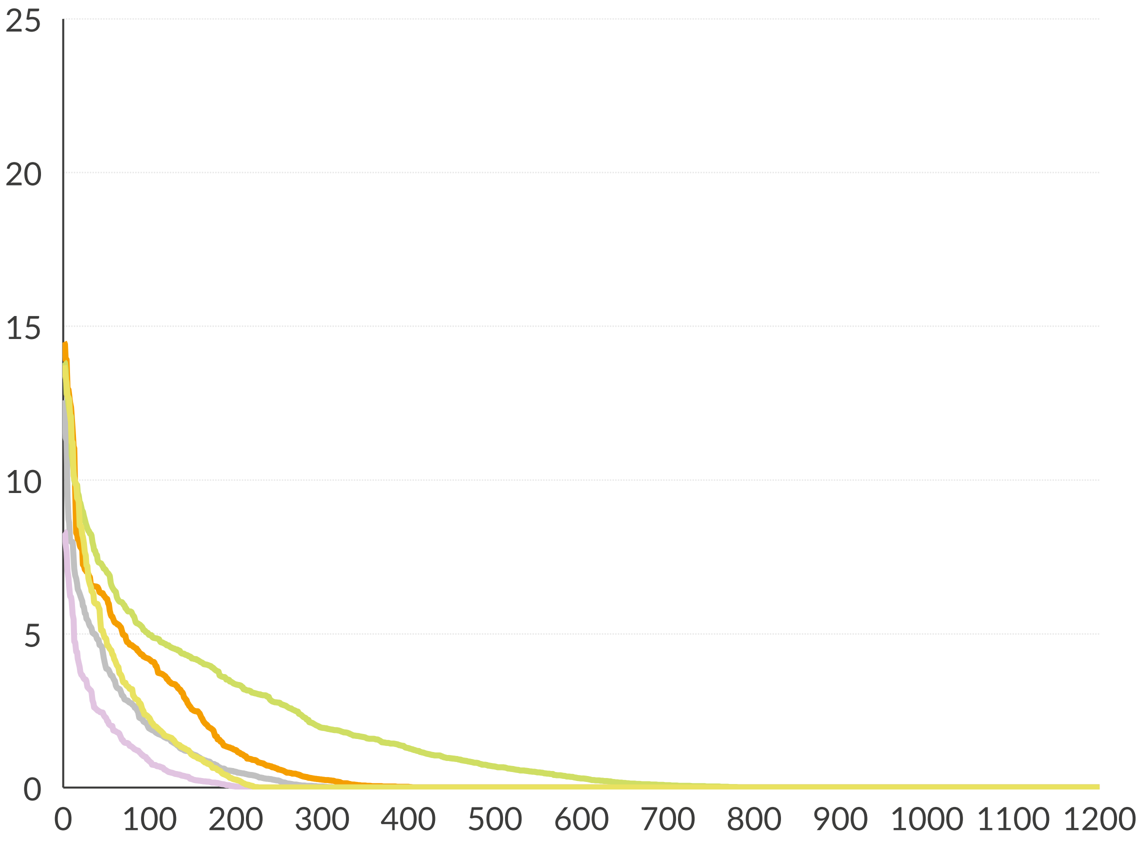
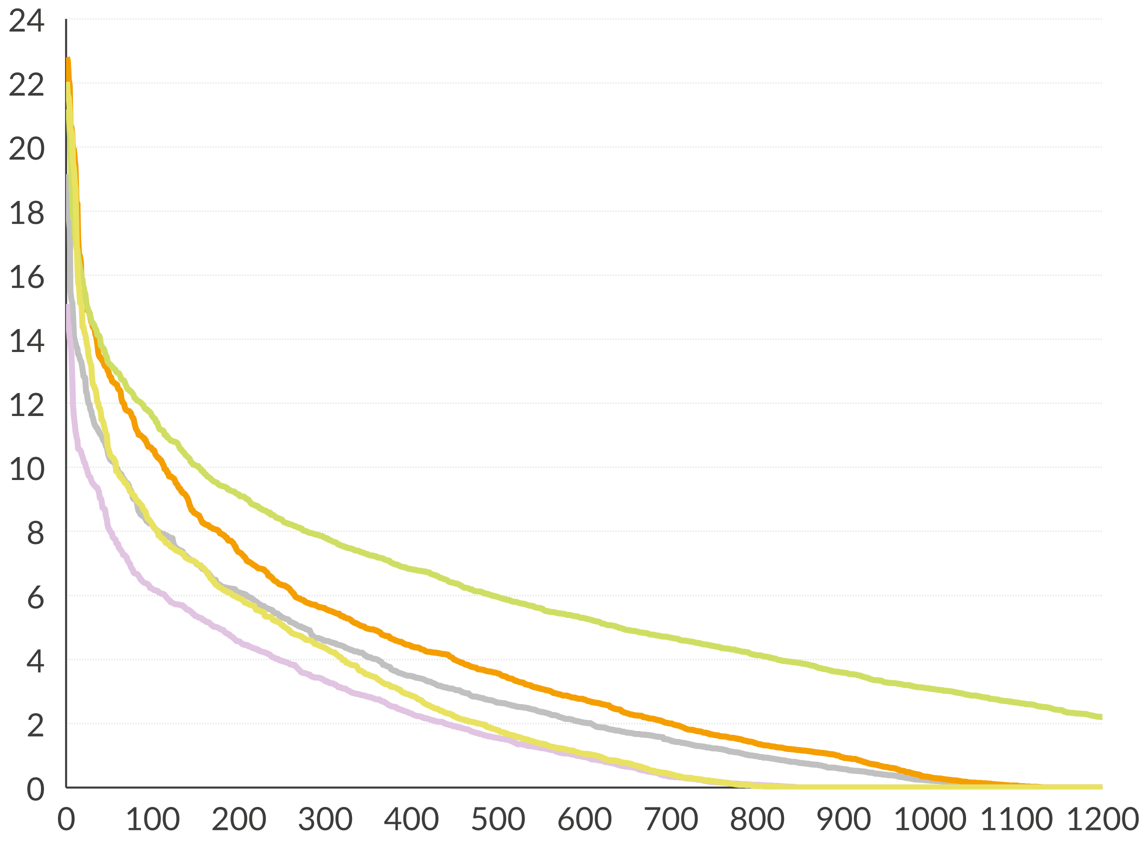
Loss of load duration curve top 1200 hours – 2040
GW (sorted)



Loss of load duration curve top 1200 hours – 2050
GW (sorted)



Note: This section covers loss of load and prices in the Base Case when only considering RES and the remaining thermal assets - without having added the flex production technologies.

Source: Aurora Energy Research

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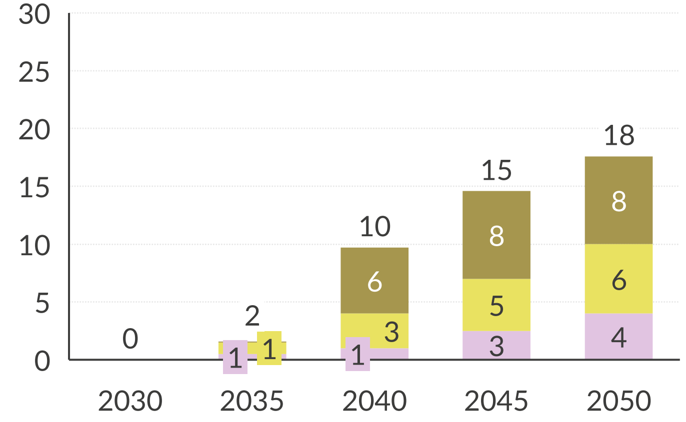
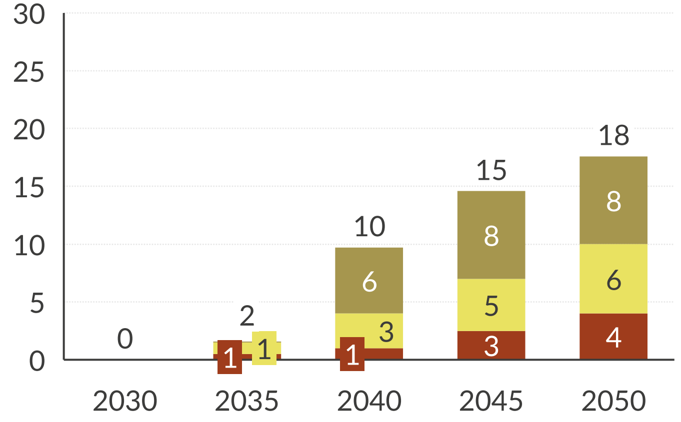
Tech Mix 1 uses H_2 CCGTs for long-duration, Tech Mix 2 Nuclear SMRs and Tech Mix 3 BECCS and Gas CCS – we test two scenarios for each

Tighter System

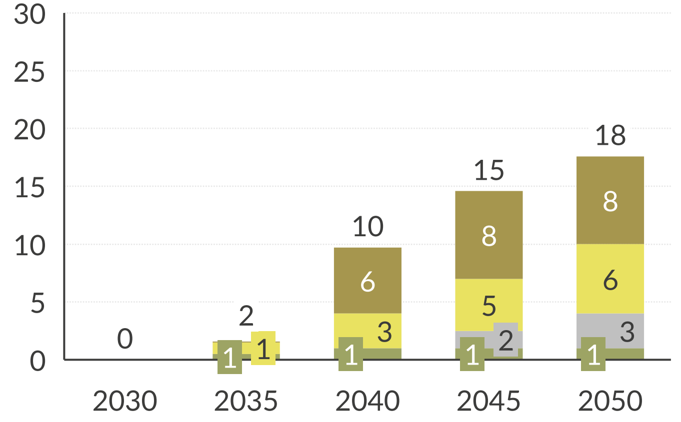
CO_2 free flexible capacities – Tech Mix 1
GW



CO_2 free flexible capacities – Tech Mix 2
GW



CO_2 free flexible capacities – Tech Mix 3
GW

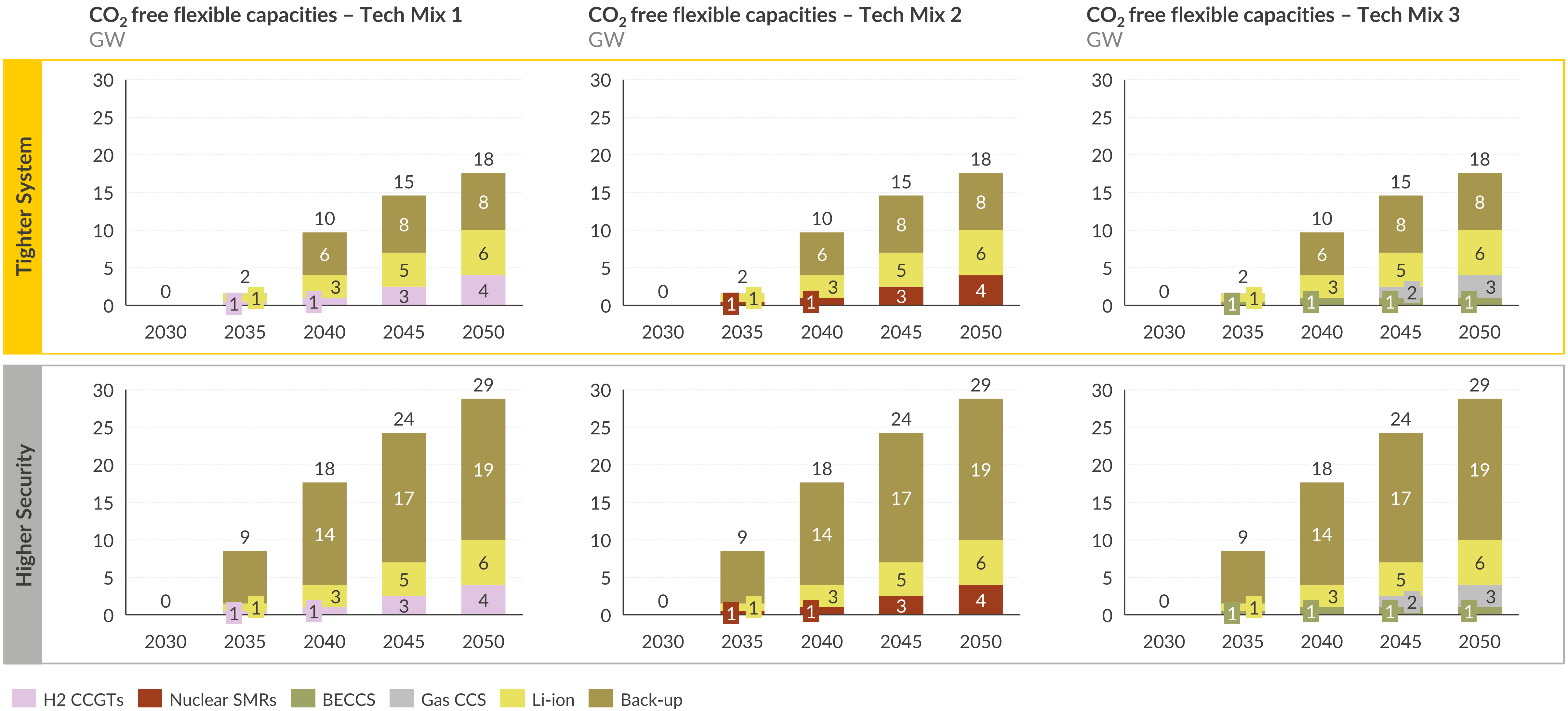


H2 CCGTs | Nuclear SMRs | BECCS | Gas CCS | Li-ion | Back-up

Note: The above graphs shows the capacities that were added to the base case in the course of creating the technology mixes. All scenarios still have nuclear power plant Borssele operating until 2033.

Source: Aurora Energy Research

Tech Mix 1 uses H_2 CCGTs for long-duration, Tech Mix 2 Nuclear SMRs and Tech Mix 3 BECCS and Gas CCS – we test two scenarios for each



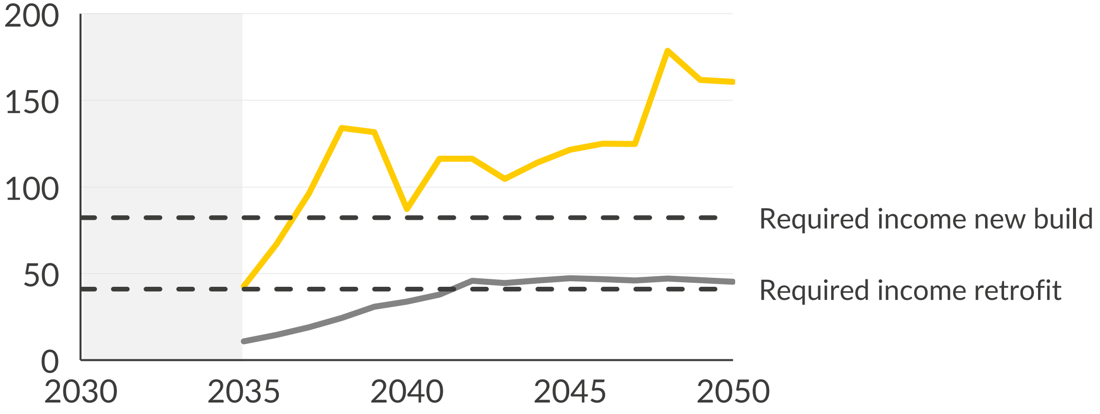
Note: The above graphs shows the capacities that were added to the base case in the course of creating the technology mixes. All scenarios still have nuclear power plant Borssele operating until 2033.

Source: Aurora Energy Research

Of the long-duration flex technologies, retrofitted H_2 CCGTs and BECCS have the highest profitability, whereas nuclear and gas CCS struggle

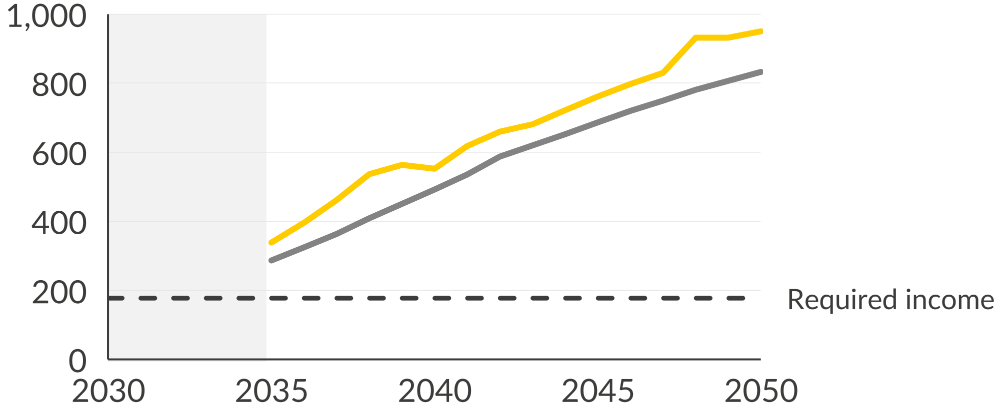
H_2 CCGT Gross margins – Tech Mix 1

€/kW/year (real 2020)



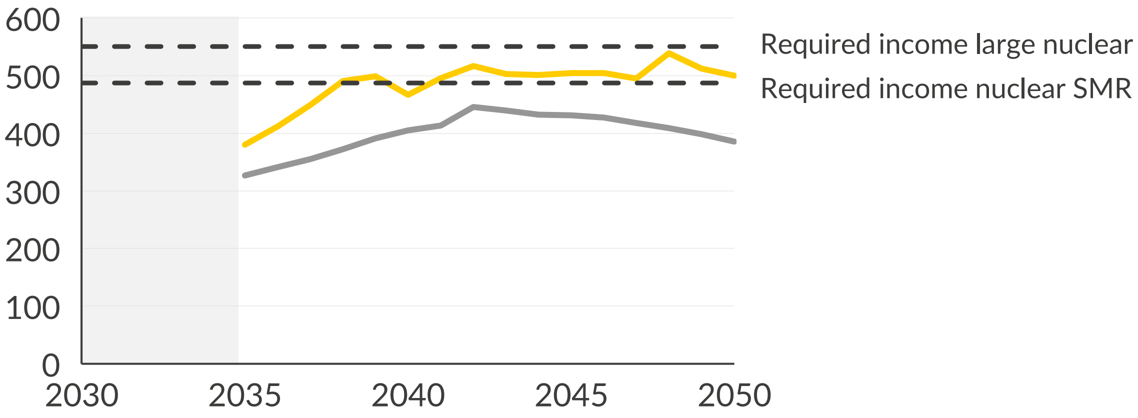
BECCS (retrofit) Gross margins – Tech Mix 3

€/kW/year (real 2020)



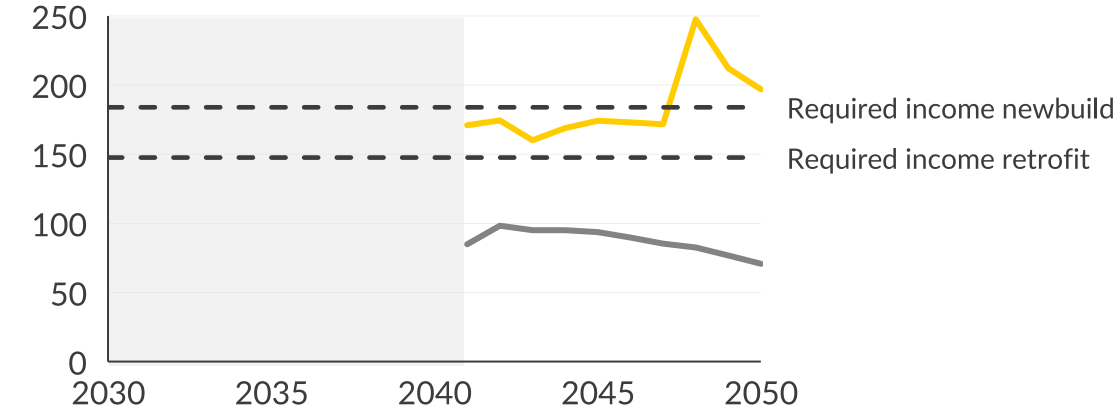
Nuclear (newbuild) Gross margins – Tech Mix 2

€/kW/year (real 2020)



Gas CCS Gross margins – Tech Mix 3

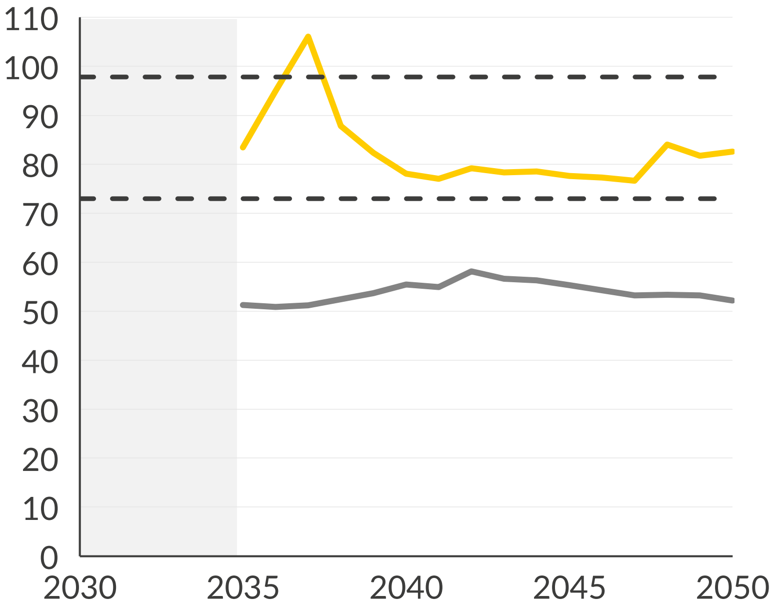
€/kW/year (real 2020)



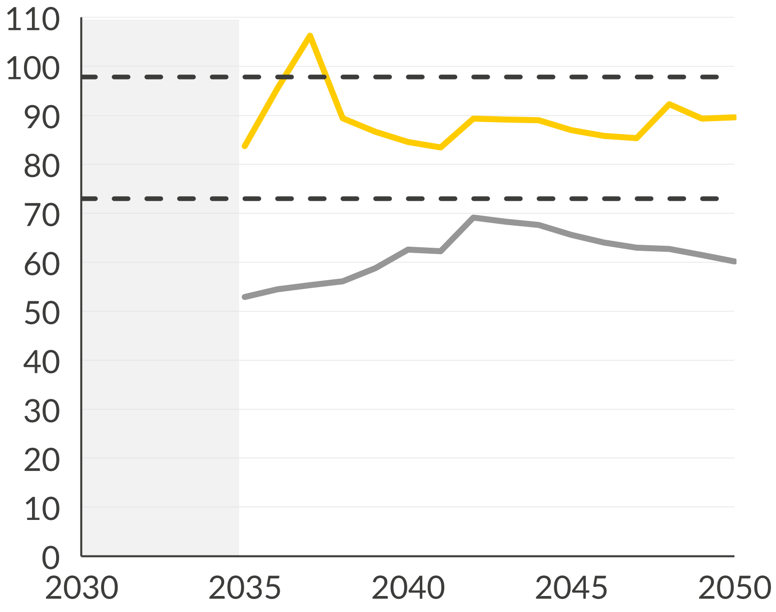
Higher Security Tighter System

Eventhough Li-ion is the cheapest storage option, it underperforms in all scenarios, and can only be profitable towards 2050 in a Tighter System

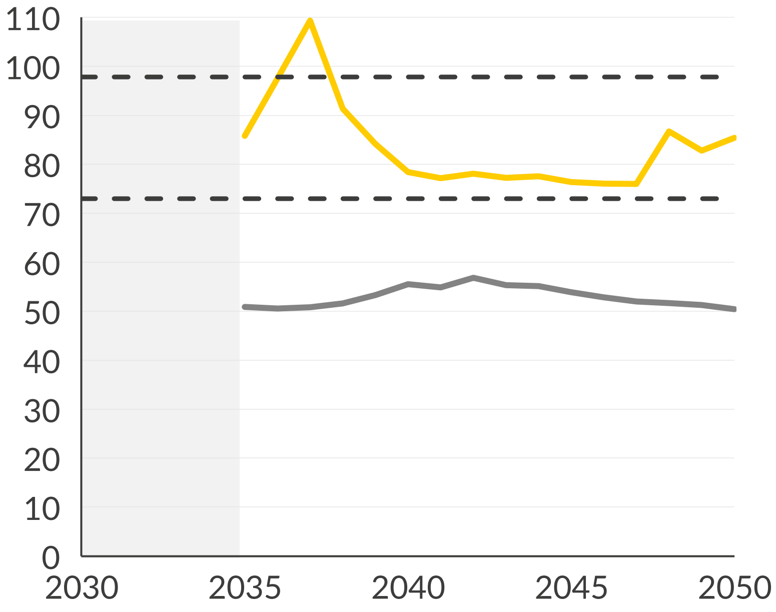
Li-ion (newbuild) Gross margins – Tech Mix 1
€/kW/year (real 2020)



Li-ion (newbuild) Gross margins – Tech Mix 2
€/kW/year (real 2020)



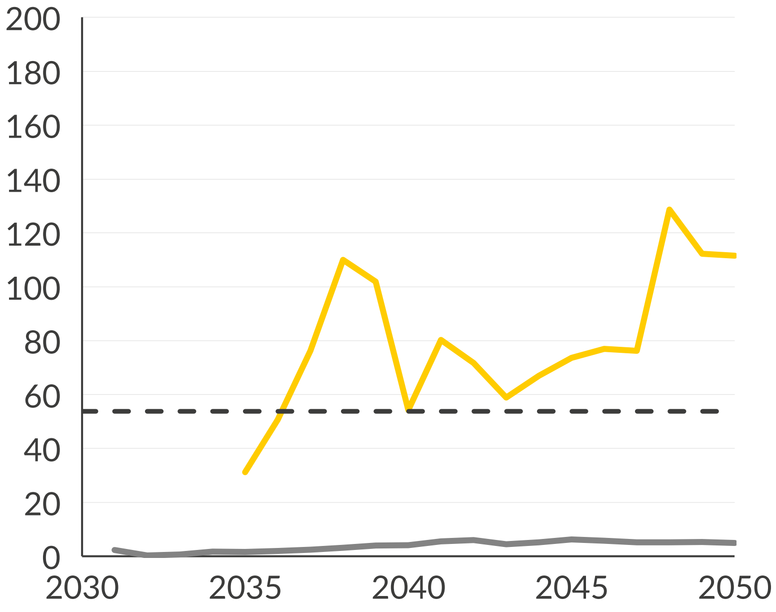
Li-ion (newbuild) Gross margins – Tech Mix 3
€/kW/year (real 2020)



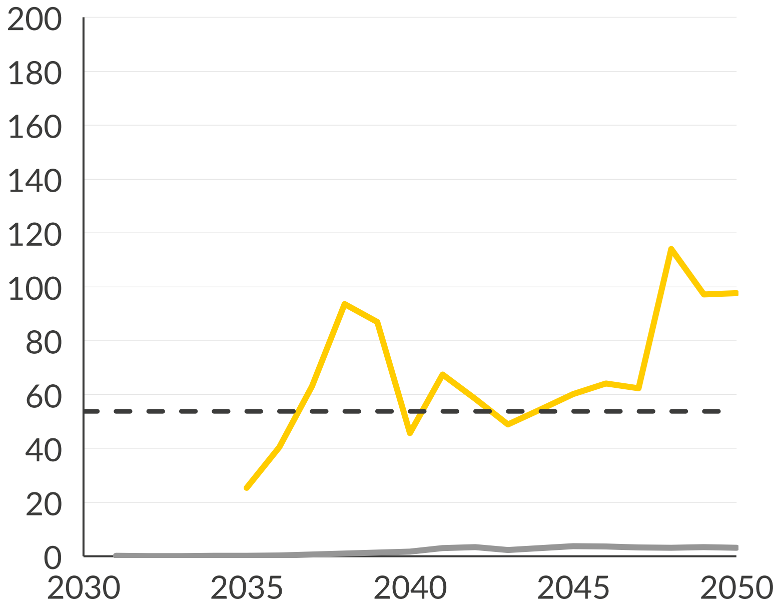
Higher Security — Required income 2030
Tighter System — Required income 2050

Backup capacity, cheapest provided by hydrogen or e-methane OCGTs, can only be profitable in a Tigher System

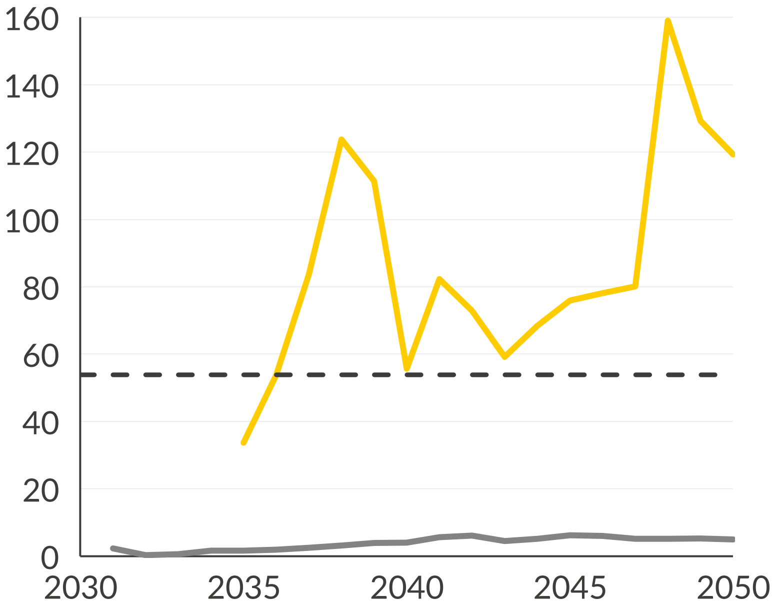
H_2 OCGT (newbuild) Gross margins – Tech Mix 1
€/kW/year (real 2020)



E-methane OCGT (newbuild) – Tech Mix 2
€/kW/year (real 2020)



H_2 OCGT (newbuild) Gross margins – Tech Mix 3
€/kW/year (real 2020)



Higher Security — Tighter System — Required income

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All of the promising technologies also face technology specific non-financial hurdles, which differ substantially in severity

	Biogas power plant	Biomass power plant	BECCS and CCS	H_2 power plant	E-methane power plant	Nuclear fission plant	Li-ion batteries	Flexible household demand[1]	Flexible power-to-heat	Flexible electrolysis
Market design & regulations			Negative emissions not reimbursed	No H_2 market	No e-methane market	High CAPEX and long lifetimes risk large write-offs with system change		Static household electricity prices; no third-party access guidelines		No H_2 market
Tariffs & taxation							Inflexible grid fees	Static household electricity fees	Inflexible grid fees	Inflexible grid fees
Infrastructure, fuel, and space availability	Limited production facilities	Uncertainty of sufficient sustainable sourcing	Possible spatial constraint due to demand from other countries	Low CO_2 free H_2 availability; limited H_2 infrastructure	Low e-methane availability	NIMBY concerns	Rare earth metal scarcity	Possible grid congestion		Little RES; no H_2 infrastructure
Technological market readiness						High lead times; SMR not yet available; few parties with know-how		Technologies exist at small scale; no integrated solutions yet available		PEM electrolysers not yet scaled up
Political support & coordinative uncertainty	Odour concerns	Limited political support	Lack of long-term political commitment	Uncertainty on future hydrogen system setup	Uncertainty on future hydrogen system setup	Safety concerns	Dependent on other sources for providing CO_2 free electricity to charge	Potential unpopularity of flexible price and tariff models		Uncertainty on future hydrogen system setup

Severity of hurdle: Mild | Intermediate | Severe | Currently being (partially) addressed

1) Includes: (i) smart / flexible EV charging, (ii) smart / flexible heat pumps, (iii) bidirectional EV charging, i.e. vehicle-to-grid. 2) For many of the future hurdles (e.g., hydrogen infrastructure development), plans to address them are already being made.

Source: Aurora Energy Research

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Details and disclaimer

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