



Energy
Transitions
Commission

Power systems transformation: emerging conclusions from the ETC's work

ETC Representatives Meeting

19th September 2024

Agenda

- 1. The transformation of the power system is bringing new challenges: building & optimising grids, and managing system balancing challenge**
- 2. A technological revolution is enabling this transformation**
- 3. Key questions on managing the system balancing challenge**
- 4. Key enablers & implications of the new system**



The transformation of the power system is bringing new challenges



There are two fundamental & interrelated key areas for power systems which the ETC is looking at this year

A

Building and optimising grids

Tx:
Grow the transmission network

Dx: Reinforcing existing & building new network infrastructure

Tx: Optimising use of existing assets via new technologies

Dx – Spreading peak load to increase grid utilisation & balance the system



Grids – e.g. interconnectors and long-distance transmission can – in part – help to solve balancing challenge

Storage and flexibility deployed to solve system balancing can – in part – reduce the grid build needed & help to optimise



B

Managing the system balancing challenge

Ix / Tx – balancing the system via interconnection / long distance transmission

Balancing the system via storage, flexibility & generation technologies



Grids build must happen faster, but four critical challenge areas slow this down

Grid build must increase markedly

Million km



Key challenge areas must be resolved

i. Implement a strategic vision for network expansion by a future date

ii. Address slow permitting & approvals and societal acceptance

iii. Address skill, component and materials gaps

iv. Reform financing structures & increase access to finance



Notes: Tx = Transmission, Dx = Distribution, Ix = Interconnection.
Source: Systemiq analysis for the ETC

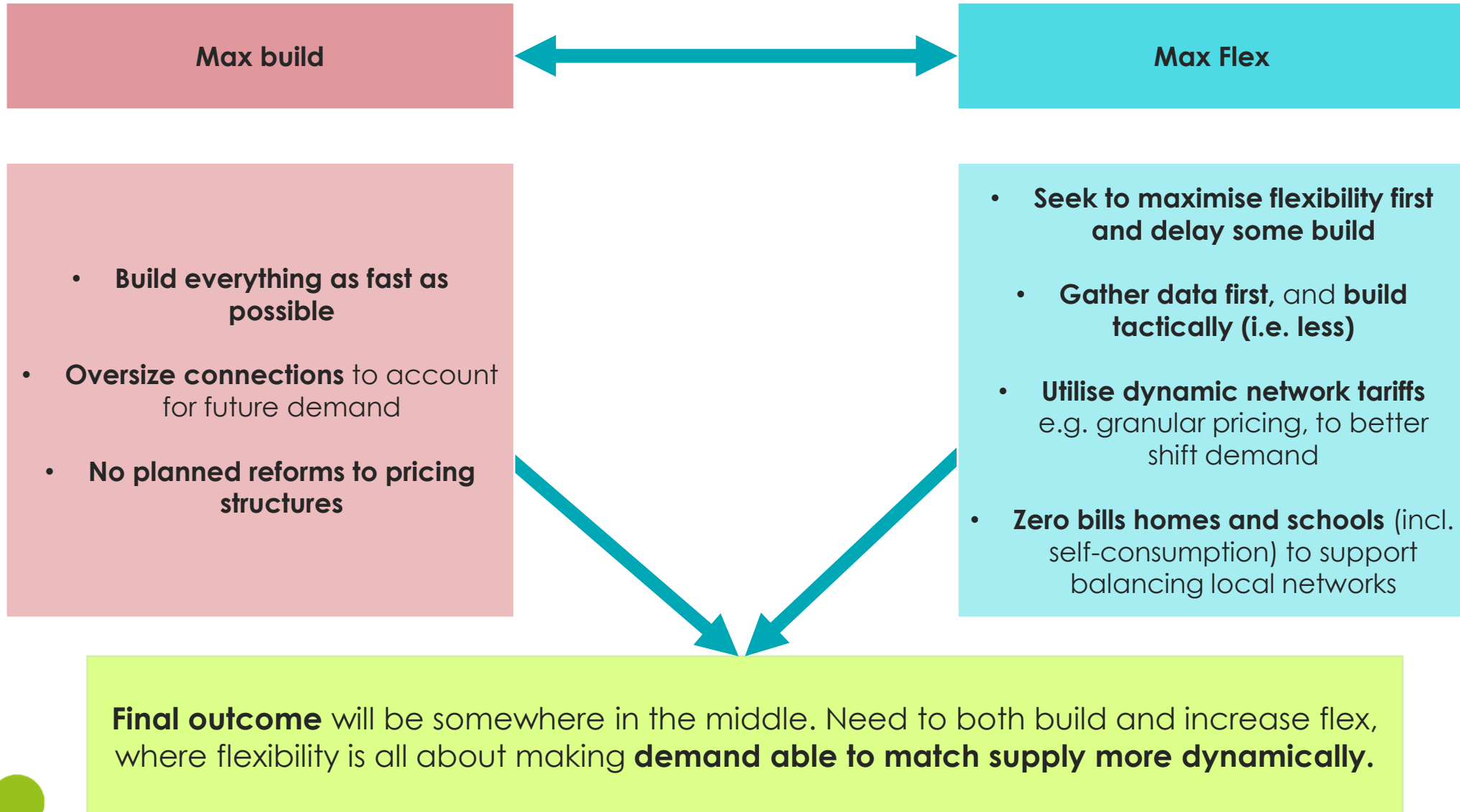
The scale of grid build can be partially offset by optimising grids – avoiding some overall build and buying time for wider reinforcements

There are several ways to optimise power flows across the grid:

- **Innovative grid technologies** could materially improve the efficiency of power flows on the system
- **Storage deployment** (in the right location) can reduce the need for new wires
- **Demand side flexibility** could reduce peak consumption in local areas
- **Long distance interconnection** deployed where optimal can reduce local transmission needs

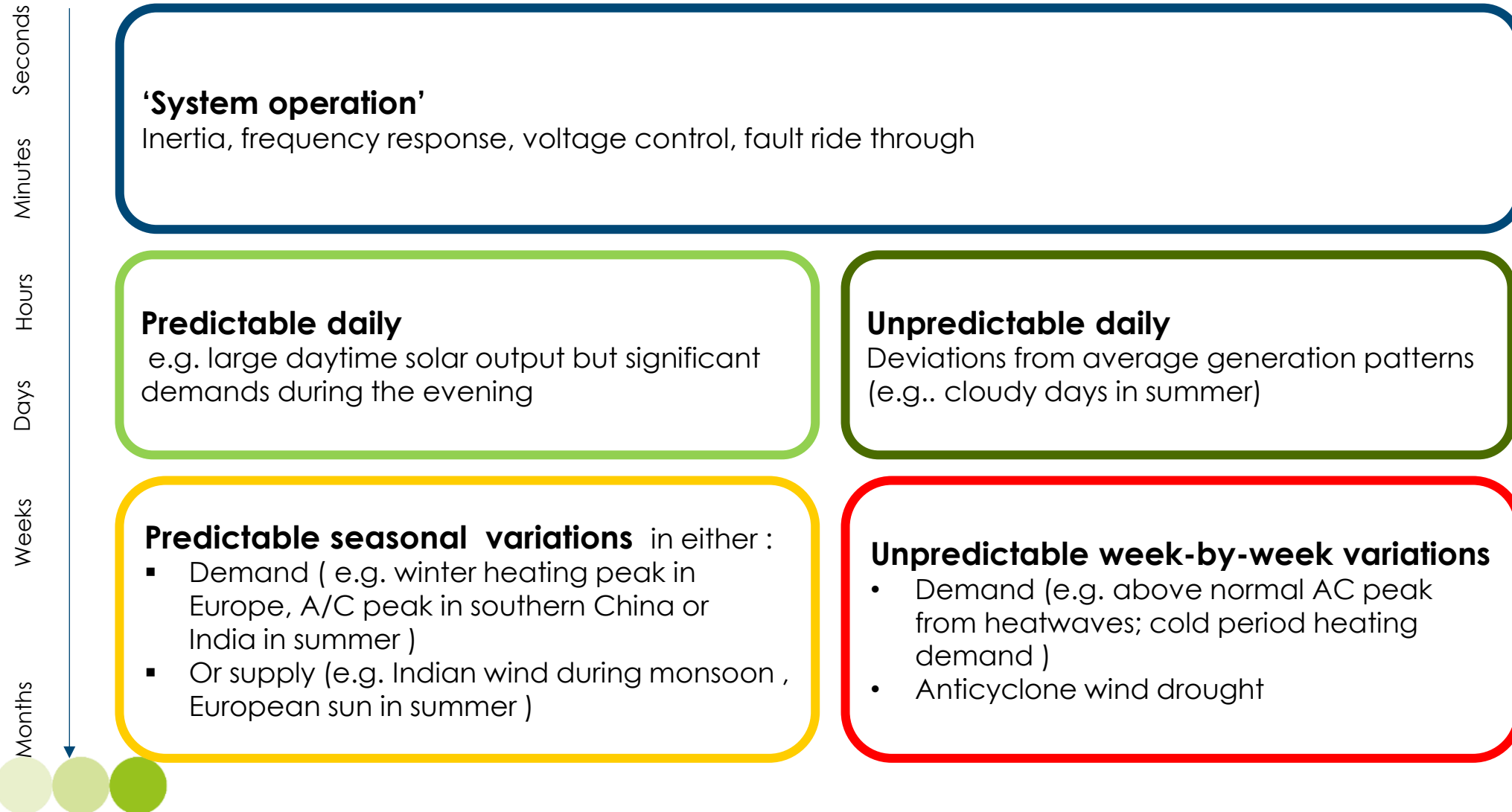


In theory, two potential extremes for evolution of the power system exist



With variable renewables the system must be balanced across all time periods, this adds complexity

A high-renewable power system must be able to meet several challenges...



Challenge that existed in fossil system, but now needs to be met with new technologies

New challenges that must be met for high-renewables power systems due to intermittent nature of generation

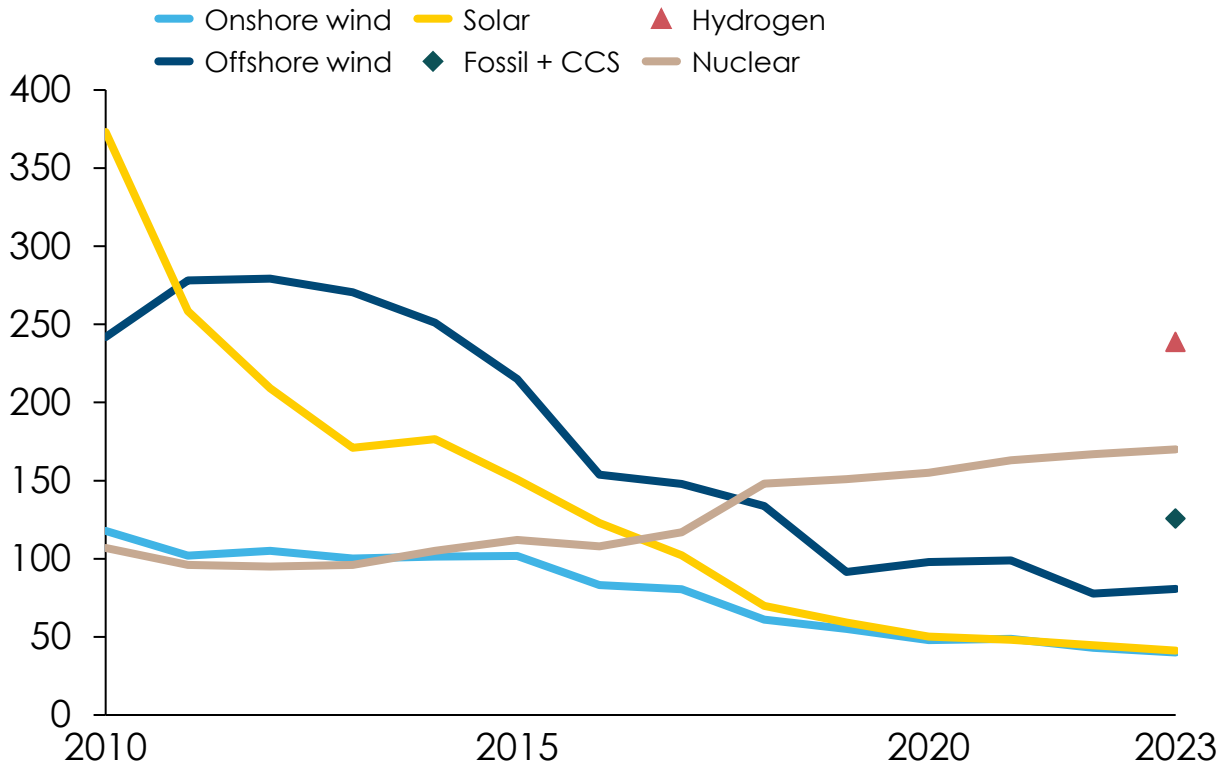
*Technological revolution is
enabling the
transformation of the
power system*



Wind, solar and batteries are continuing to get cheaper against fossil

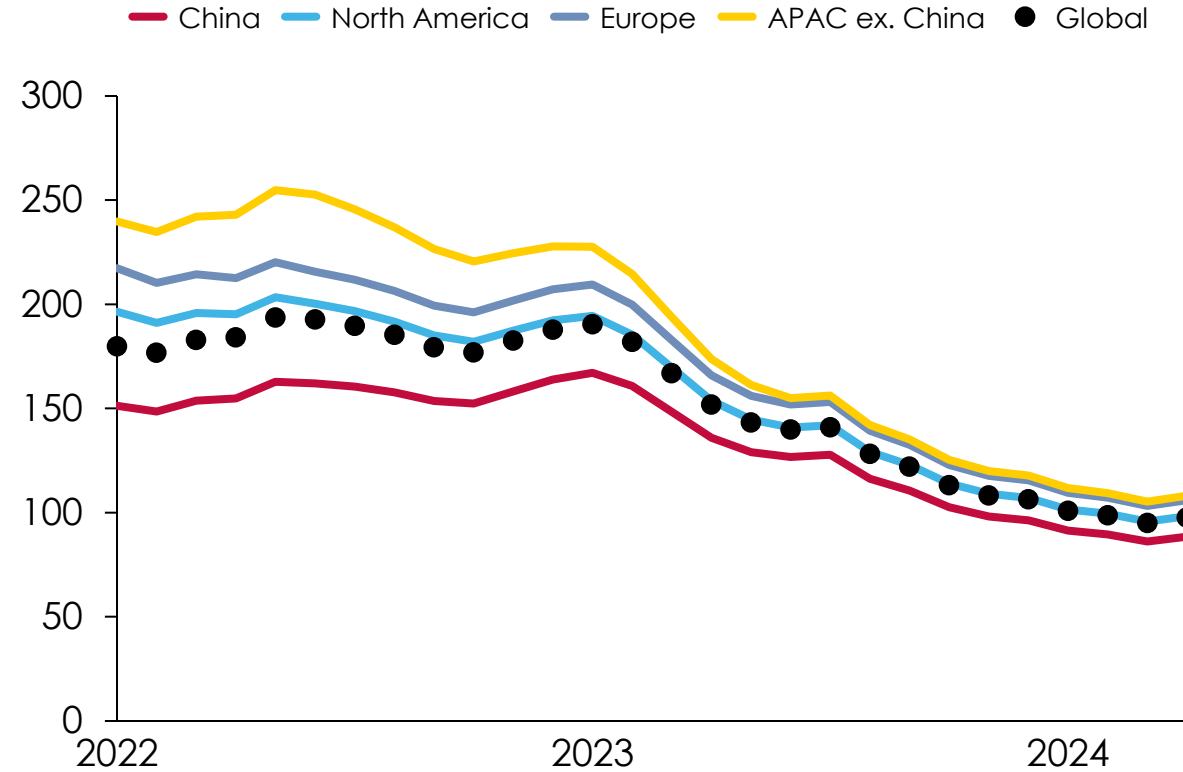
Global LCOE benchmarks for renewables remain competitive

\$/MWh (real 2022)



Estimated average monthly lithium-ion battery pack prices

\$/kWh (nominal 2024)



Notes: The global benchmarks are capacity-weighted averages using the latest country estimates – apart from nuclear, hydrogen and CCS, which are simple averages. Offshore wind includes offshore transmission costs. Fossil + CCS is the average of Coal- and gas-fired power include carbon pricing where policies are already active. LCOEs do not include subsidies or tax-credits. Solar refers to fixed-axis PV. Nuclear data from Lazard. Source: BNEF (2023) 2H 2023 LCOE Update; BNEF (2024) China Lithium-Ion Battery Supply Chain Update 2024; Lazard (2021), LCOE, Levelized Cost of Energy Comparison—Historical Utility-Scale Generation Comparison

Technology exists both to better optimise and balance the system, with promising progress made in recent years

Better optimising grids

Managing system balancing



Innovative grid technologies



Flexible dispatchable generation



Long distance interconnection



Effective energy storage



Heat storage



Demand side management



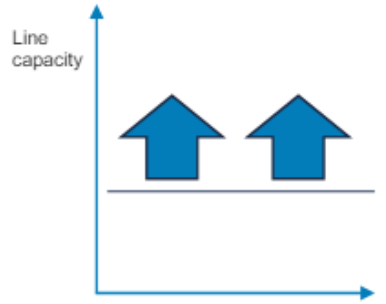
Innovative Grid Technologies can help circulate power more efficiently

Existing rights of way *Changes to pylons and wires*

Existing wires and networks *No changes to pylons and wires*

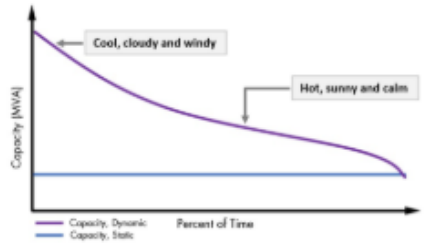
Main methods to increase grid capacity:

Capacity increase for a given line



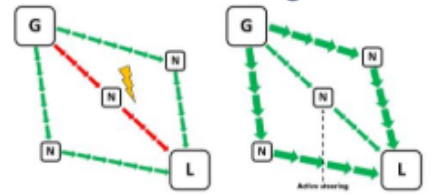
- Direct capacity improvement compared to conventional technologies

Better understanding of actual line limits



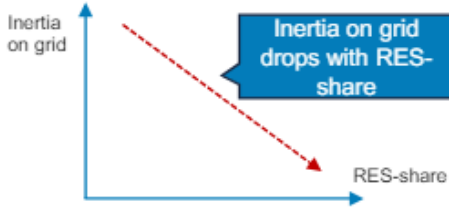
- A static limit must be very conservative, to not overload lines in adverse (hot) conditions;
- Dynamic ratings exploit natural line cooling

Dynamically controlling power flows on the grid



- Power flows through a network are often limited by its weakest line
- By dynamically controlling power flows (e.g. like road traffic management) more capacity is unlocked on the existing grid

Better understanding of actual inertia limits/stability limits



- Inertia on the grid decreases with more RES in the system, which may cause stability issues and RES curtailment
- Precise measurement of inertia allows curtailment to only happen when necessary

Technology options:

- **Advanced conductors**
- **Superconductors**
- **Voltage upgrade** (via larger pylons)
- **Double circuiting**
- **SATA** (Storage as transmission asset)

- **Dynamic Line Rating**

- **FACTS** (Flexible AC Transmission systems)

- **Grid inertia measurements**

- **Digital twins, Flexibility software management solutions**

Notes: The term "Grid Enhancing technologies" can also be used to describe technologies that "maximise the transmission of electricity across the existing system through a family of technologies that include sensors, power flow control devices, and analytical tools". This theoretical framework does not provide an exhaustive classification of IGTs, and of their effects. Other technologies and effects could potentially be considered. Substations and switching stations must be upgraded in tandem with grid capacity upgrades to manage the additional power in the system, key solutions here include gas-insulated switchgear and superconducting transformers. Source: CURRENT (2024), *Prospects for innovative power grid technologies*.

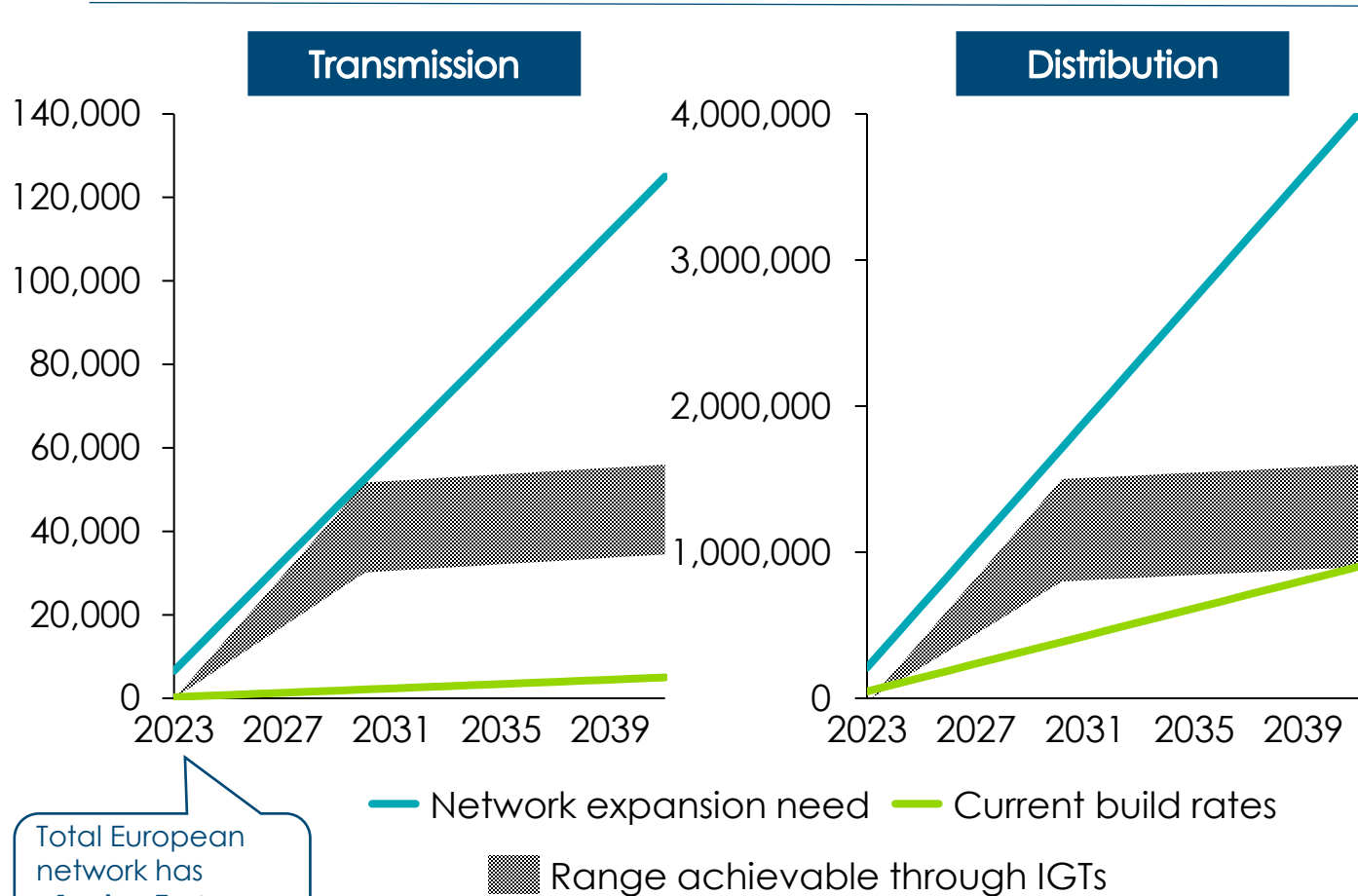


Innovative Grid Technologies could meet substantial portion of network expansion needs



Benefits of IGTs compared to expansion needs and past trends

Line length equivalent, FR, DE, ES, IT, DK, NL and GB



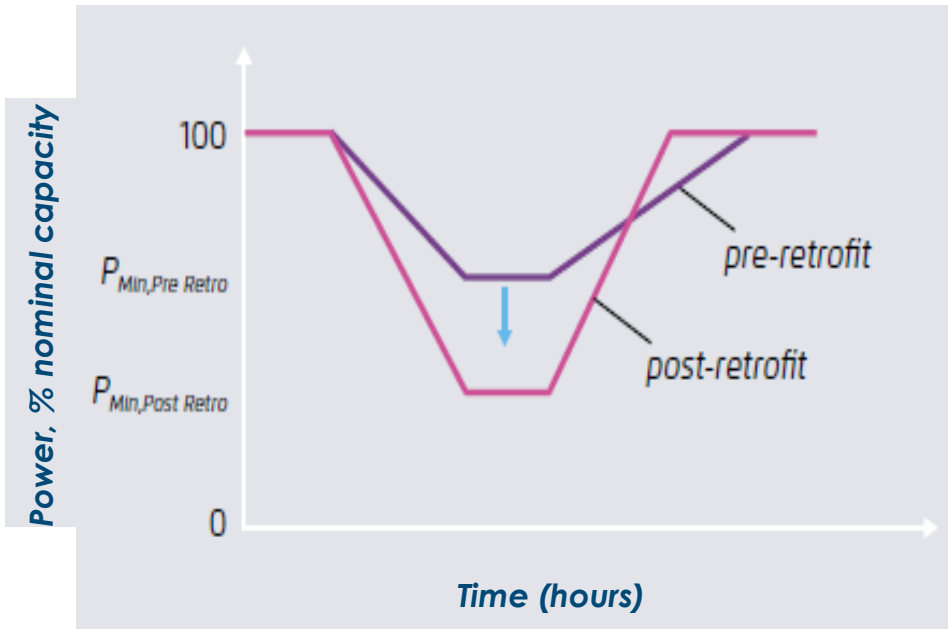
Total European network has
~1 mkm Tx &
~7 mkm Dx

- A 2024 CURRENT study concluded **potential for current capacity to increase 20%-40%** from Innovative Grid Technologies on the wider network.
- Conservatively assuming that this could lead to 10-20% expansion of capacity via the current network, **over 40% of network expansion needs could be met by IGTs.**
- Key enablers need to be enacted to help rollout:
 - **Regulatory incentives for non-capex-intensive solutions** (current capex bias via regulated returns)
 - **New approach to TO/DSO investment doctrine**, taking a technology neutral approach
 - **Better access to funding** for IGT deployment

Notes: Charts take conservative assumption of 10-20% capacity increase out of potential 20-40%. TSO = Transmission System Operator, DSO = Distribution System Operator. European countries included in study include France, Germany, Spain, Italy, Denmark, Netherlands, Great Britain. Source: CURRENT (2024), Prospects for innovative power grid technologies; BNEF (2023) New Energy Outlook Grids.

In some cases retrofit of existing coal plants is useful to increase renewables penetration, this is increasingly possible but comes with moral hazard

Load curves for pre- and post-retrofit of German Neurath Block E coal plant
% of nominal capacity



Coal retrofits key focus as gas is inherently more flexible. GB has transitioned from 500->150 gCO₂/kWh from 2012->2023 using gas for flex.

 Flexible dispatchable generation

Coal retrofits can:

- **Extend life**
- **Increase efficiency**
- **Reduce minimum load**
- **Increase ramp rate**
- **Shorten start-up time**



Retrofitting plants comes with moral hazard from extending plant life, this varies by age of plant:

- **Young plants – less moral hazard** (likely beneficial)
- **Old plants – high moral hazard** (consider other options first)
- **New plants – max moral hazard** (choose different balancing tech)

Germany have demonstrated it is possible to retrofit a large portion of coal plants to effectively provide flexibility

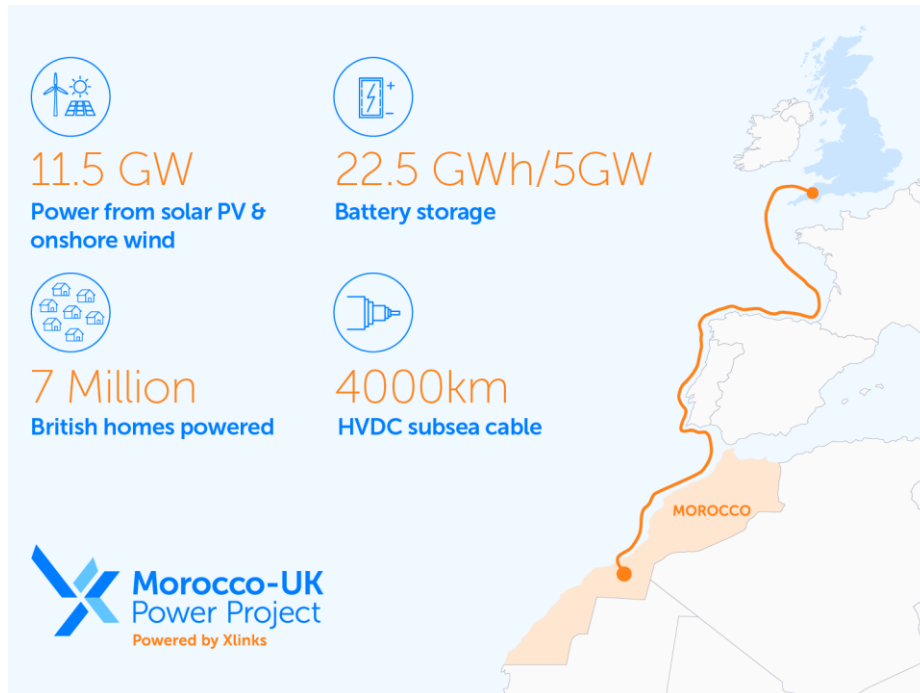
Retrofitting plants in coal dominated systems could be useful – however building new coal plants to balance should be avoided



Interconnection will be possible at greater and greater distances – however some projects have been delayed due to international permitting issues

Long distance interconnection

X-Links 4,000 km cable from Morocco to the UK




Suncable 4,300 km cable from Australia to Singapore



ETC are conducting analysis to establish the global potential for interconnection, and will highlight the most effective potential new interconnectors according to cost, energy security, and emissions reductions



New energy storage technology options are emerging to enable balancing across different time periods

 Effective energy storage



Lithium-ion battery (Li-ion)

Key players:



Iron-air battery (Fe-air)

Key players:



Hydrogen in Combined Cycle Gas Turbines (CCGT)

Key players:




Sodium-ion battery (Na-ion)

Key players:

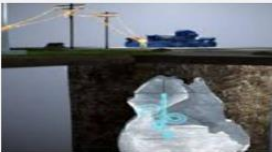


Compressed Air Energy Storage


Key players:



In caverns





In high-pressure tanks

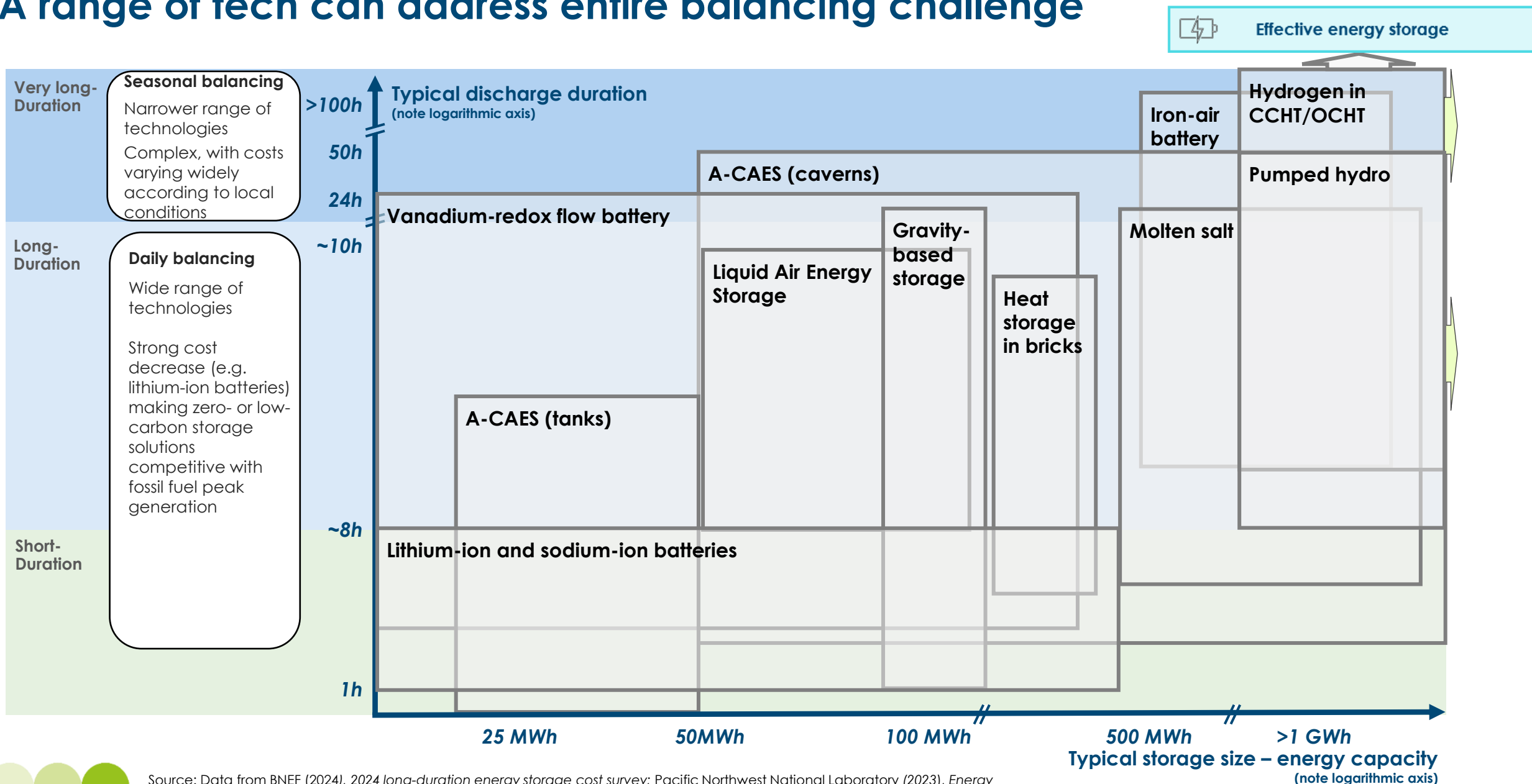


Heat storage in bricks

Key players:

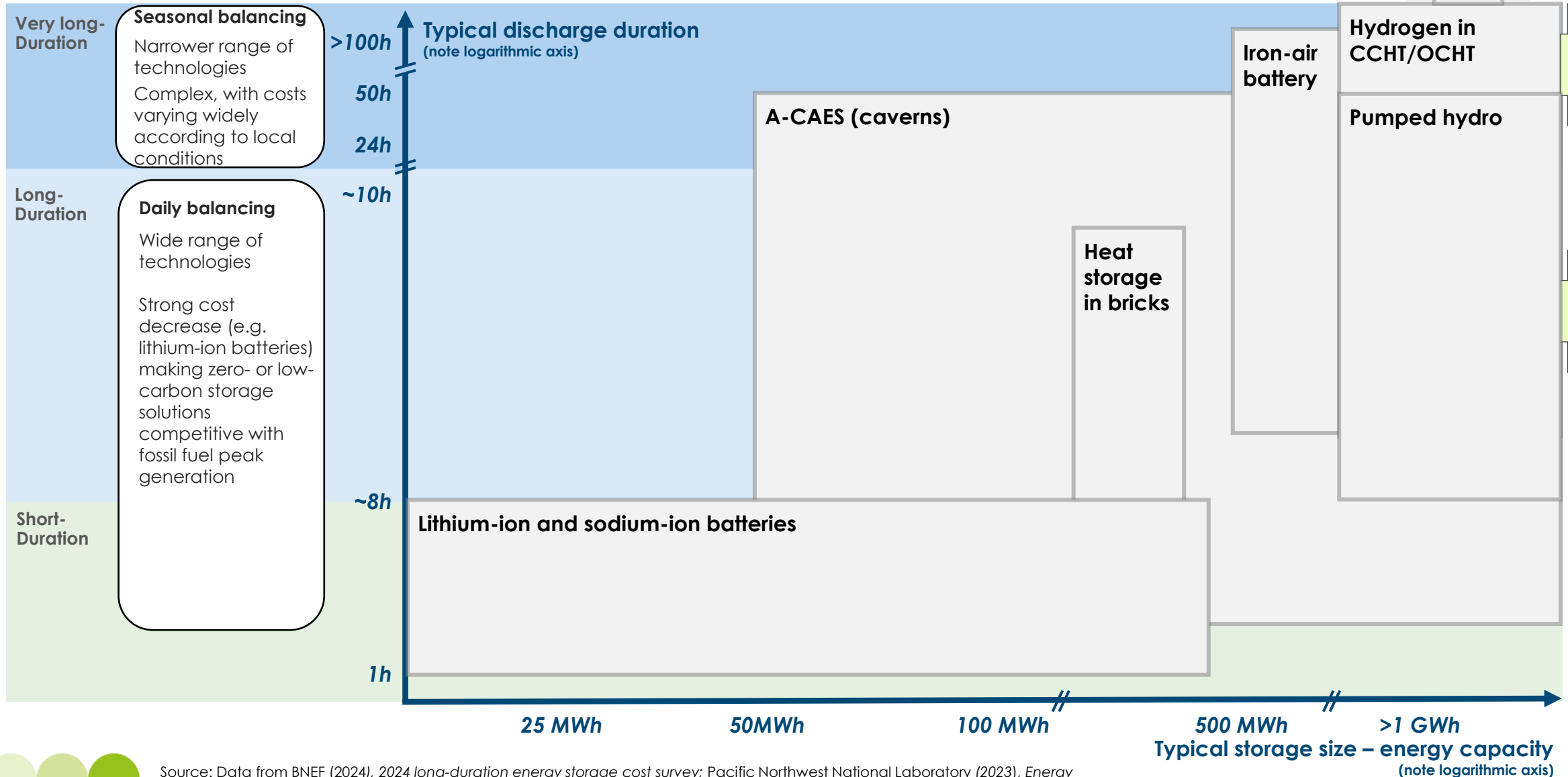


A range of tech can address entire balancing challenge



Source: Data from BNEF (2024), 2024 long-duration energy storage cost survey; Pacific Northwest National Laboratory (2023), Energy Storage Cost and Performance Database; IEA (2024), ETP Clean Energy Technology Guide; others from sources on deep dive slides;. Note: Simplified visual description for improved readability.

ETC assessment points to key techs at given durations/sizes



Source: Data from BNEF (2024), 2024 long-duration energy storage cost survey; Pacific Northwest National Laboratory (2023), Energy Storage Cost and Performance Database; IEA (2024), ETP Clean Energy Technology Guide; others from sources on deep dive slides;. Note: Simplified visual description for improved readability.

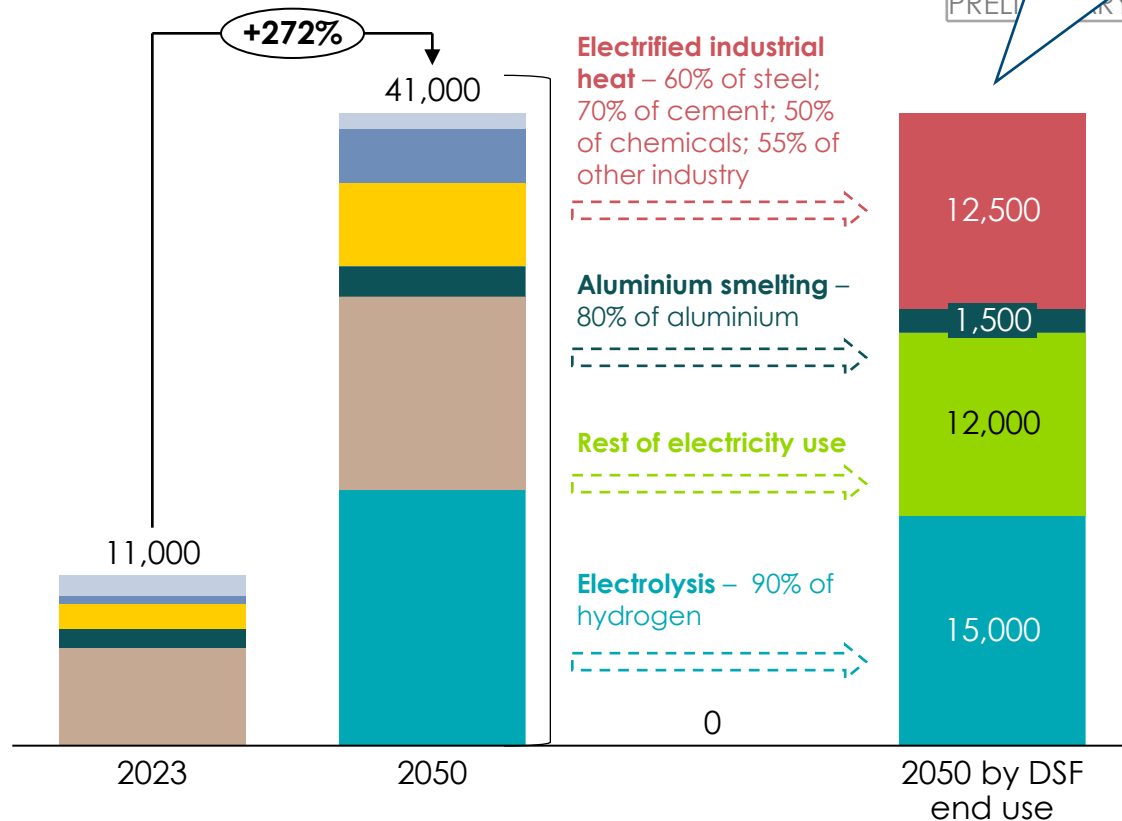


Heat storage is a very promising new avenue to balance industrial heat demand and optimise power flows

Global industry electricity demand by sector, 2050

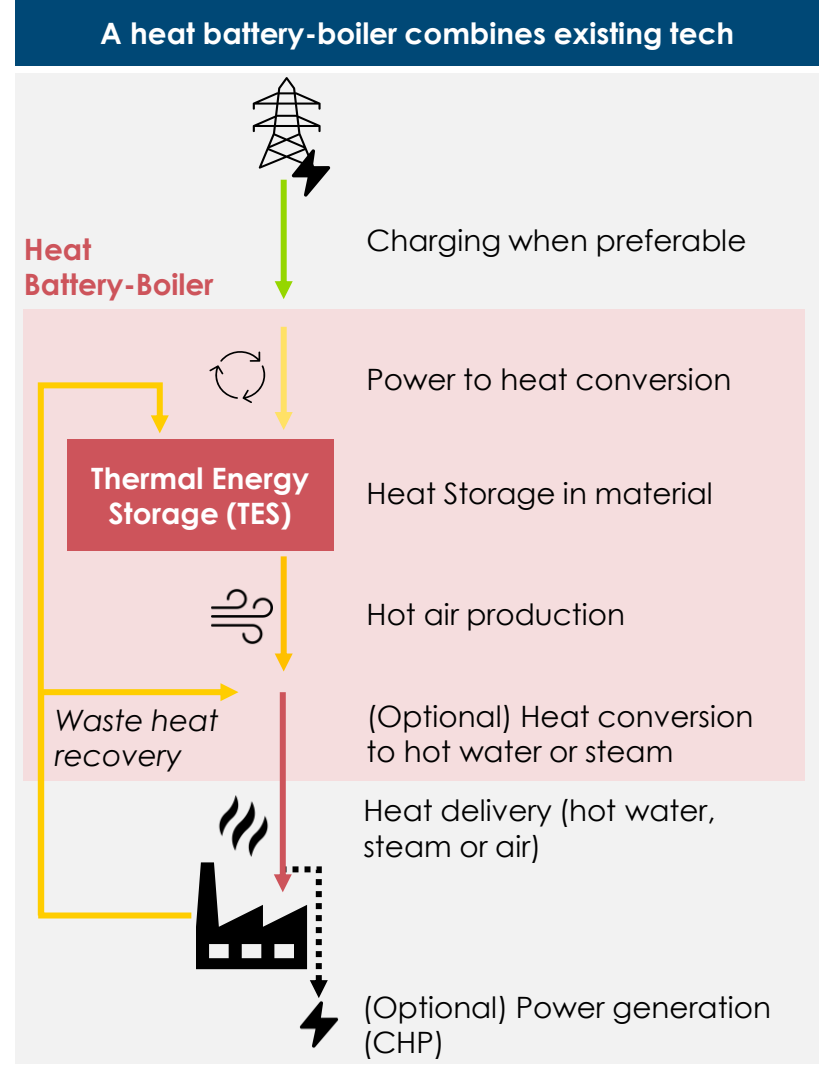
TWh

- Steel
- Chemicals
- Other industry
- Cement
- Aluminium
- Hydrogen



New avenues are emerging which enable storage at all temperatures

Heat storage



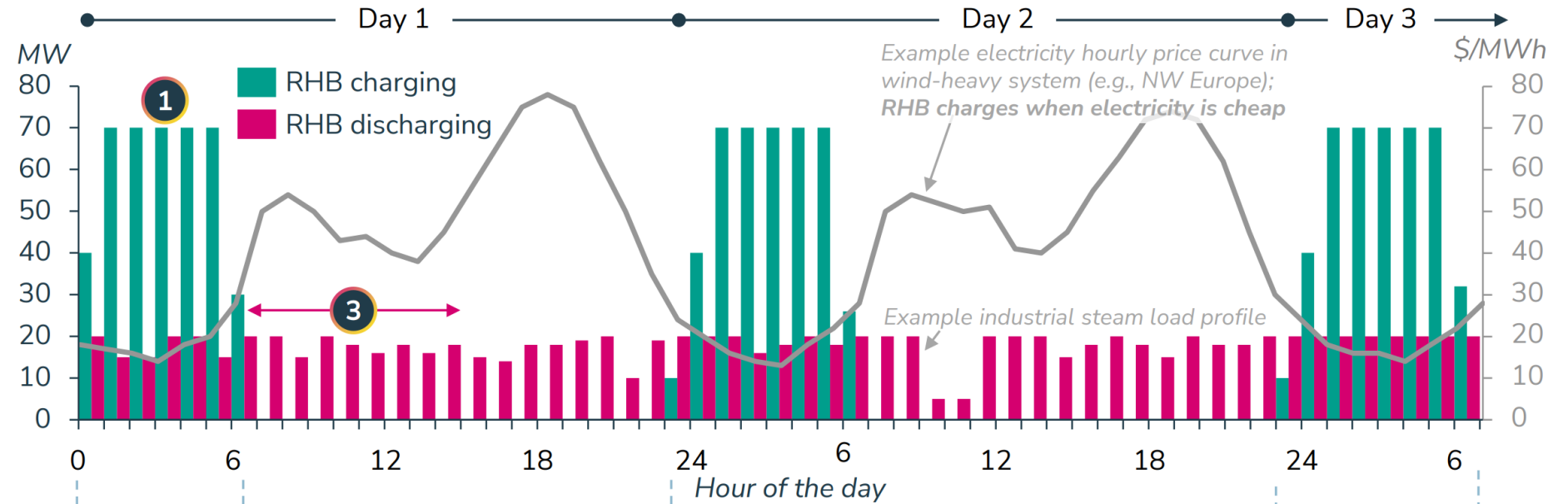
Notes: [1] Combined Heat & Power; high pressure steam can drive a steam turbine to produce electric power and low-pressure steam, providing 95% efficient combined heat and power.
 Source: Systemiq analysis for the ETC; NGFS (2024), Phase 4 Scenario Explorer – Latest 2024 GCAM Version

The Rondo heat battery can leverage 6-8 hours of cheap electricity and turn it into baseload steam or hot air



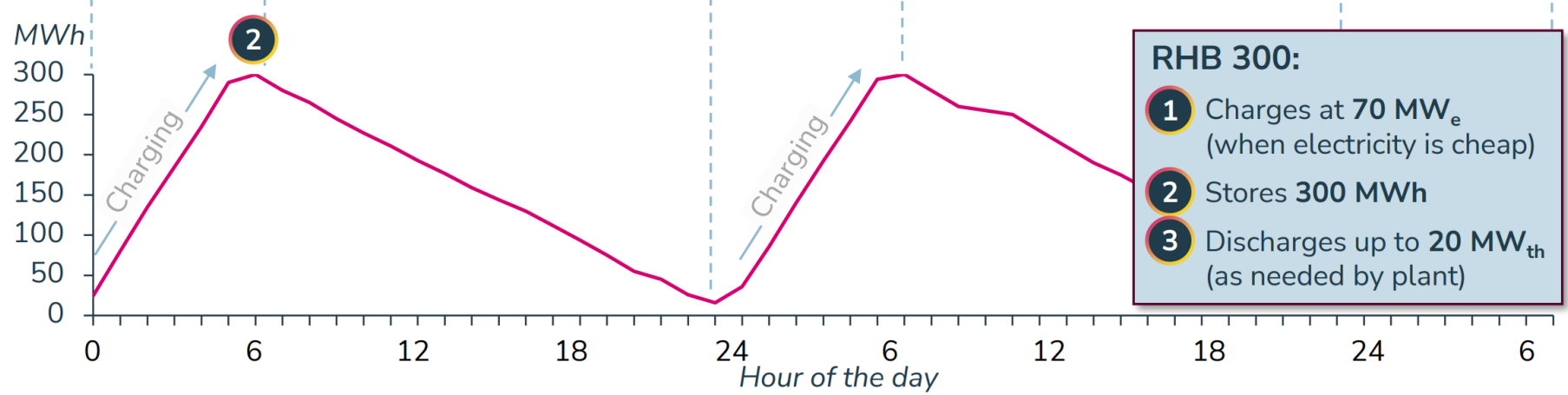
Rondo Heat Battery (RHB) CHARGE & DISCHARGE

Example pattern for RHB300¹



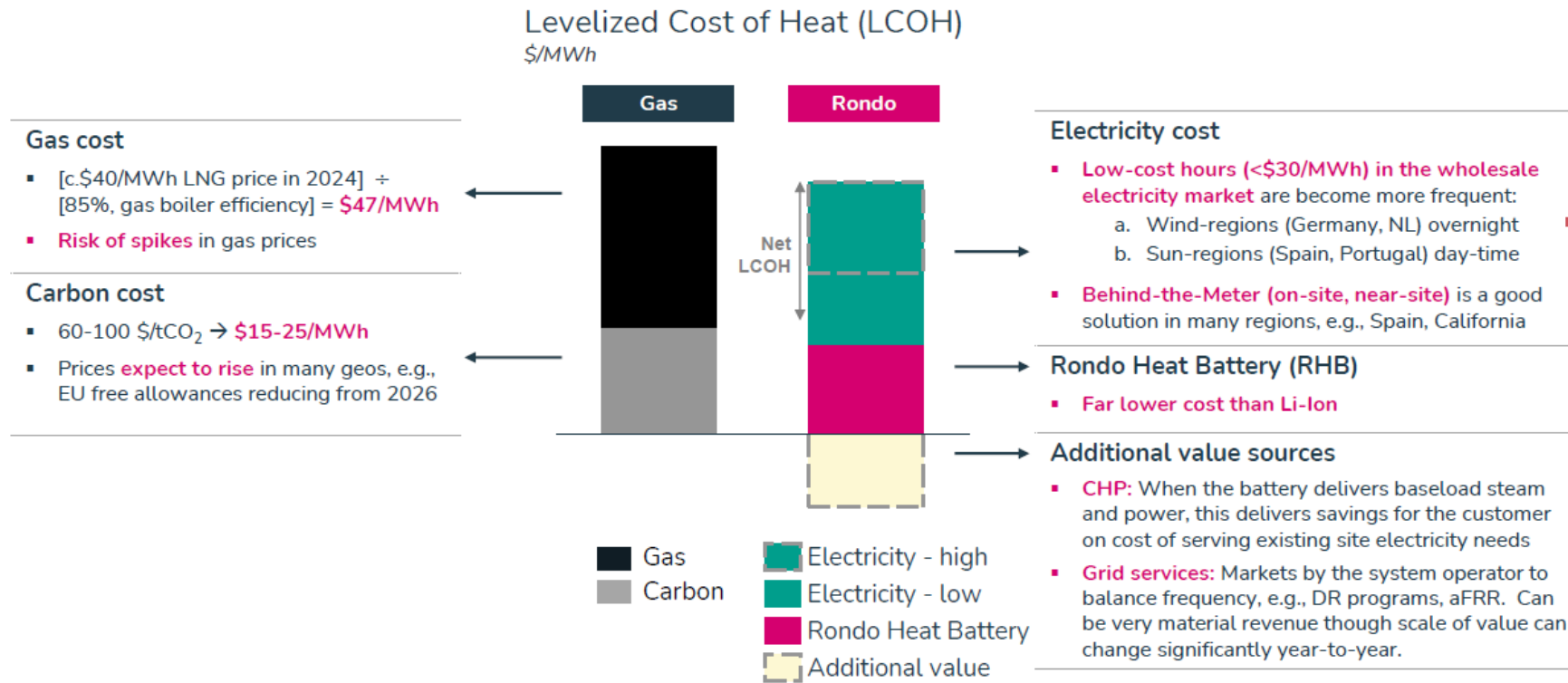
Rondo Heat Battery (RHB) STORAGE

Energy stored in RHB



The Rondo heat battery could enable companies to save money vs gas, depending on access to liberalised markets

ILLUSTRATIVE
Relative scale of each element is highly country and site dependent



Liberalised markets make access to cheap wholesale prices more readily available.

Outside such markets, **off-peak tariffs** or **PPAs with generators** who “see” the wholesale price can suffice.

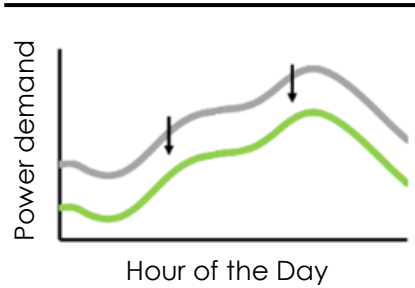
Locational pricing can open up particular opportunities of **extremely low pricing near congestion points**



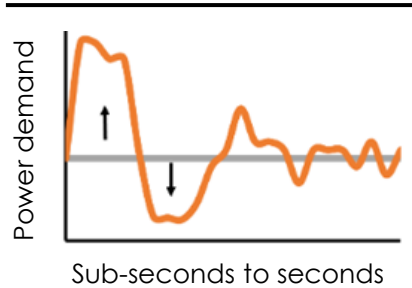
There are five key demand side management (DSM) strategies to provide flexibility, which can be implemented either manually or automatically



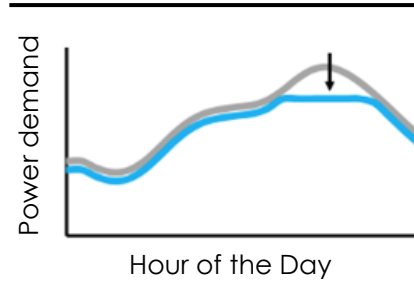
Efficiency



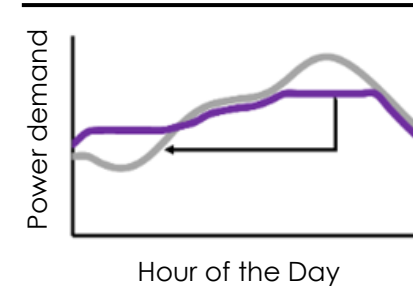
Modulate



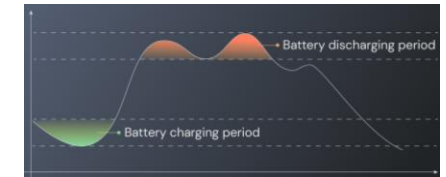
Load shed



Load shift



Distributed storage



Details

- The ongoing **reduction in energy use** while providing the same or improved level of building function

- The ability to **balance power supply/demand or reactive power draw/supply autonomously** (within seconds to sub-seconds) in response to a signal from the grid operator during the dispatch period

- The ability to **reduce electricity use** for a short time period and typically on short notice
- Shedding is typically **dispatched during peak demand** periods and during emergencies

- The ability to **change the timing** of electricity use (intra-day, inter-day and seasonal)
- In some situations, a shift may lead to **changing the amount of electricity** that is consumed

- Provide flexibility by **storing excess energy** (e.g., electricity, heat) during low-demand periods and releasing it during peak demand, helping to balance the grid

Example

- Manual:** Replacing old appliances new models
- Automatic:** Building management systems optimising energy use

- Manual:** Adjusting thermostat to reduce heating during peak
- Automatic:** Fridges adjusting compressor cycles to off-peak

- Manual:** Turning off lights during peak times
- Automatic:** Smart plugs cutting power to non-essential devices

- Manual:** Running washers at late night instead of during peak times
- Automatic:** schedule EV to charge in off-peak

- Manual:** Configuring home batteries/EVs to charge and discharge
- Automatic:** Software controlled storage responds to price signals

Changes to consumer behaviour and at grid level

Change at grid level but not to consumer behaviour



*Key questions on
managing the system
balancing challenge*



ETC is currently exploring three key questions

1. Size of balancing requirements by duration

- Different countries/regions will have different balancing needs, e.g. depending on daily fluctuations and seasonal variations driven by supply and demand (e.g. Northern latitude countries have higher demand in winter, lower latitude countries primarily have a daily balancing challenge due to high solar penetration).
- To understand the need for balancing, looking at weather patterns to understand 'low' renewable supply years is critical. The ETC is using a modelling approach looking at the past ~30 years of weather data in key country archetypes, as a basis to size balancing needs.

2. Total system cost by region

- ETC work will look at evolution of total system generation costs, which depend on balancing needs and technologies to solve for these; additionally, critical to understand the evolution of grid costs.

3. Potential for interconnection

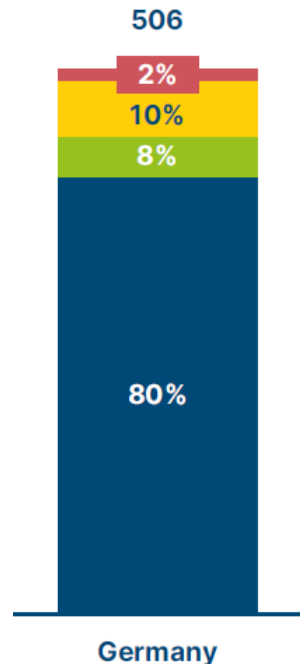
- Longer distance interconnectors are increasingly being demonstrated (with X-Links set to be 4,000 km), whilst some countries are limited in space to host renewables domestically. ETC is undertaking a deepdive to understand where the most impactful interconnectors should be located, and how much these can help with local balancing challenges.



1) Size of balancing requirements by duration

Existing ETC work – 2017 analysis

Balancing variability across markets in a near 100% renewable system



- Week-by-week variation (unpredictable)
- Seasonal balancing (predicatable)
- Daily balancing
- Concomitant generation

New analysis for 2024

Updated ETC analysis will assess 2050 energy balance requirements based on renewable generation from offshore wind, onshore wind, and solar PV. It will match a view of:

- **Supply**, via realistic 2050 wind and solar generation profiles, which will be derived using weather data from the past 30 years to create minimum, average and maximum scenarios over 2 hourly generation periods.
- **Demand**, via 2050 hourly demand forecasts obtained from expert models (i.e. Imperial College for UK), accounting for new loads (e.g. EVs, heat pumps) and load patterns.

In order to determine country-specific balancing requirements across time periods. The model will illustrate the size and duration of balancing requirements across daily, weekly, and seasonal needs.

This will be done for key country archetypes.

Notes: 2% week-by-week variation is approximate, and range will vary by market. Generation scaled up to meet 100% demand based on current VRE ratio: Wind (64%), solar (34%) and run of river hydro (2%). Potential countries in scope are: UK, India, Indonesia, USA, Germany, China, Chile, Colombia, Australia, Kenya.

Source: Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017)

2) Total system generation costs will vary across countries with a primarily daily vs a primarily seasonal balancing challenge

Geographies with primarily daily balancing challenge e.g. Saudi Arabia, India, Indonesia

Geographies with primarily a daily balancing challenge likely to have **lower total generation costs, thanks to cheap solar & batteries**

Geographies with daily and seasonal balancing challenge e.g. UK, USA, Germany

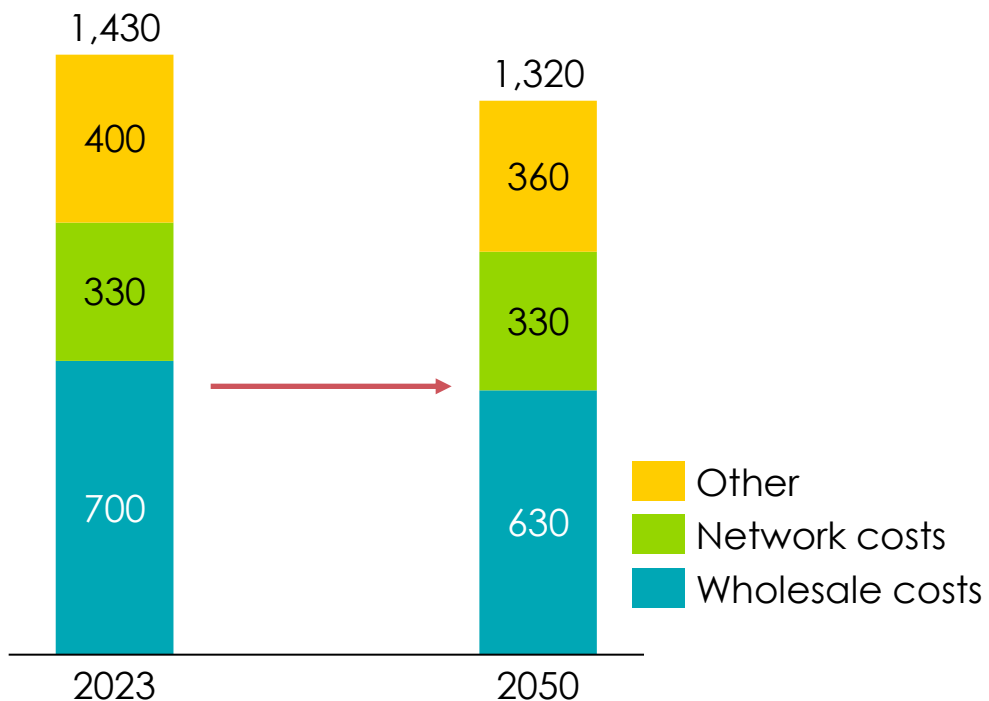
Geographies with additional seasonal balancing challenge **could have lower total generation costs, but will be dependent on LDES costs and quantity required**



2) ETC Hypothesis – overall consumer bills should be less than or remain broadly consistent with long term averages in 2050

Illustrative German household electricity bill

Annual bill, €



Based on evolution of:

Other costs – expected to decline once legacy payments for transition to expensive early renewables expire

Network costs – expected to remain broadly similar per unit of electricity, as increase in electrification increases the user base so rates/bills do not change, even as overall network costs rise due to growth of the system

Wholesale costs – expected to decline slightly with the shift away from fossil fuels towards renewables + balancing options



Notes: Values calculated from 2023 costs of ~41 ct/kWh, assuming 3,500 kWh annual consumption. Other includes taxes, fees, levies and charges. Illustrative 10% reduction in 'Energy and supply' and 'Other' categories.

Source: Eurostat (2024), *Electricity prices components for household consumers*

Key enablers & implications of new system



Current processes won't make the most of innovation, enablers are required

Strategic vision & planning

- **Smart targets for deployment** – including renewables, energy storage, and size of gas turbine fleet
- **Accurate models and forecasting** – to help set targets and provide rationale for market design changes
- **Political will for the transition** – To enable both phasing down of fossil, and quicker interconnection agreements

Market design

- Need to **incentivise energy storage / capacity / kWh at specific hours** of need; market and contract mechanisms currently missing
- **Potential evolution of electricity price mechanisms** – to provide locational signals to help optimise power flows
- **Consumer pricing**: Need to incentivise demand-response; even with a growing renewable portfolio, **gas prices are still likely to set majority of market prices**

Deepdive on next slide

Grid regulation

- **Network reinforcements** – anticipatory investment required to build ahead of bottlenecks, particularly to reinforce Dx system
- **Reform of grid fees** - often paid by storage companies for both storing and discharging energy, making them pay twice for services which are beneficial to the grid

Consumer behaviour

- **Behavioural change** – In some instances may need to change to pursue flexibility, can be better enabled through effective pricing structures



Several key market design areas required to incentivise a full transition

Key debates

Issue

Potential solutions

Timing:

Decided by system operator or by individual market players?

Need to incentivise **energy storage / capacity / kWh at specific hours** of need; market and contract mechanisms currently missing

- **Capacity markets** (i.e. payments to generators for being available)
- **Quantitative targets for storage** across key durations (i.e. 5 GW of 100hr+ storage)
- **Clean energy contracts across all/most time periods**, (i.e. India Round the Clock)
- **Contracts for constant import of clean power** (i.e. X-Links Morocco-UK link)
- **Energy markets short settlement blocks** (i.e. US MISO region 5-minute blocks)

Location:

Single national wholesale price, an evolution of this, or narrower locational prices?

Single wholesale price may give the wrong signal to low carbon flexible assets and worsen network constraints

- **Zonal** divides electricity markets into regions, setting prices based on supply and demand (i.e. has Australia 5 zones, where generators & retailers use zonal price)
- **Nodal** with further divides zones into nodes, allowing more granular price adjustments based on local supply and demand (i.e. Texas has 17,000 nodes)
- **Evolutionary reforms** to single national wholesale market (i.e. giving ESOs more control; amending grid use charges; redesigning balancing system)

Consumer pricing:

How to incentivise demand response and reflect low-cost renewables?

Need to incentivise demand-response; even with a growing renewable portfolio, **gas prices are still likely to set majority of market prices**

- **Time of use tariffs** which are cheaper when supply exceeds demand (i.e. Octopus' agile tariff in the UK, or at a local level via dynamic network charges)
- **Reform consumer pricing to ensure pass through of low renewables costs** (i.e. growing proportion of bills linked directly to CfDs/PPAs, remainder resolved by wholesale market e.g. recent Draghi report for EU Commission)

Next steps in power systems transformation workplan

