Aurora's outlook on flexibility and battery storage

15 November 2018

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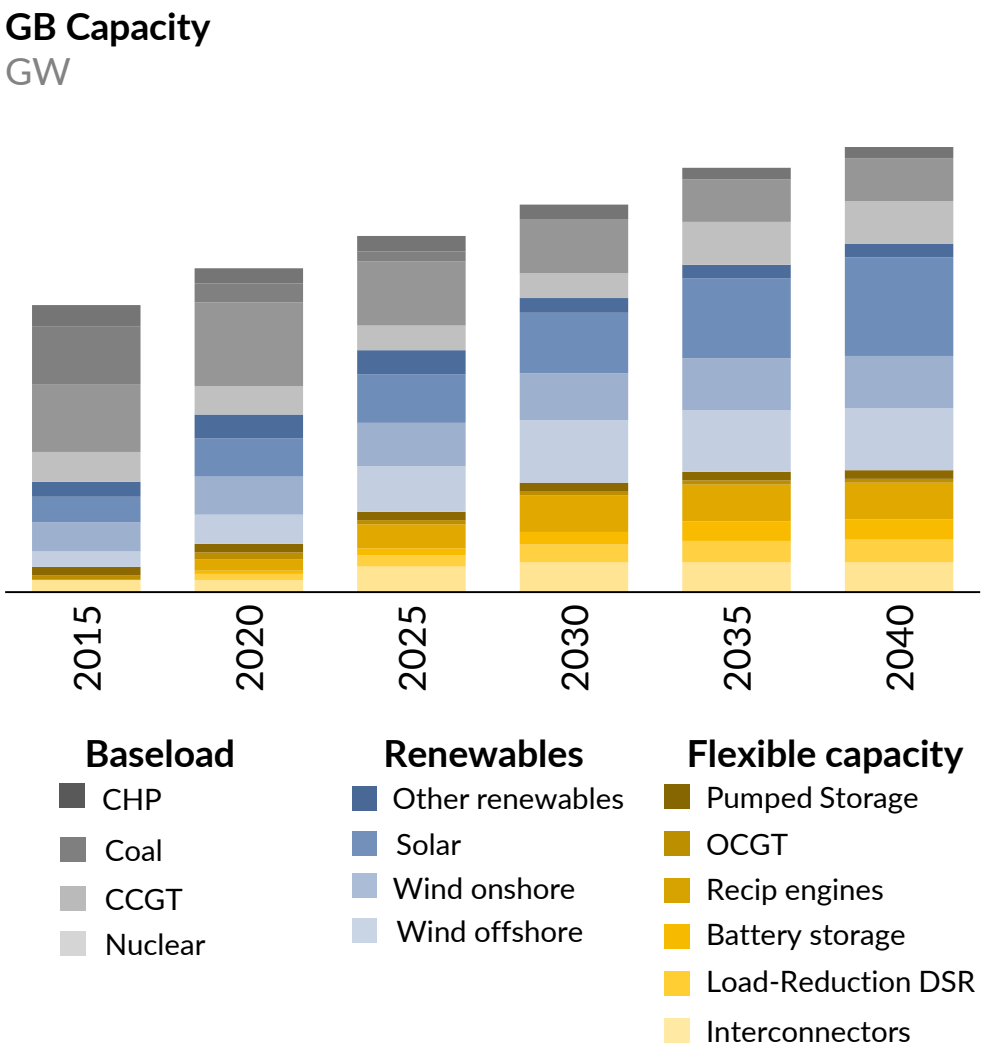
The GB energy market is expected to undergo significant capacity mix changes



Total change 2015-2040

-45%[1]

+166%

+385%

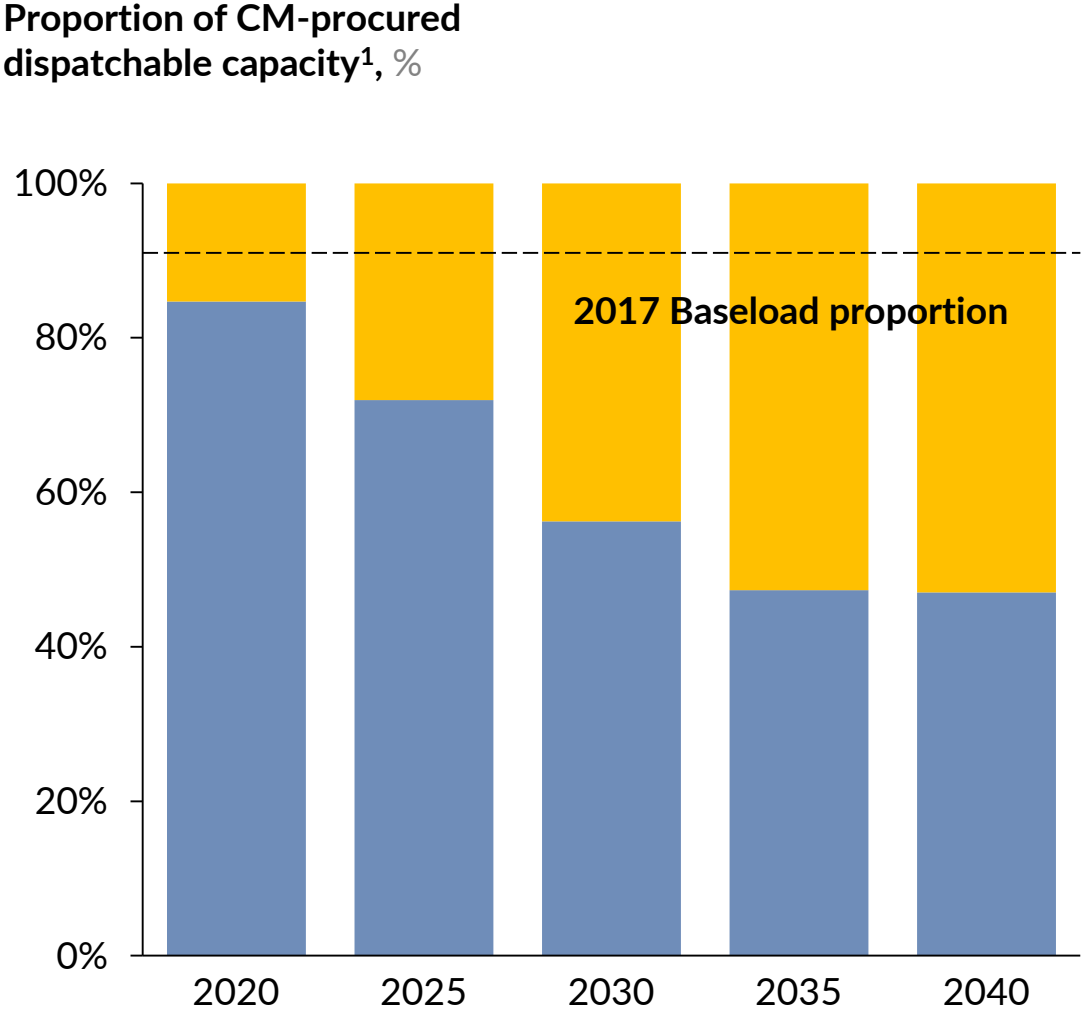
1. Increase in low carbon generation (Nuclear, Wind and Solar)
2. Lower utilisation and retirement of baseload Coal and CCGT
3. Greater interconnector capacities and cross-border trading with EU
4. Declines in storage capex and emergence of long-duration capability

1. Under the Limited Lifetime Derogation (LLD), coal plants that are not compliant with the IED (Industrial Emissions Directive) must close by 2023; currently, only 2 out of the 7 existing coal plants in GB are IED-compliant

Sources: Aurora Energy Research

Increase in renewables necessitates a rebalancing of the system from baseload to peak load capacity

Proportion of CM-procured dispatchable capacity[1], %

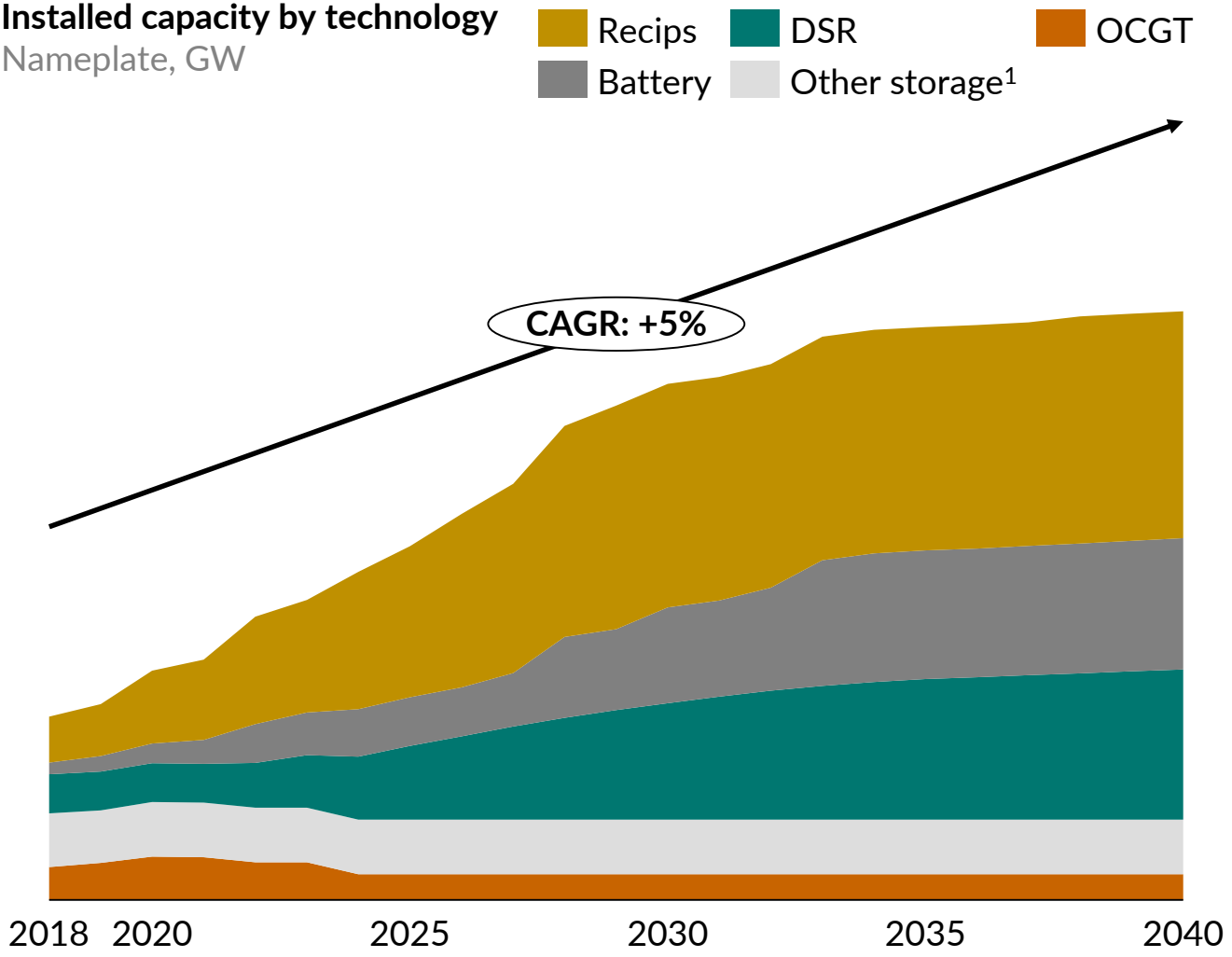


- The future system will require at least 15-20 GW of capacity with load factors below 15%
- CCGTs running below 15% load factor are very uncompetitive against flexible technologies like recips and batteries
- If the current pipeline of nuclear, interconnectors and renewables materialises, the residual load duration curve implies an over-supply of CCGTs

1. Primarily thermal technologies including CCGT, CHP, OCGT, Coal, and Reciprocating engines

Initial growth in flexible energy from recip engines; batteries and DSR continue growth from mid-late 2020s

Installed capacity by technology
Nameplate, GW



- Initial growth in flexible technologies is expected to be driven primarily by recip engines
- Batteries are expected to take off in the mid-2020s to dominate the flexible energy space
- DSR growth increases in mid-2020s as potential demand flexibility is unlocked
- Energy trading business models will attract the majority of new flexible capacity to 2030

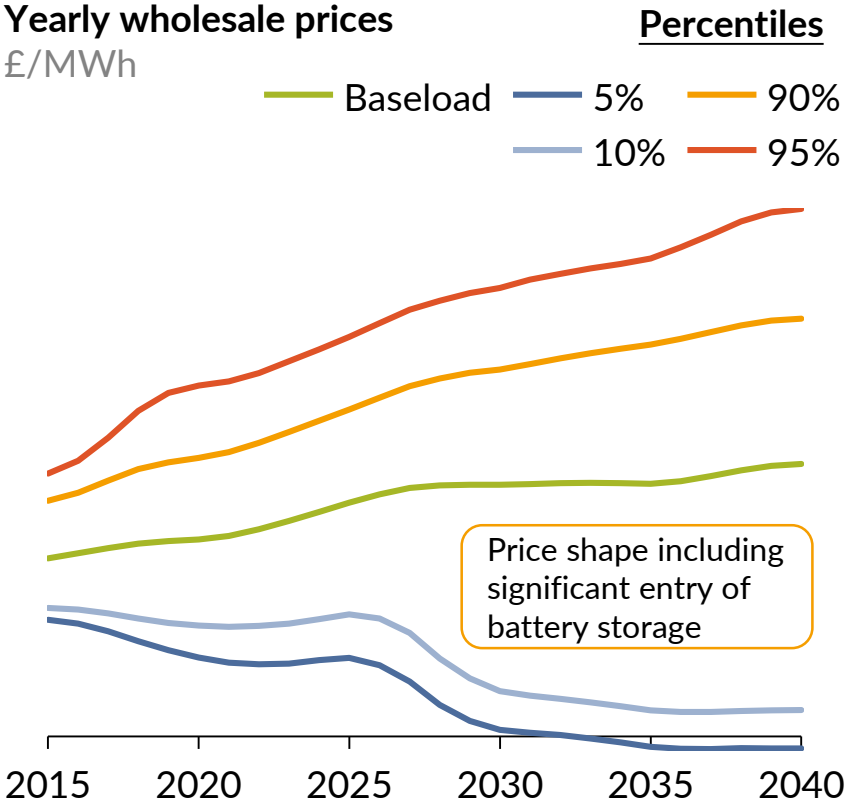
1. Pumped storage

Sources: Aurora Energy Research

Volatility of wholesale prices is expected to increase, opening up opportunities for flexible technologies

Yearly wholesale prices

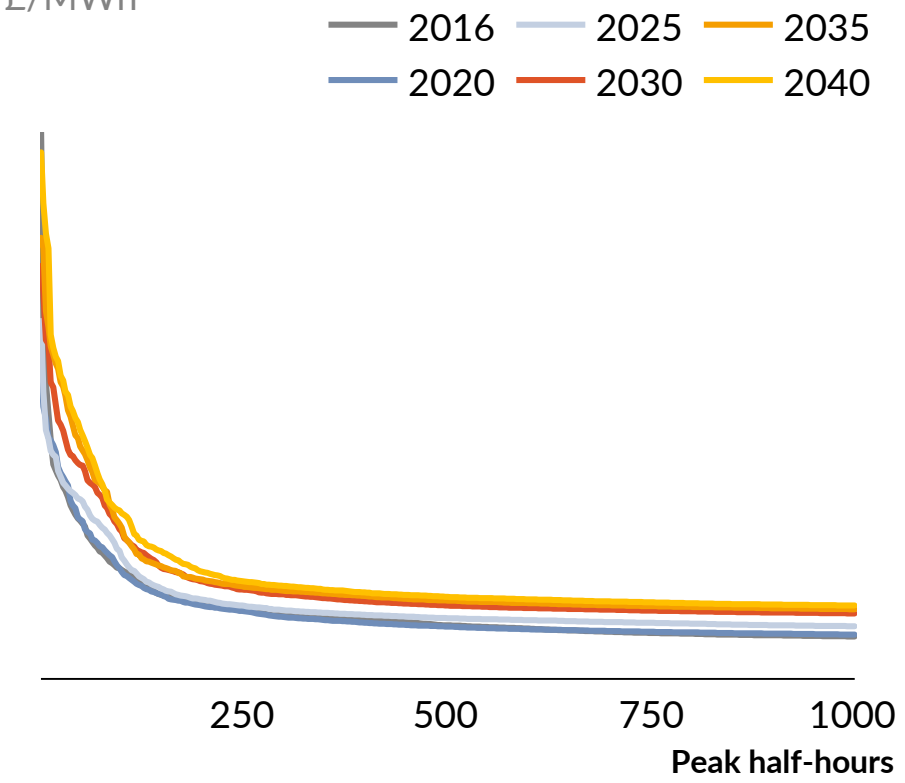
£/MWh



- Nuclear, wind and solar deployments cause top and bottom prices to diverge
- Interconnectors remove very negative prices by exporting to Europe

Half-hourly wholesale prices

£/MWh

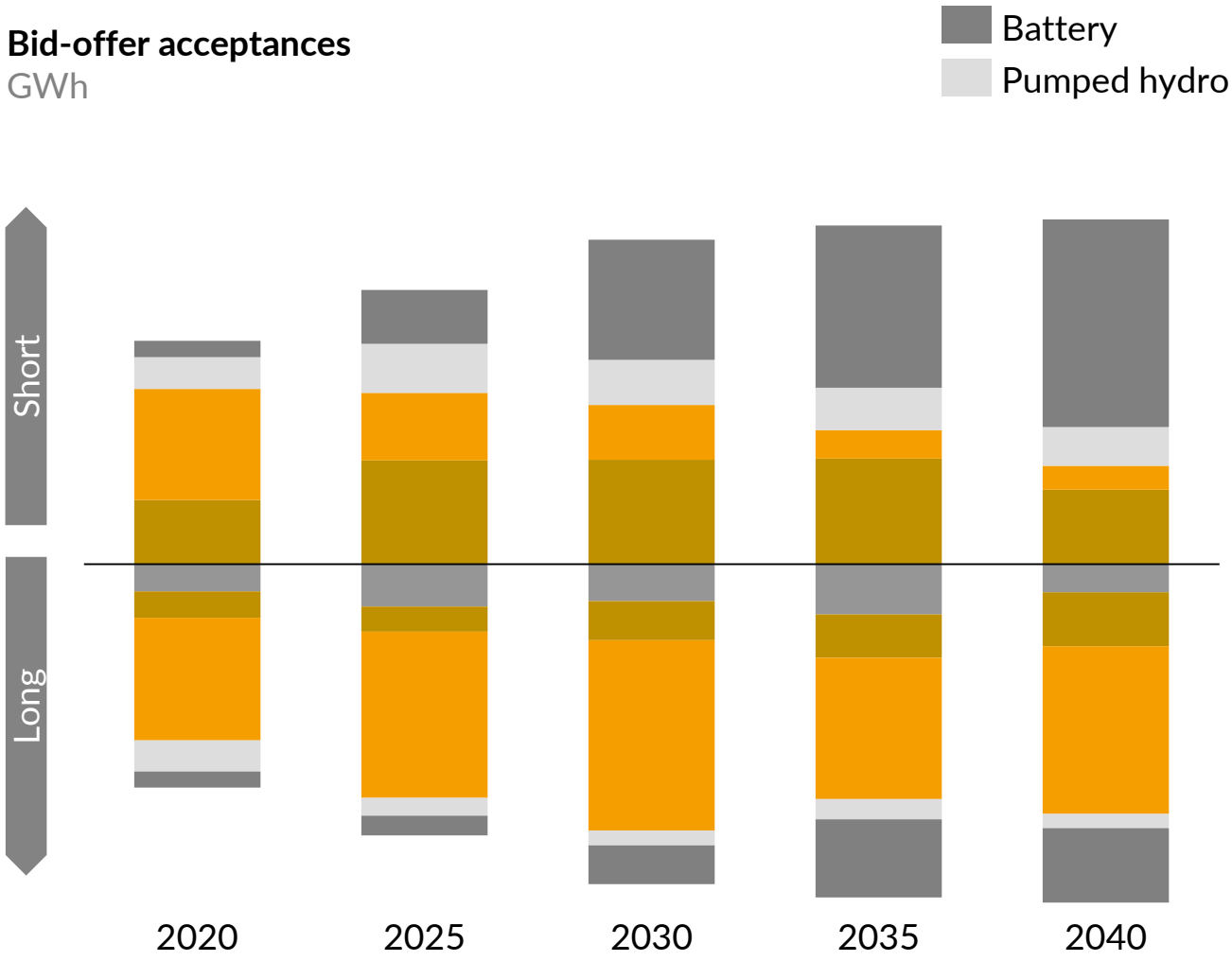


- Highest prices in the year are expected to increase
- Battery capacity is unable to offset higher prices during periods of low wind output

Sources: Aurora Energy Research

Batteries and recips become the dominant technologies for upward balancing by 2030

Bid-offer acceptances
GWh



- Overall long and short imbalance volumes increase over the horizon due to strong wind deployment
- On the short side, Batteries and recips are expected to capture market share from thermal technologies
- On the long side, CCGTs are expected to provide majority of required downward balancing

Sources: Aurora Energy Research

New technologies are emerging in GB as potential technological alternatives for long-duration storage

Commercial Viability

Mature → *In development* → *Testing*

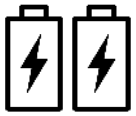
Pumped Storage

Operational in GB since 1963. Most technologically mature

2.6 GW currently deployed

Largest projects in GB:
- Dinorwig – 1.8 GW
- Cruachan – 400 MW
- Ffestiniog – 360 MW

Lithium Ion Batteries

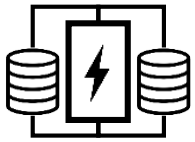


Mostly 1-1.5h durations in operation, primary focus for storage developers

~500 MW currently deployed

Largest portfolios[1] in GB:
- Statera – 150 MW
- Arenko – 140 MW
- UKPR – 120 MW

Flow Machines



60kW/300kWh RedT unit sold in Aug-18, with units sold in Australia as well

>60 kW currently deployed

Largest projects[1] in GB: (kW/kWh)
- Olde House (90/1000)
- Anglian Water (60/300)

Liquid Air Energy Storage

5MW/15MWh Highview plant launched in Jun-18, plans for 50MW/200MWh

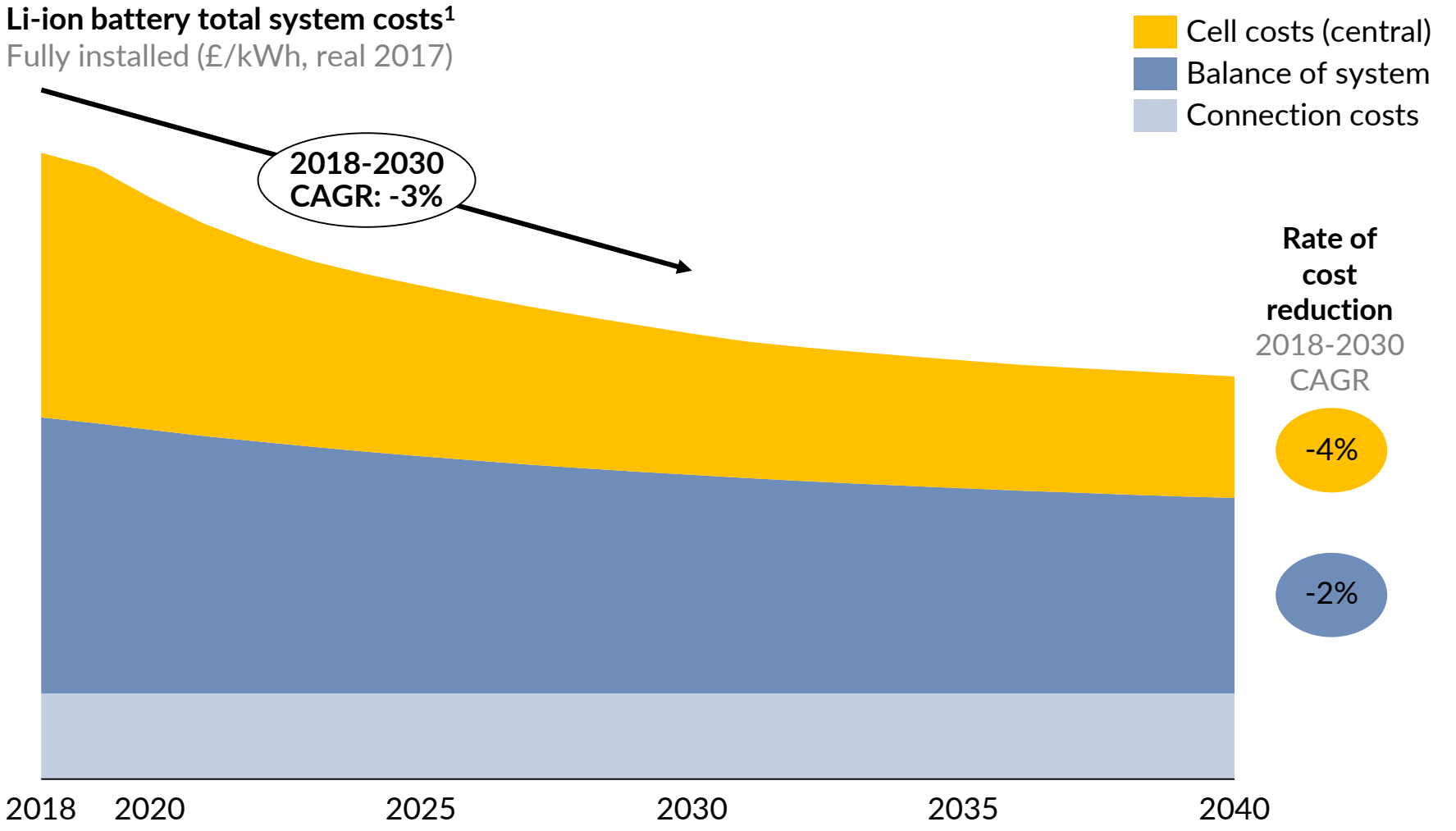
5 MW currently deployed

Largest projects in GB: (MW/MWh)
- Bury (5/15)

1. Operational and in development

Sources: RedT, Highview Power, Aurora Energy Research

Battery costs expected to come down ~3% pa, essentially driven by cell costs

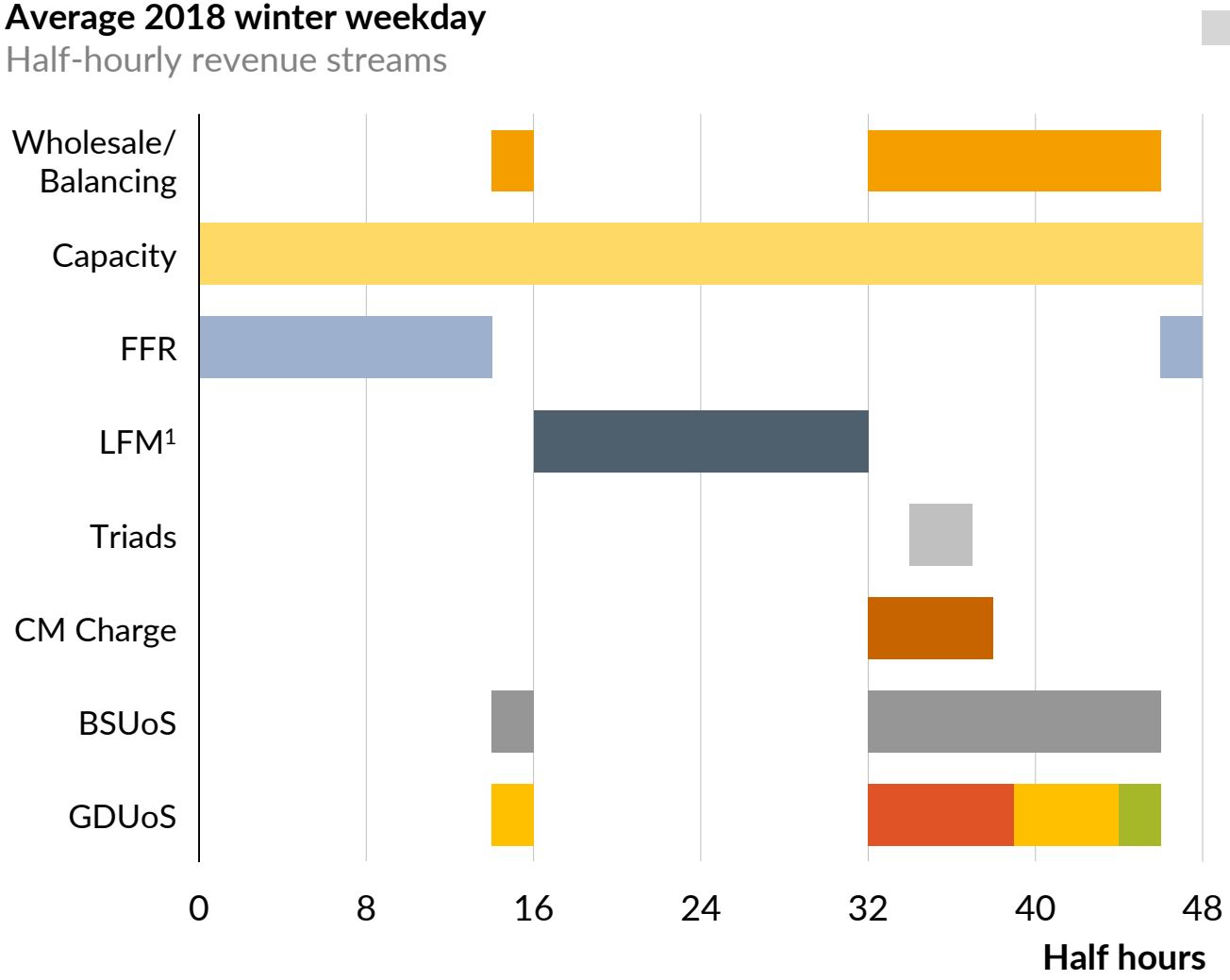


1. Based on a 1-hour duration battery installation of size 5-10 MW. 2. Balance of system includes Battery Management System, Power Conversion System, installation costs and other engineering, procurement and construction. 3. Connection costs include all contestable and non-contestable works.

Sources: Aurora Energy Research, National Renewable Energy Laboratory, GTM Research

Revenue stacking allows multitude of business models, currently 8 revenue streams accessible within a day

Average 2018 winter weekday
Half-hourly revenue streams



- Capacity payments are an availability payment, and stackable with all other revenue streams
- Overnight FFR contracts run from 11pm to 7am (EFA[2] blocks 1 and 2)
- LFM contracts are location-dependent, but can be a significant source of revenue for eligible assets
- Other embedded and BTM benefits are primarily accessible through export or demand reduction, typically during peak periods in the Wholesale/balancing markets

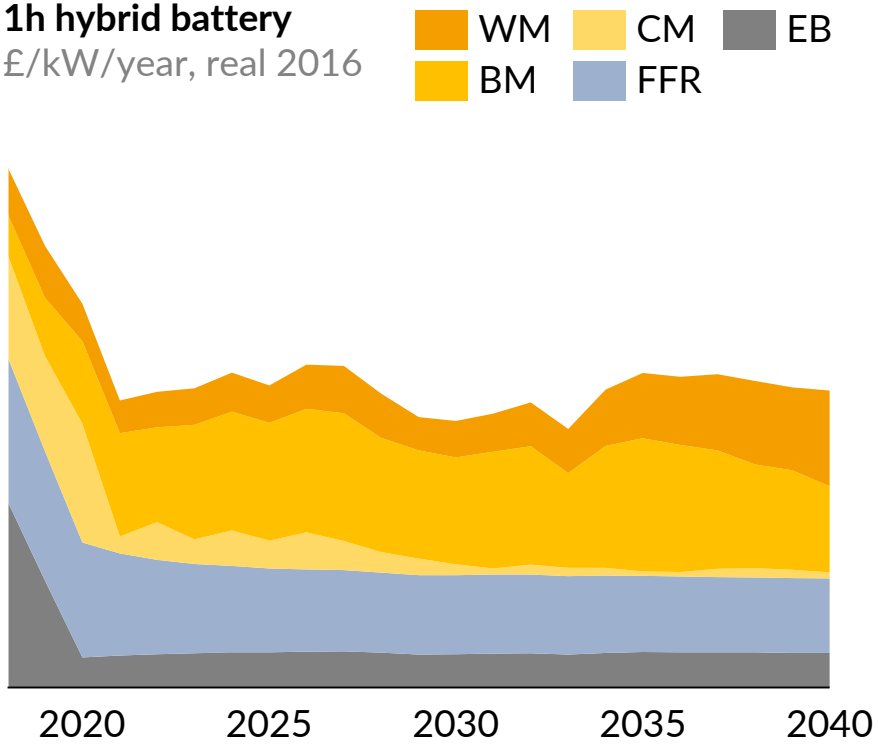
1. Local Flexibility Markets. 2. Six four-hourly blocks within the day that begin at 11pm

Sources: Aurora Energy Research

Margins for a 1h hybrid model are similar to that of a 1h energy arbitrage model due to operational constraints

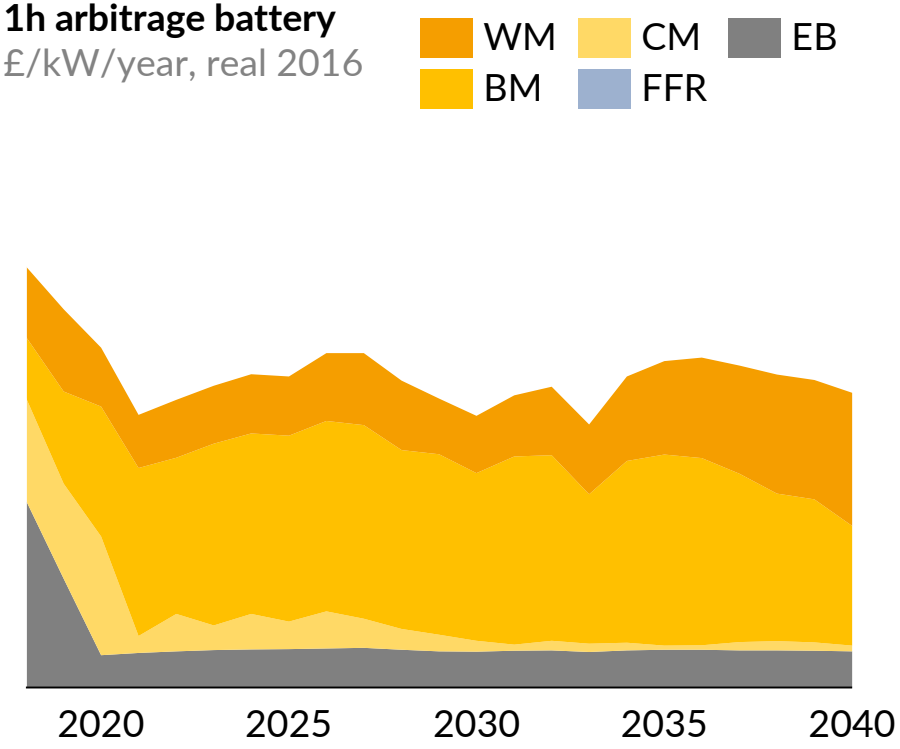
A hybrid business case captures similar margins to an energy arbitrage business case due to:
1. Payment of FFR by power output, and 2. Lost value in arbitrage due to suboptimal charging times

1h hybrid battery
£/kW/year, real 2016



- Battery can only charge in the morning (after 07:00), lowering total captured spreads
- FFR makes up between 24-36% of total margins over the horizon

1h arbitrage battery
£/kW/year, real 2016

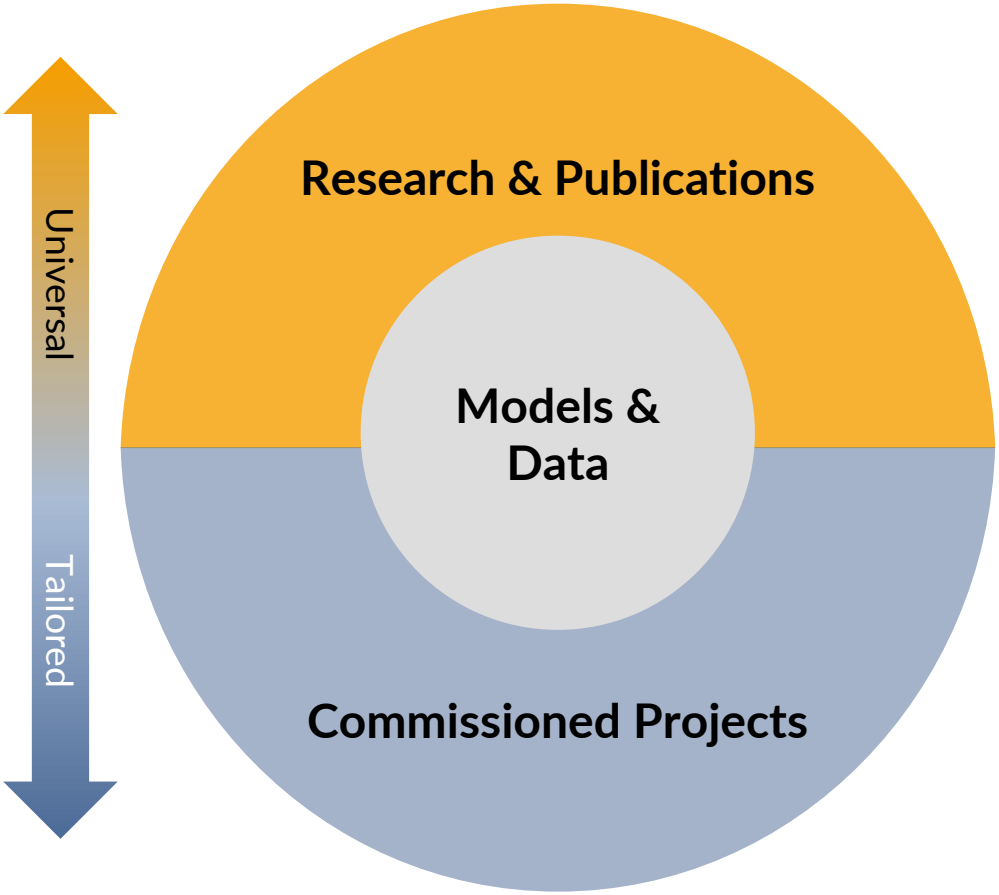


- Battery can charge overnight, where Wholesale and Balancing prices are typically lowest
- Pure arbitrage margins from WM and BM remain fairly constant

Sources: Aurora Energy Research

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

Aurora's offering



- We produce widely-read publications covering European power and gas as well as global energy markets
- Our subscribers meet regularly to discuss and challenge our analysis

- Market leading long-term models for power, gas, carbon, oil and coal markets
- Our online EOS platform transparently provides all of our data and analysis

- Our Commissioned Projects team provides tailored support and advice, drawing upon our models and data
- Typical projects include valuation, strategy, forecasting, and policy engagement

Source: Aurora Energy Research

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