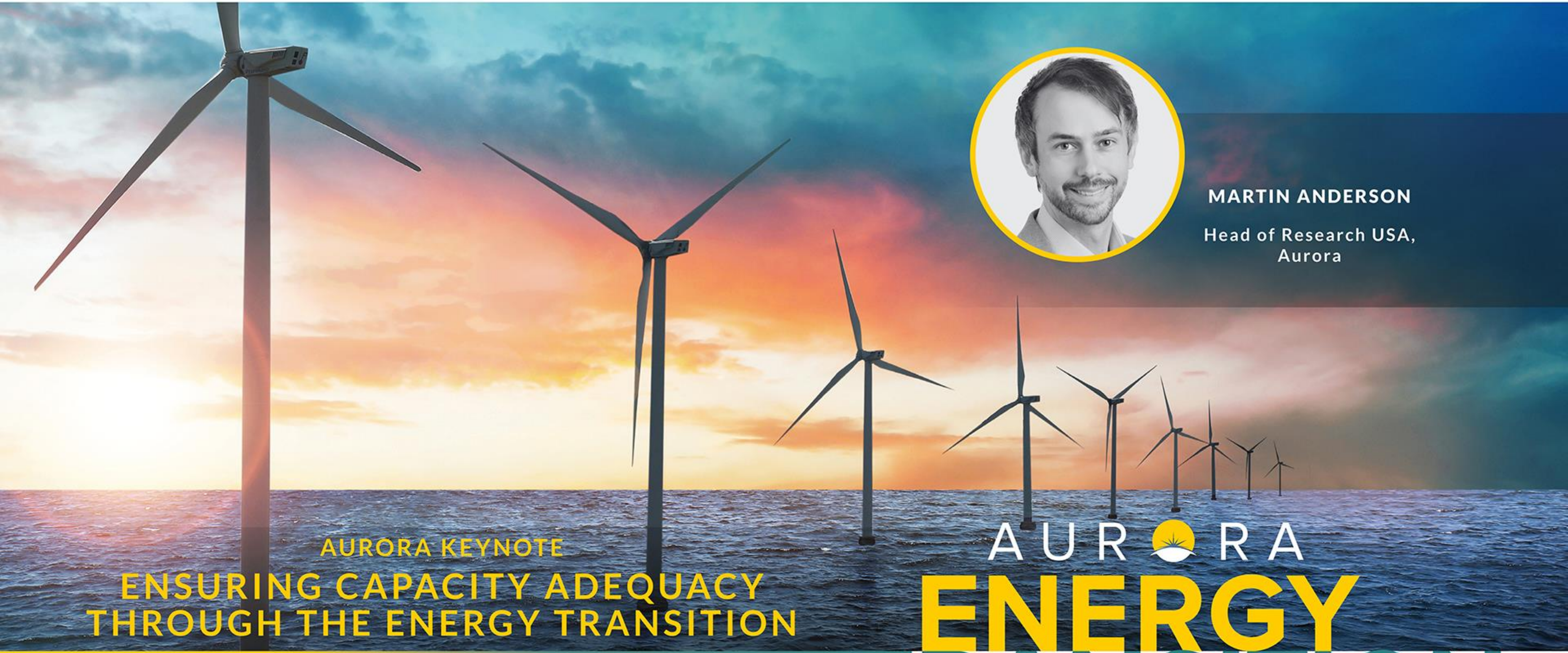

MARTIN ANDERSON

Head of Research USA,
Aurora

AURORA KEYNOTE

ENSURING CAPACITY ADEQUACY THROUGH THE ENERGY TRANSITION

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ENERGY TRANSITION

FORUM 2024

Margins across ISOs have largely exceeded targets for the past 15 years, yet outage events have continued

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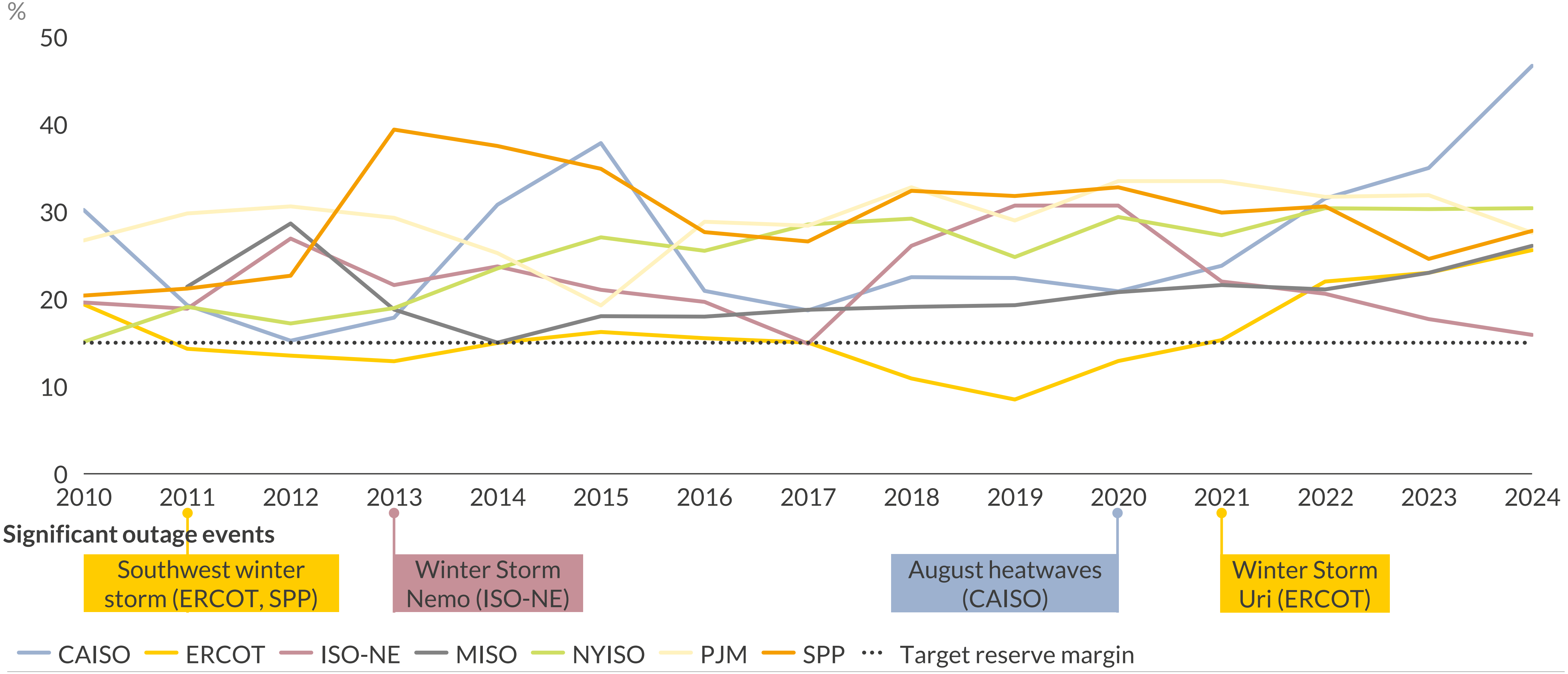
Summer reliability margins by US ISO

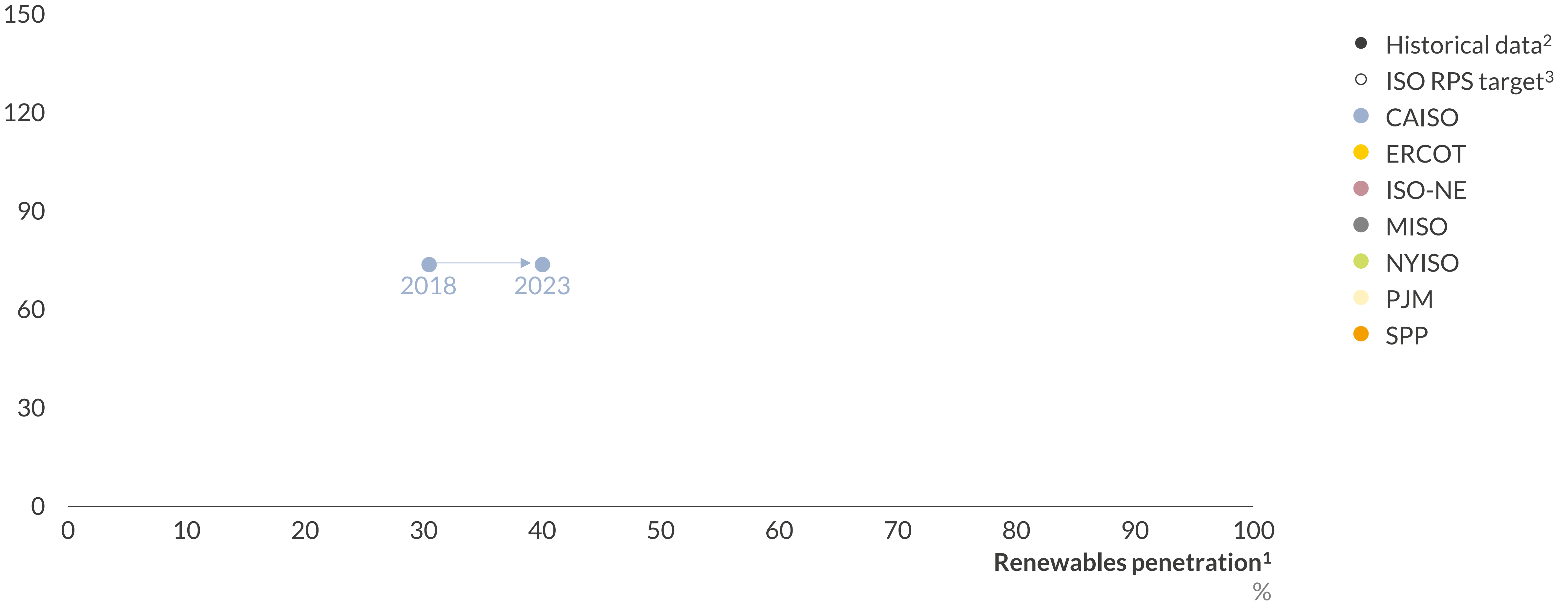


Sources: Aurora Energy Research, NERC

Regions are targeting high renewables deployment; the role of unabated thermal capacity remains unclear

Unabated dispatchable thermal nameplate capacity vs. ISO peak demand

%



1) Sum of metered solar, wind, geothermal, and hydroelectric (excluding pumped storage). 2. Shown for 2018 and 2023. 3) Shown for 2030 and 2050 unless otherwise indicated. ISO values are a weighted average of state RPS targets by share of total demand. Targets already exceeded not shown.

Sources: Aurora Energy Research, EIA

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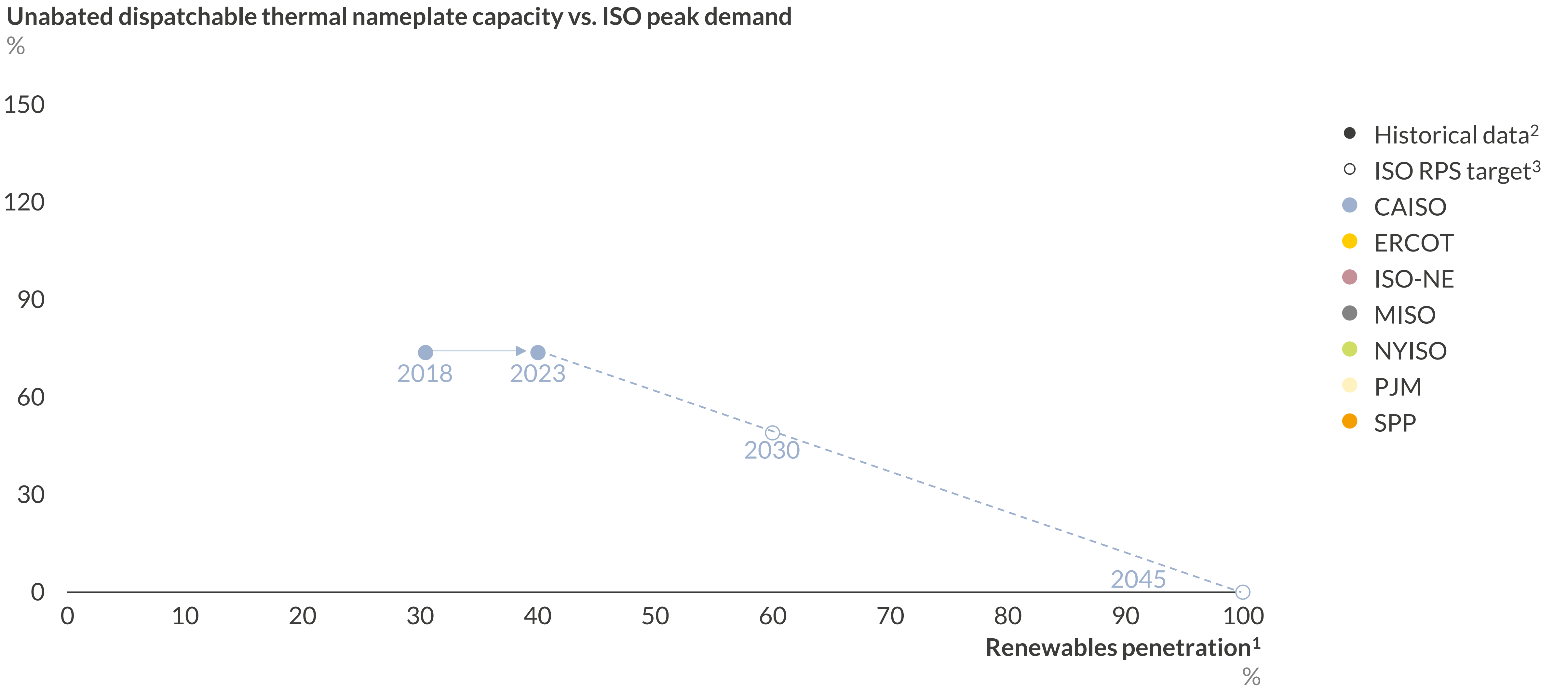

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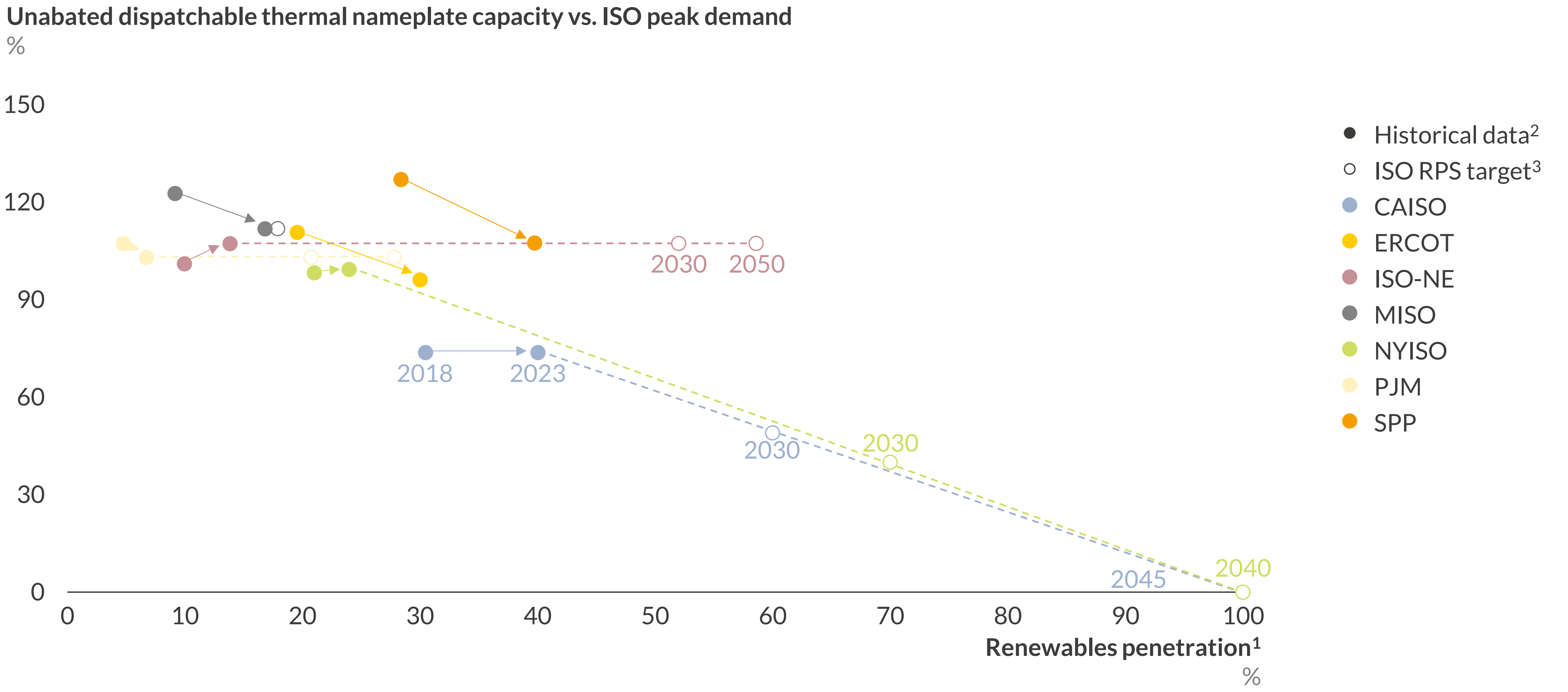

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Sources: Aurora Energy Research, EIA

The existing thermal capacity is aging; over 227GW of thermal capacity across the US is over 40 years old, representing 31% of installed capacity

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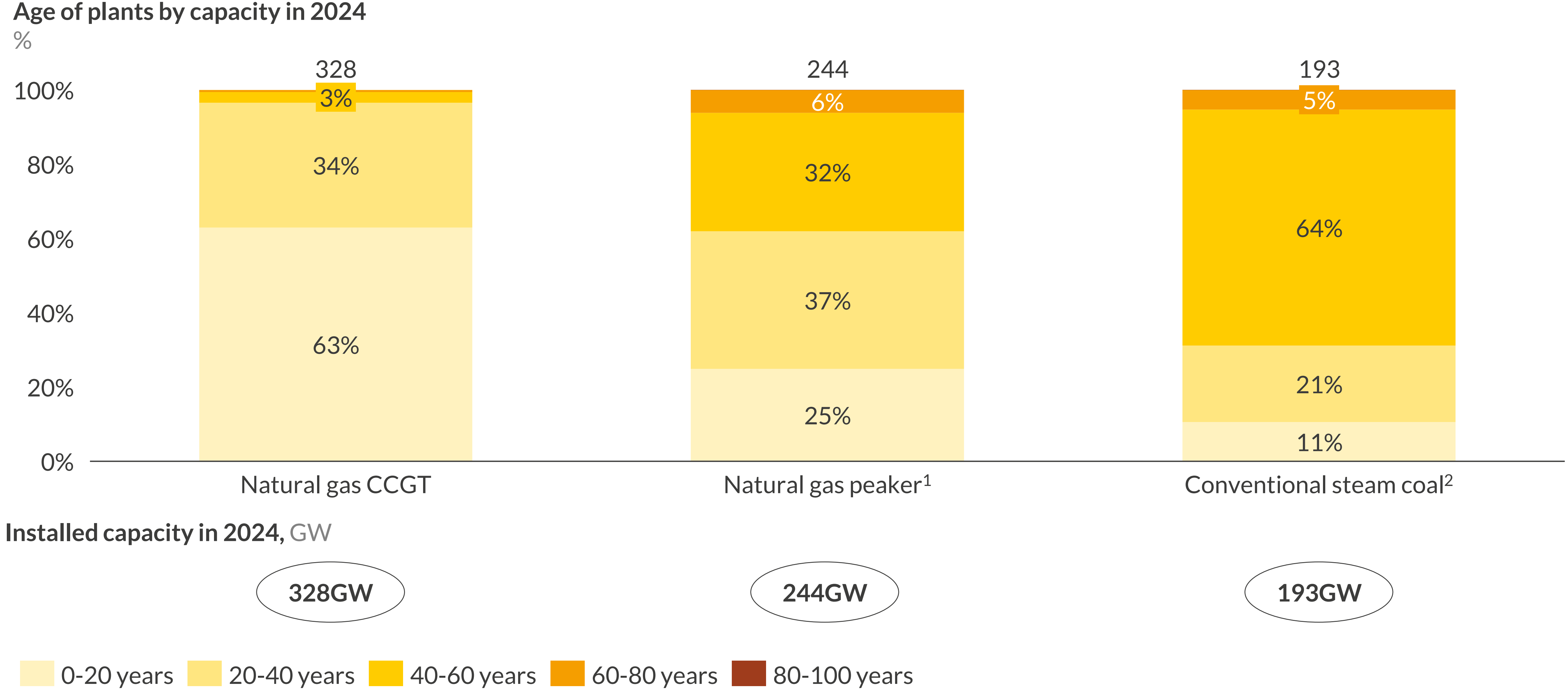

1) Includes combustion tubine, steam turbine, internal combustion engine. 2) Includes lignite.

Sources: Aurora Energy Research, EIA

A high-renewables system increases the need for flexibility and reliability

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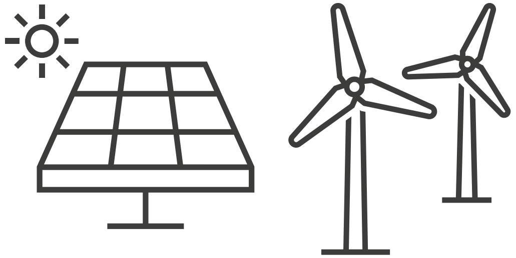
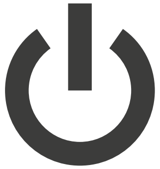
Characteristics of renewables	High-renewables system requirements
	
Unpredictable	Ramping
Variable	Inter-seasonal supply-demand matching
Undispatchable	Reliability

Ramping: increasing renewables penetration is expected to exacerbate the "duck curve," leading to a 30-40 GW summer net load ramp by 2040

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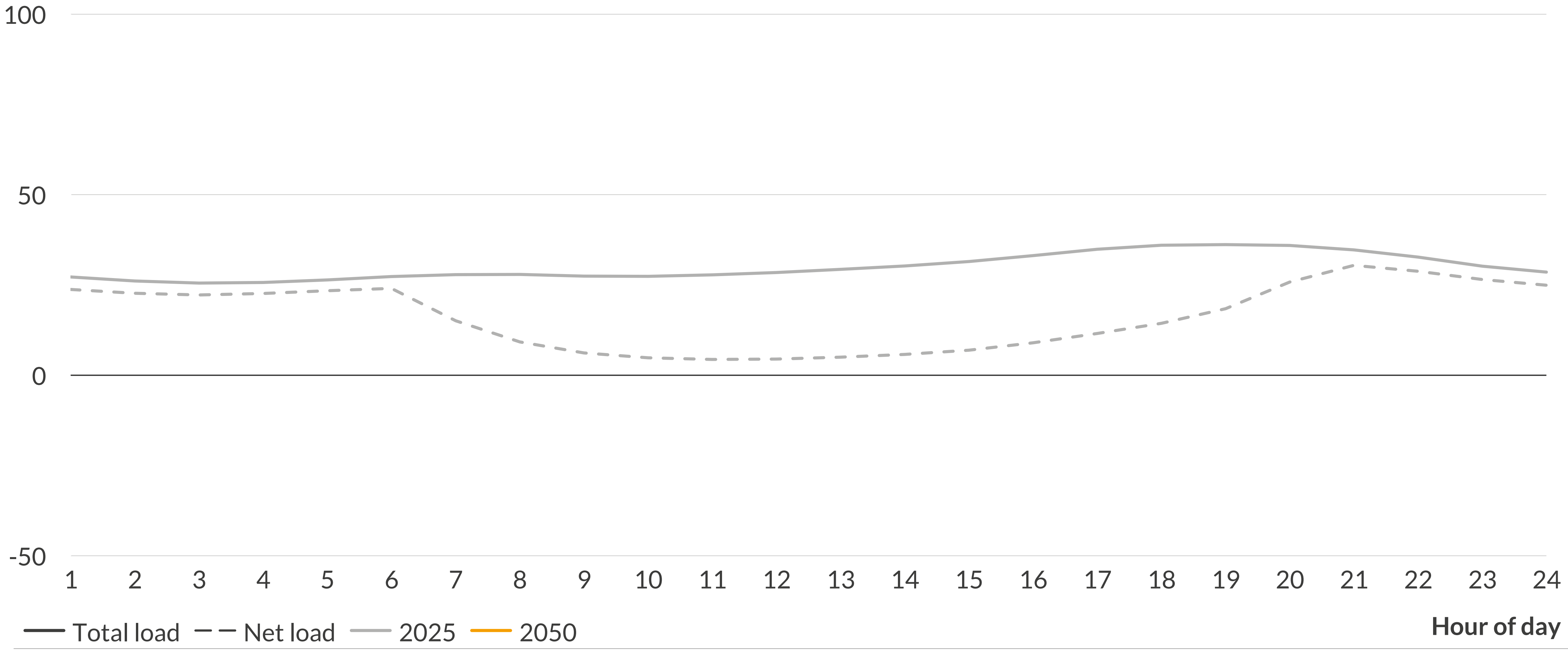
CAISO summer total and net load
GW



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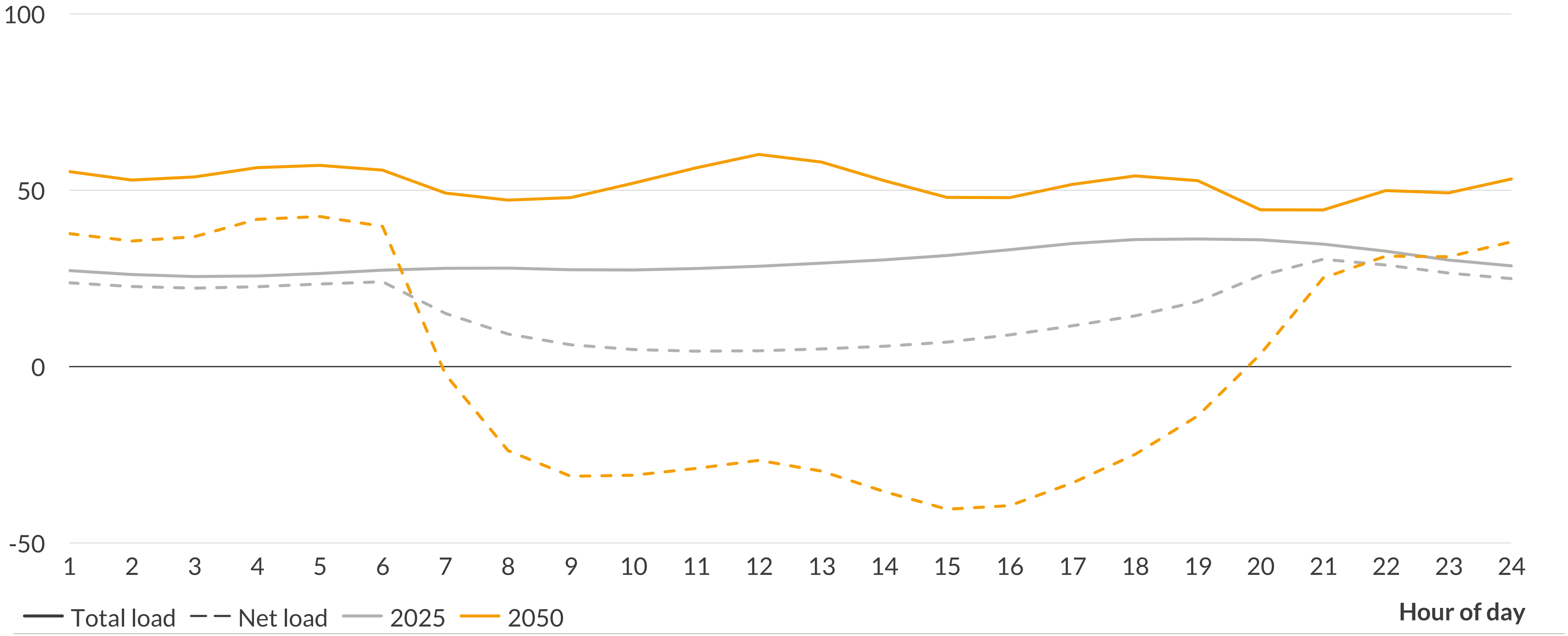

Sources: Aurora Energy Research

Ramping: as a result, we expect a 20% of hours to have a ramping requirement of at least 6 GW by 2050, up from 4% today

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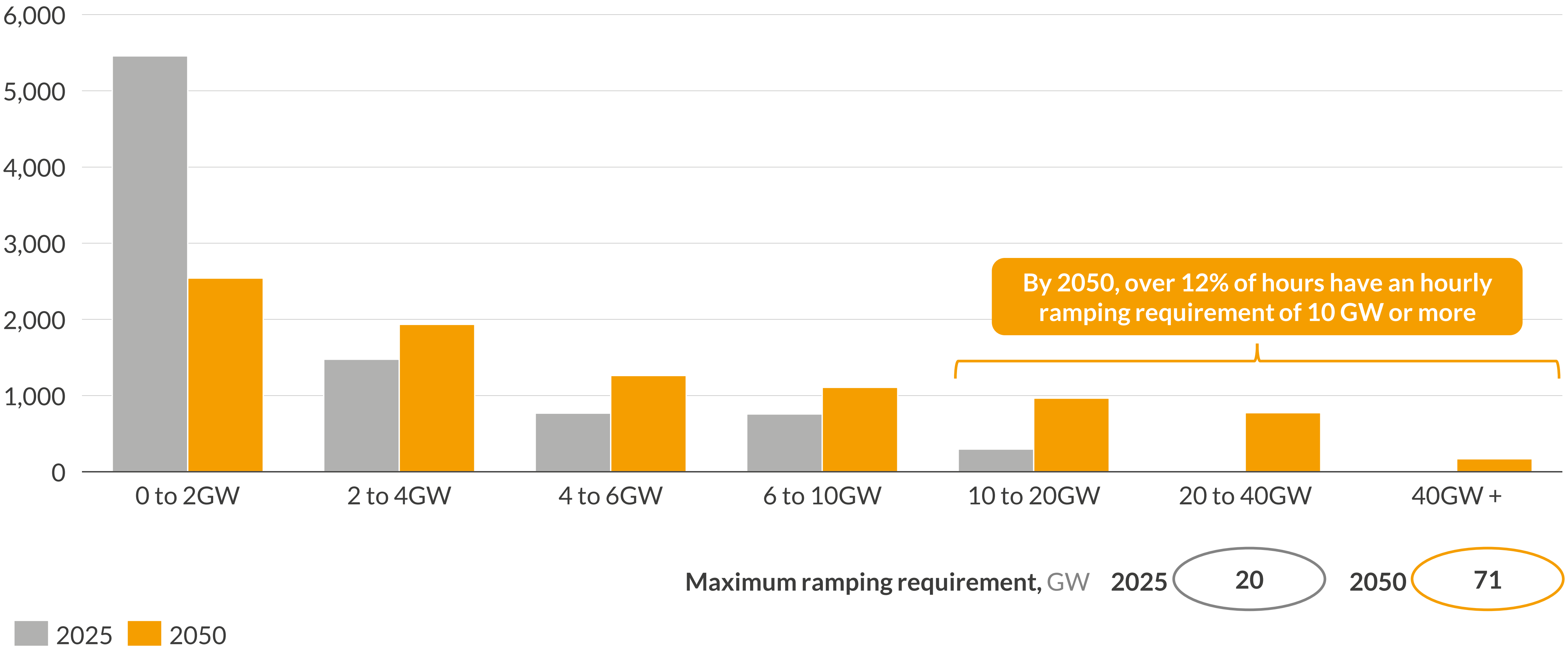
Frequency distribution of hourly ramping requirement[1] in CAISO
Number of hours



1) Ramping requirement is the difference in net load between consecutive hours. Net load is calculated as the difference between total load and generation from renewables (wind and solar).

Sources: Aurora Energy Research

A high-renewables system increases the need for flexibility and reliability

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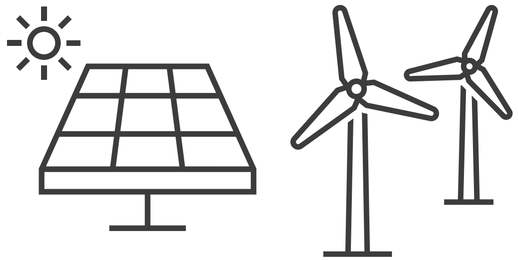
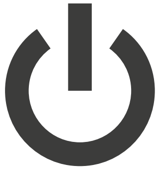
Characteristics of renewables



- Unpredictable
- Variable
- Undispatchable

High-renewables system requirements

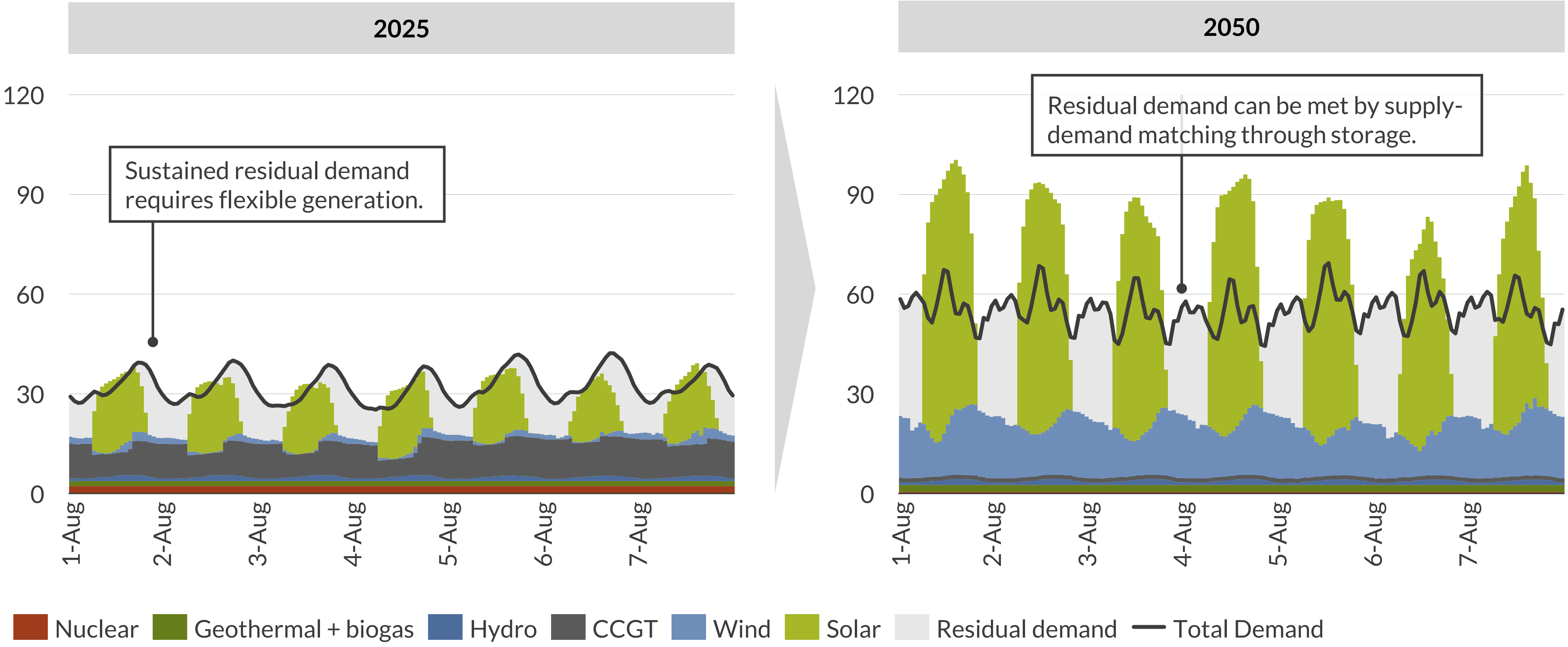


- Ramping
- **Inter-seasonal supply-demand matching**
- Reliability

Supply-demand matching: high levels of storage are required for the effective utilization of intermittent renewables

Illustrative power demand and generation in CAISO for a typical summer week

GW



Sources: Aurora Energy Research

Inter-seasonal supply-demand matching : Storing excess daily renewables for use later in the year will require 15GW of 1-month duration storage

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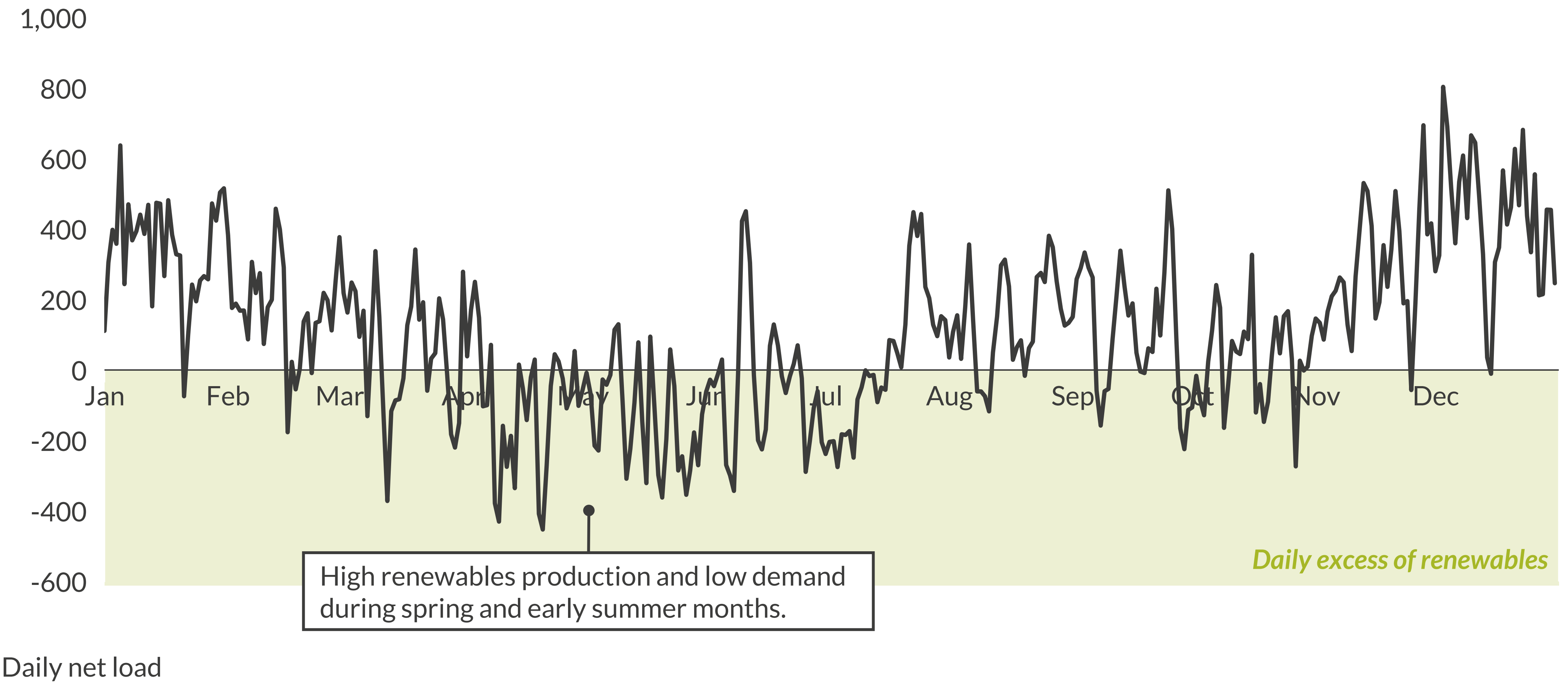
2050 daily net load
GWh



Sources: Aurora Energy Research

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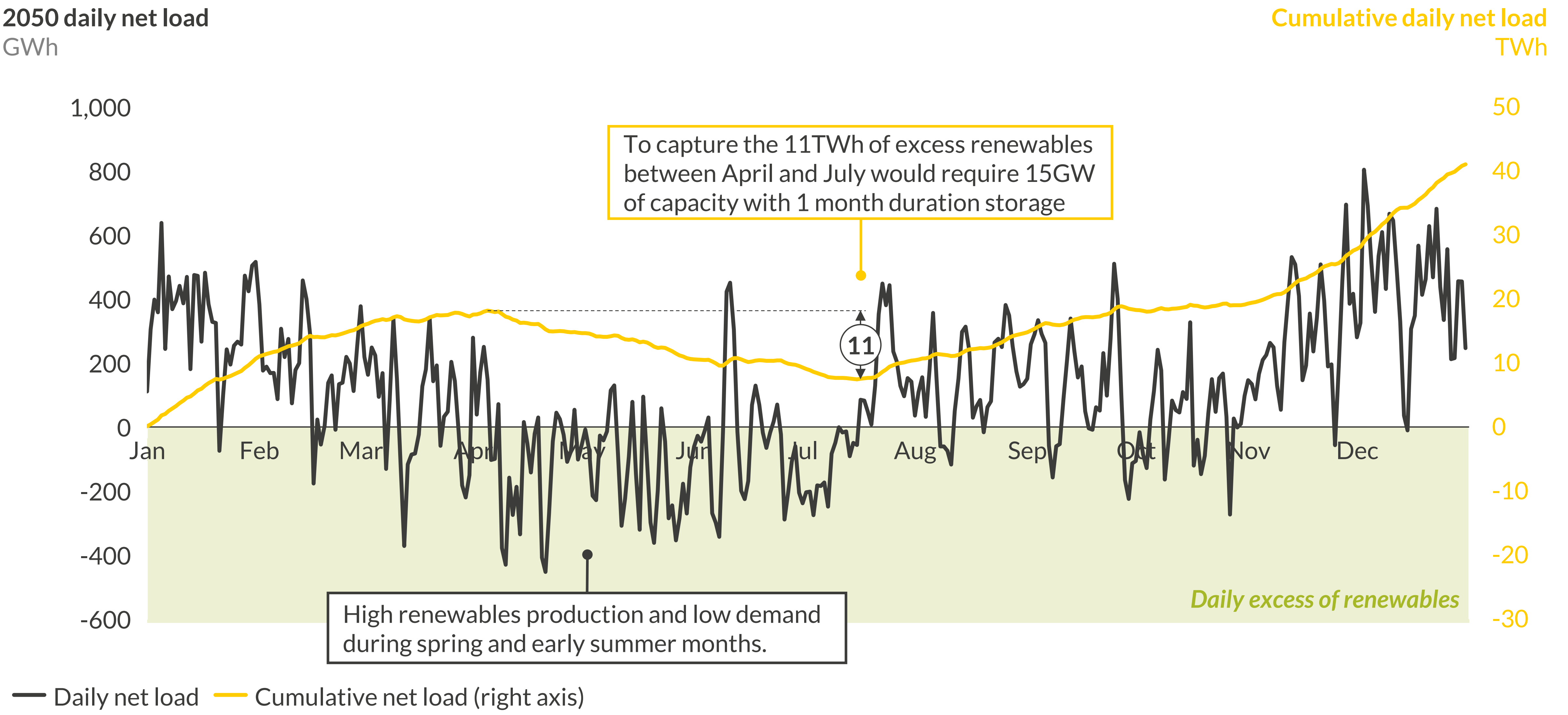

Sources: Aurora Energy Research

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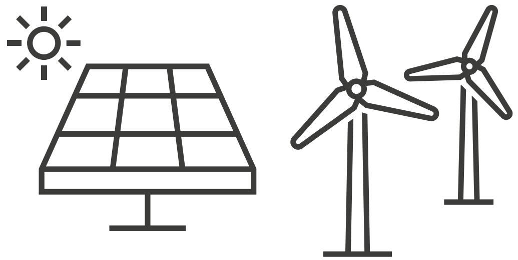
Characteristics of renewables



- Unpredictable
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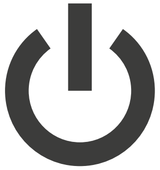
High-renewables system requirements



- Ramping
- Inter-seasonal supply-demand matching
- **Reliability**

Reliability: flexible technologies are necessary to complement renewables growth; over 60GW of net load will need to be met

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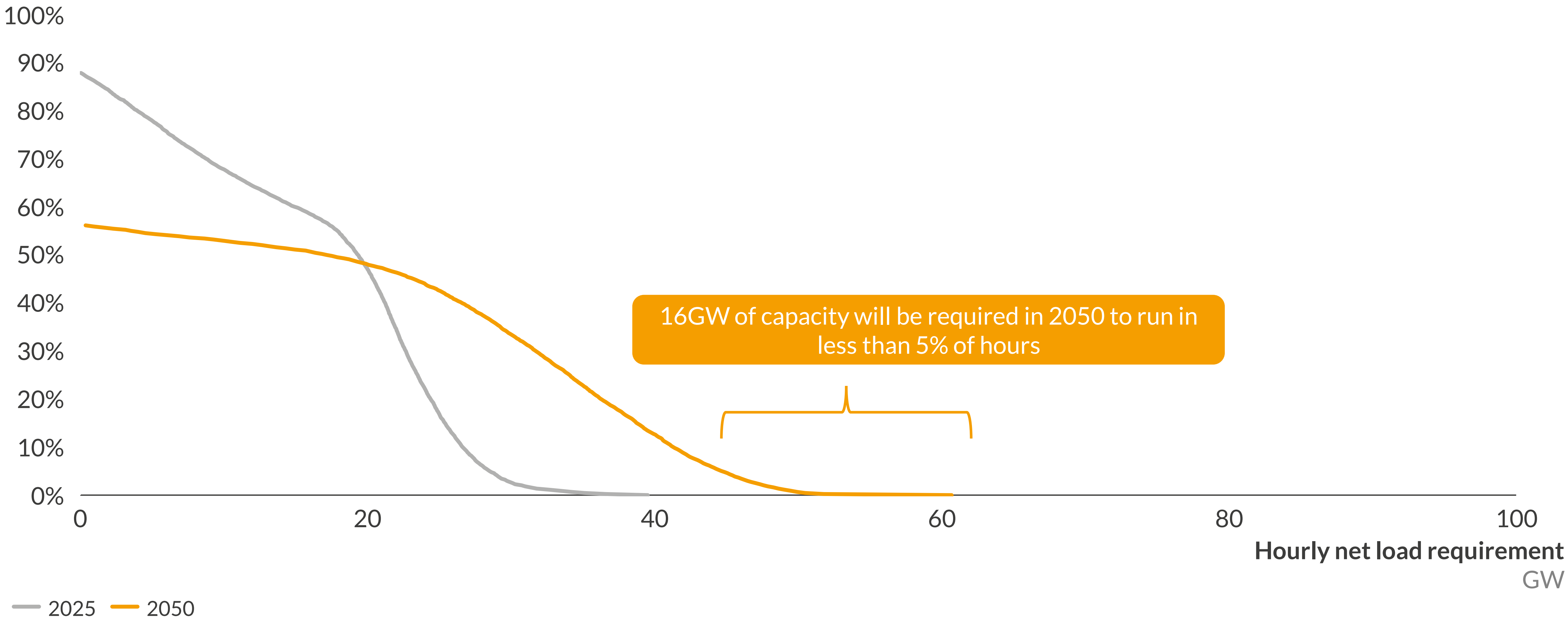
Hours per year with hourly net load requirement



Sources: Aurora Energy Research

Reliability: replacing the output of ~31GW of thermal dispatch in a high demand week would require over 10x the battery CAPEX investment of CT

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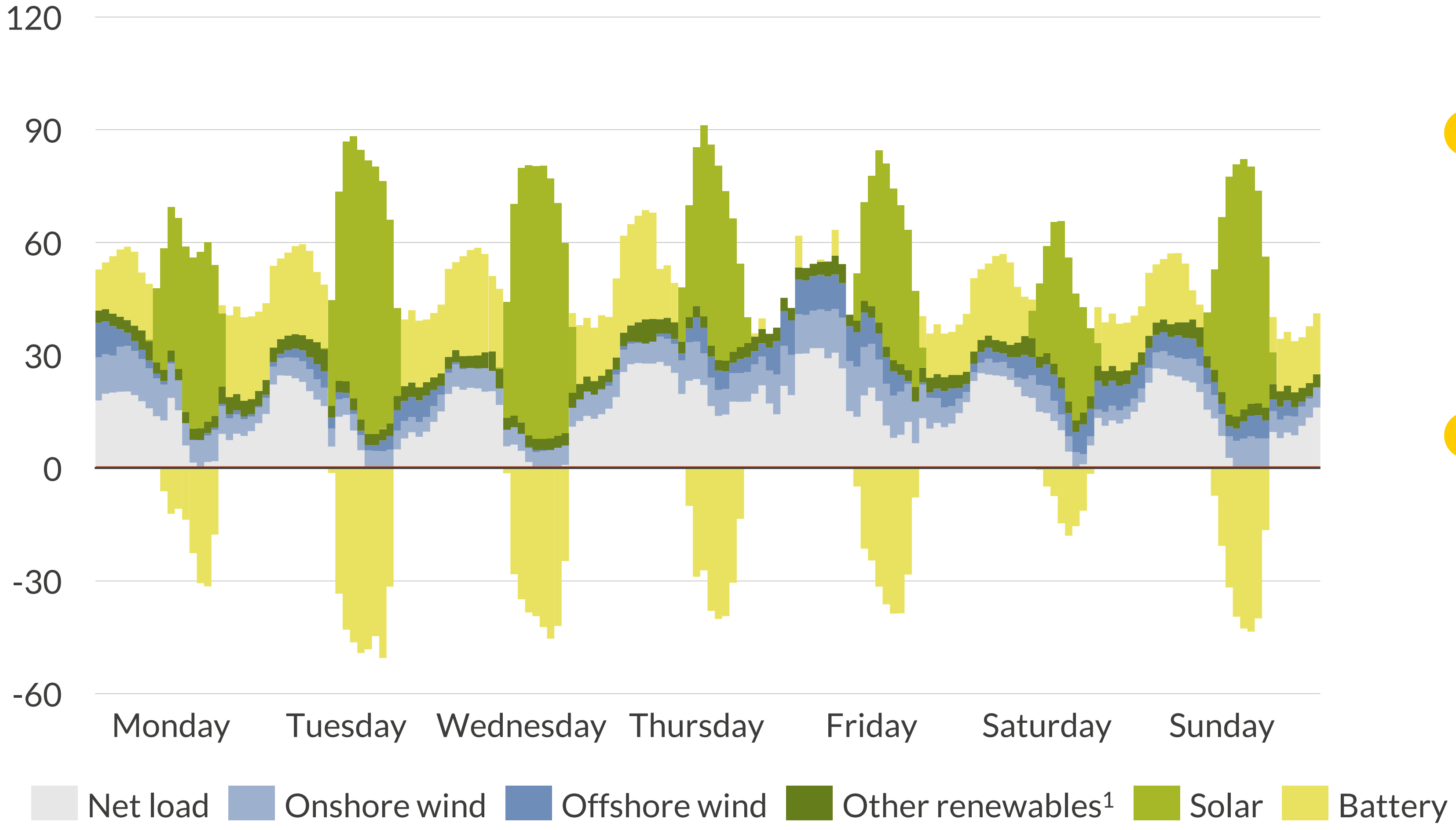
Production throughout the week of December 18-24, 2050 in CAISO
GW



During this period, net load makes up 2,418GWh of electricity (or 31GW of firm capacity)

1 Peaking generation required to fill this gap requires investment of $31bn

Technology	GW	Plant CAPEX[2]
Peaker (CT)	31	$31bn

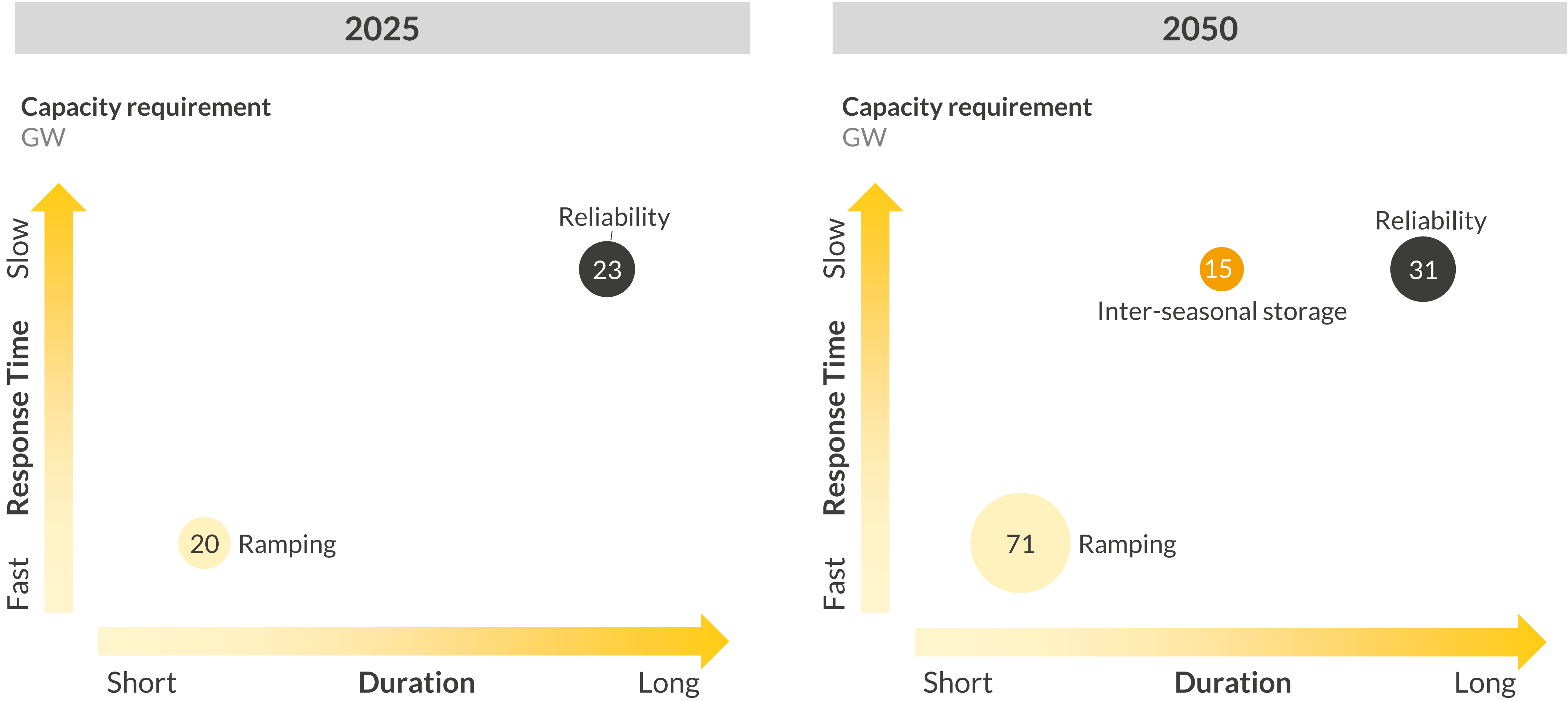
2 Battery storage required to fill the gap requires significantly higher investment

4-hour battery	605	$516bn
8-hour battery	302	$358bn

1) Includes hydro, pumped storage, geothermal, and biomass. 2) Using 2024 CAPEX values. Assumes 1 cycle/day for batteries. Pre-ITC value.

Sources: Aurora Energy Research

Reliability: the system's requirement for quick-response, long-duration generation increases as renewable penetration increases



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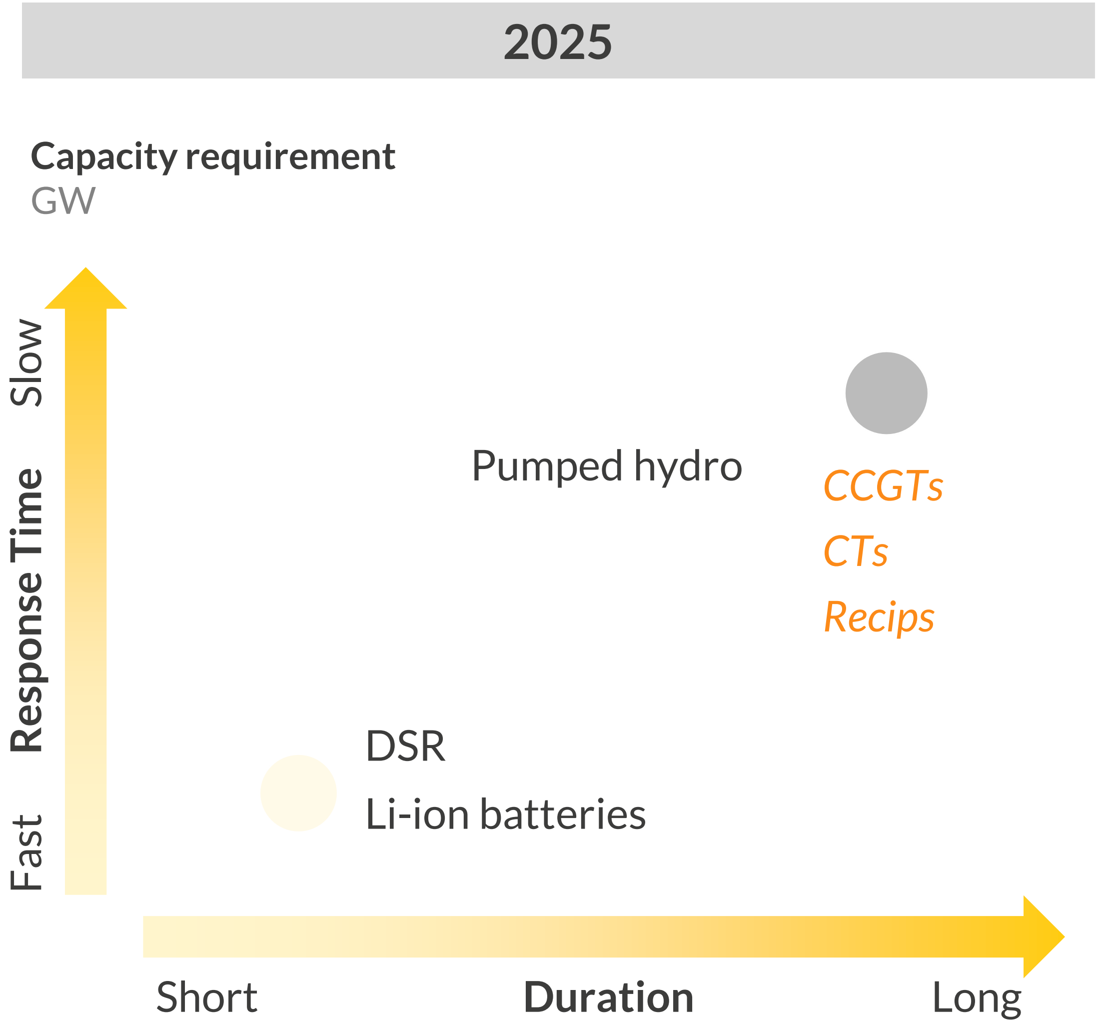

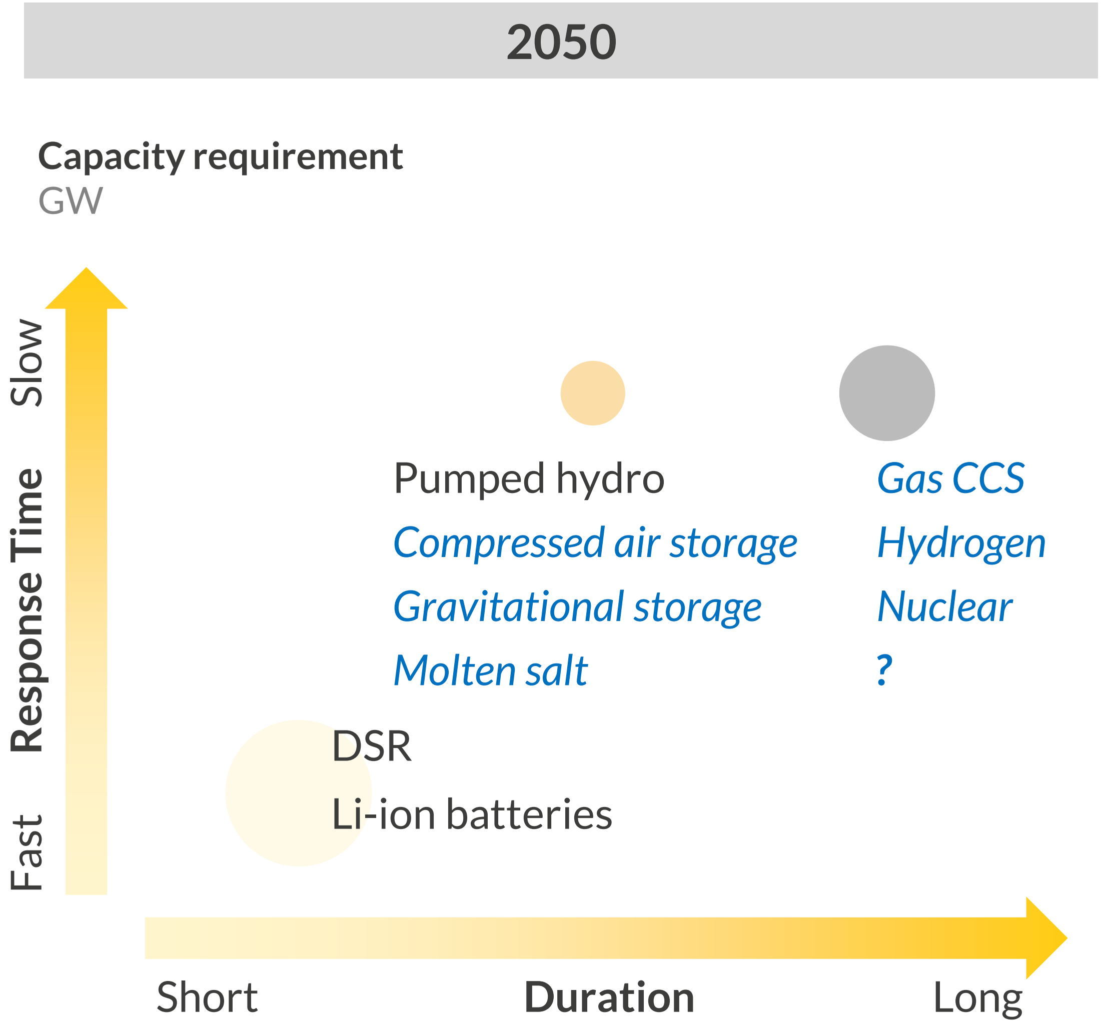

Even in a highly decarbonized scenario, thermal plants will still be the marginal resource in 40-50% of hours

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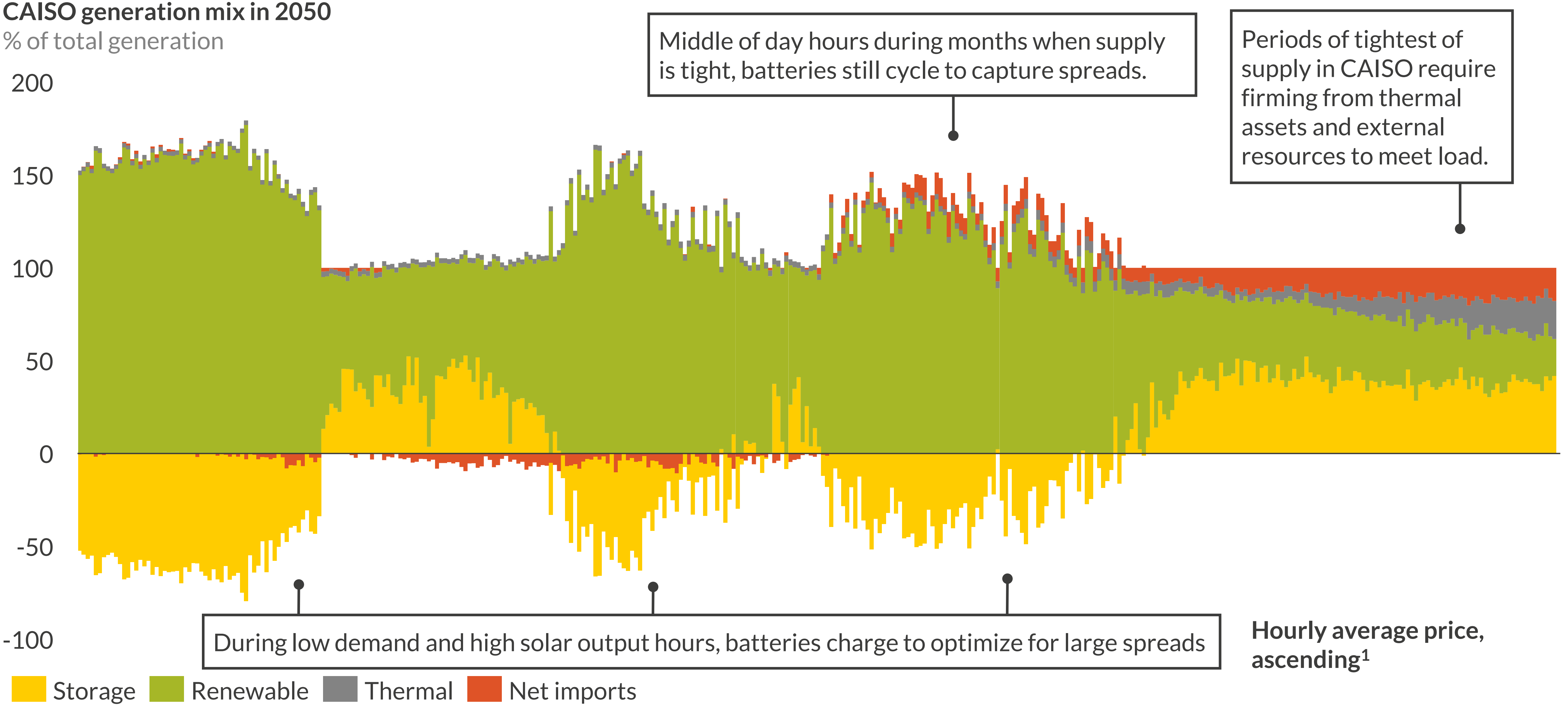
CAISO generation mix in 2050

% of total generation



1) For presentation purposes, the hourly data has been grouped into 24-hour intervals.

Sources: Aurora Energy Research

Current market design rewards ramping and reliability; there is no market signal for inter-seasonal supply-demand matching

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High-renewables system requirements	Existing market design: Wholesale market (RT/DA)	Existing market design: Ancillary Services	Existing market design: Capacity Market
Ramping	✓	✓	
Inter-seasonal supply-demand matching			
Reliability	✓	✓	✓

Policy principles

- Price the externalities
- Define the system needs
- Let the market decide

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