Cleanergi (projects)
Business Lift (advisory)

Enabling renewables to power the grid
affordably, reliably and resiliently

Challenges of Intermittent Renewables, Storage and the Grid

Cleanergi

Mark Howitt
+44 (0) 7910 020 686
mhowitt@cleanergi.com
mhowitt@business-lift.co.uk

Business Lift

About Business Lift

Cleanergi Business Lift

Energy

1. Internationally recognized expert in the energy transition:
   - Technologies
   - Regulations
   - Market design
   - Politics
2. Project development support
   - LDES (large-scale long-duration energy storage: electricity and/or hydrogen)
   - Integrated projects, 3 or more of renewables, electricity storage, grid, electricity off-takers, electrolysis, hydrogen economy
3. Energy advisory
   - Strategic
   - Technical
   - Commercial

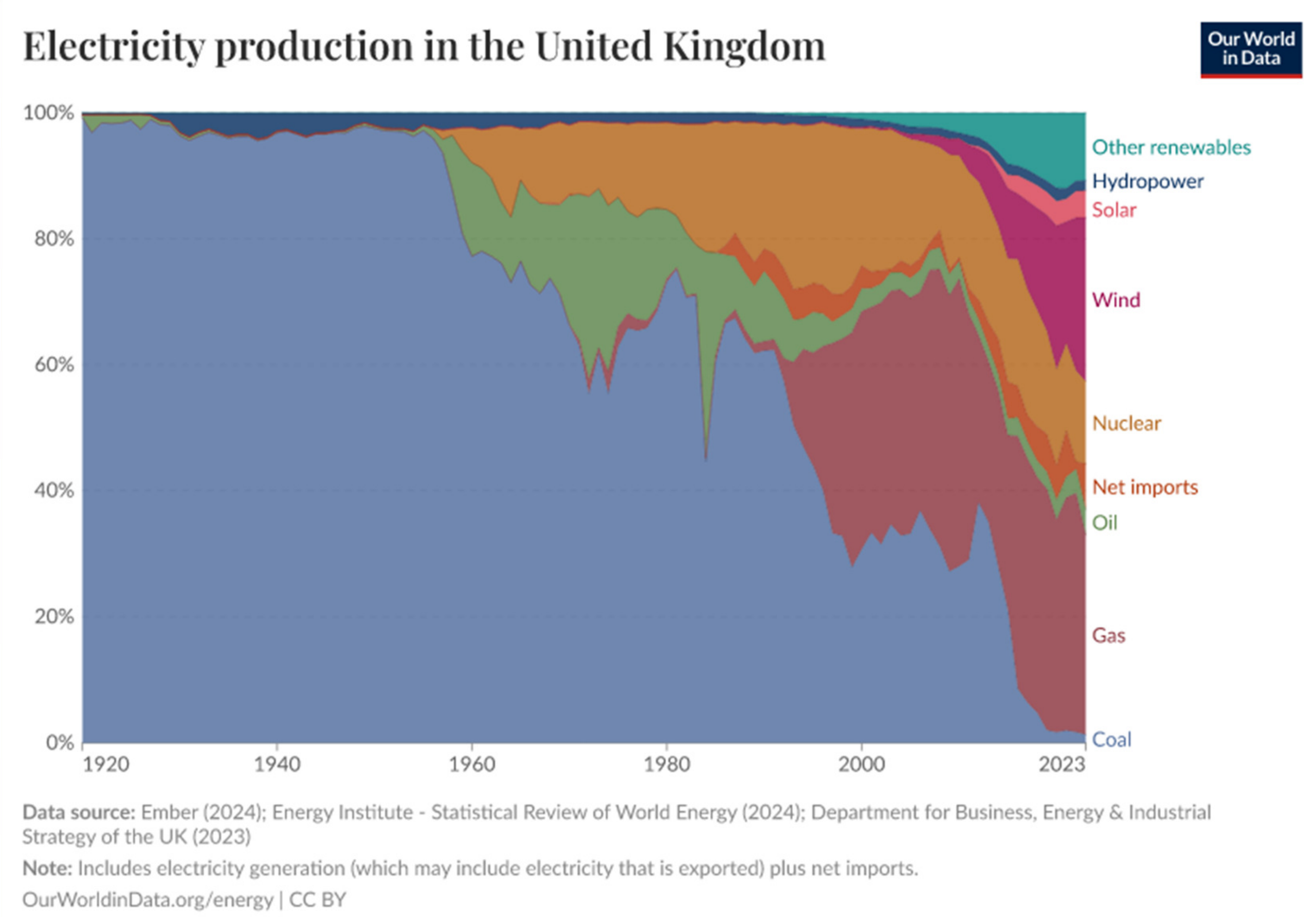
Advisory

1. Innovation
   - Technical innovations and solutions – doing
   - Technical innovations and solutions – assessing
   - Products, processes (technical and/or operational), services, businesses
2. Strategy
3. Marketing
   - Market assessment, drivers and targeting
   - Structuring products and/or services for each market
4. Management
   - Structure
   - Efficiency and effectiveness
5. Non-Executive Director

Energy Transition – Fuels

This talk will use the energy transition experience in Britain and Europe as an example for the rest of the world.

Every grid will have these challenges when renewable generation passes ~16% of demand.



The Energy Transition

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What the Energy Transition Does:

1. Replaces hydrocarbons with renewables
2. Replacing dispatchability with intermittency
   - Dispatchable: available on demand
   - Intermittent: when it wants, not when we want
3. Replacing synchronous with asynchronous
   - Synchronous: large AC-connected rotating machines
   - Asynchronous: DC-connected
4. Loss of Black Start capability

What It Means:

1. Technologies must be at the scale and duration of hydrocarbons
2. Balance the energy to make intermittency dispatchable
   - Balancing energy generation with demand, day & night
   - Providing for weather-related longer-duration shortfalls
3. Create synchronicity on the grid, in the locations needed
   - Grid stability, controllability, power quality
4. DC connected plant can't do Black Start
   - Proved by National Grid's Distributed ReStart project

Renewable generation is the right scale but doesn't do the rest.

Most storage on offer is the wrong scale, duration, cost and capabilities.

So we need storage with the right scale, duration, cost and capabilities.

Inertia: What Does It Do?

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1. If a car engine fails, the car's weight gives inertia so the car can stop safely
   - Otherwise comes to a dead halt immediately
2. Inertia in the electricity system slows the rate of change of voltage and frequency
3. Power stations deliver inertia
   - Large rotating machines
   - Power stations are closing fast
4. Too little inertia means an unstable grid

Services that inertia delivers:

1. Stability
   - Preventing faults cascading round the system
   - Inertia itself
   - Phase-locked loops, fault currents and other obscure technical issues
2. Operability
   - Voltage & Frequency Regulation
   - Reactive power and load
     - Power: gives the "push" to send the electricity round the grid
     - Load: reduces any excessive "push"
   - Absorbing disturbances
3. Power quality, harmonics, etc.
4. Restoration and Black Start

A Power Station Delivering Inertia

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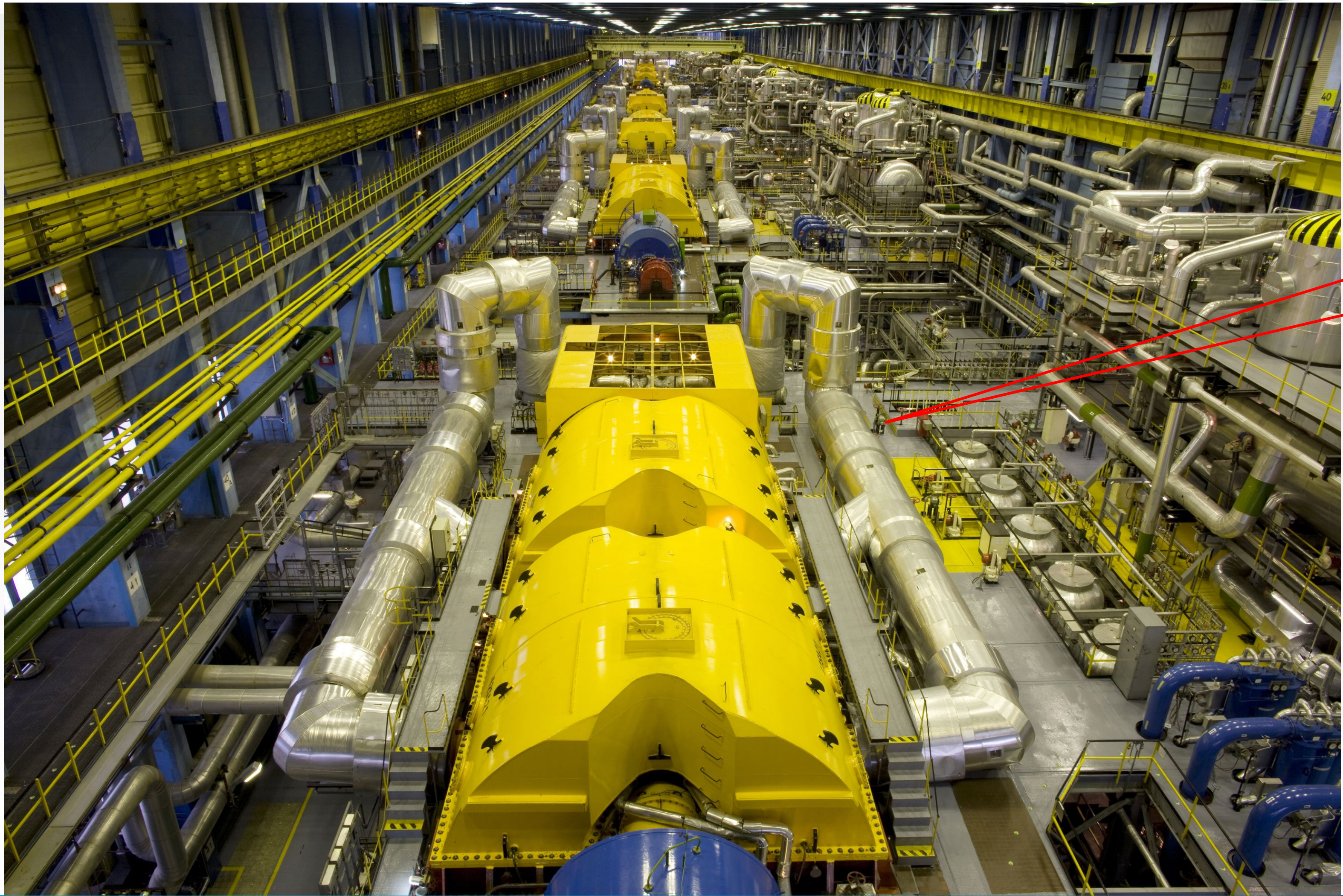


A person
(for scale)

Why Markets Don't Support This

Balancing Services

1. Lead time (up to 1 year) too short to use contracts to support funding.
2. Contract duration (up to 1 year, v plant life 30-60 years) insufficient to amortise plants.
3. Real inertia renders ultra-fast response times unnecessary.
   - Yet ultra-fast response times are key criteria.

Ancillary Services

1. Salami slicing contracts
   - Legal impossibilities if some won and some lost.
   - Excessive workload administering so many, so frequent, bids and contracts.
   - Lower-capability plants can cream off the best from revenue stacks: adding cost not capability to the system.
2. Real and synthetic inertia are not the same.
   - Synthetic: response times in tens of milliseconds are inadequate to stop spikes (milliseconds) cascading through the grid.
   - Real: always on, no response time needed.

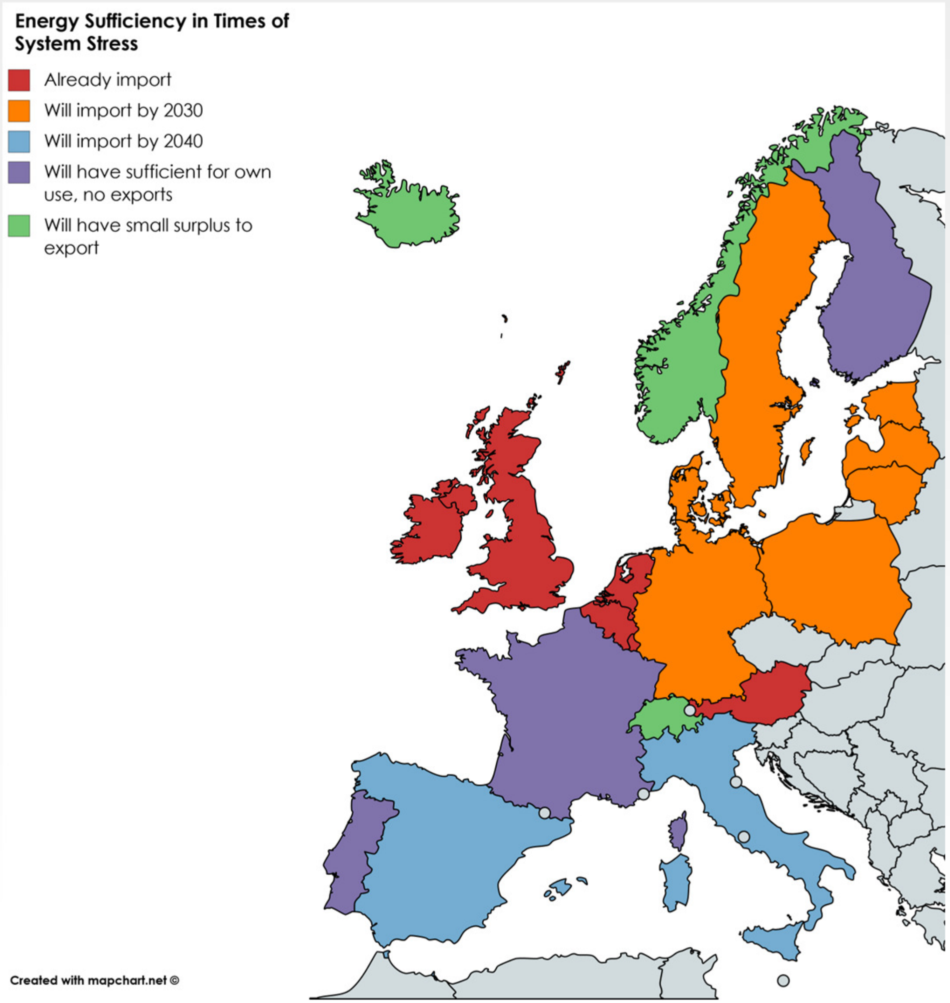
Energy Transition Plans

Most EU countries expect to import during times of system stress

1. After sunset on a windless winter evening
2. Weather patterns that extend this to max. 2 weeks over most of the continent (“*kalte dunkel Flaute*”)
3. Cost of 120-180GW interconnectors 2,000 miles across EU, both north-south and east-west
4. Cost of grid stability services

But if all are importing, who is exporting?

1. Need to store to keep the lights on
2. Large-scale long-duration storage: multi-GW, up to 2 weeks, in each country



Curtailment Rises with Renewable Penetration

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Without suitable volumes of large-scale, long-duration AND inertial electricity storage, curtailment rates rise almost linearly with renewable penetration.

This is global.

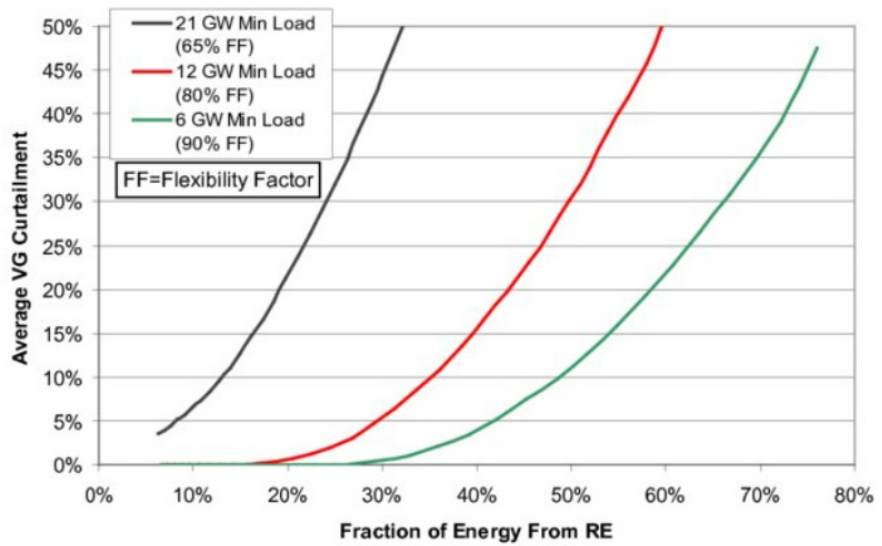

Figure 4.7. Average curtailment rate as a function of variable generation penetration for different flexibilities in ERCOT, Texas, USA

The Role of Energy Storage with Renewable Electricity Generation, Paul Denholm et al.

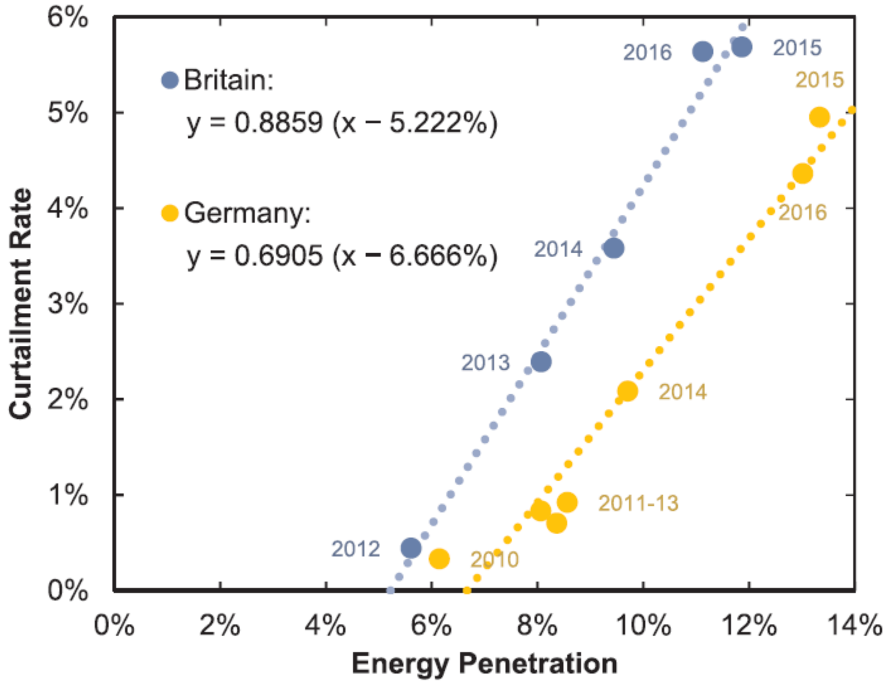

Fig. 10. Curtailment rates against penetration levels for wind power in Britain and Germany; data: [1,11,42,56,59]. For context, China experienced 15% curtailment for a 3.2% penetration in 2015 [67].

Renewable and Sustainable Energy Reviews 86 (2018) 45–65

Short-term integration costs of variable renewable energy: Wind Curtailment and balancing in Britain and Germany, Michael Joos (Element Energy) and Iain Stafell (Imperial College London)

Balancing Energy: Current Methods

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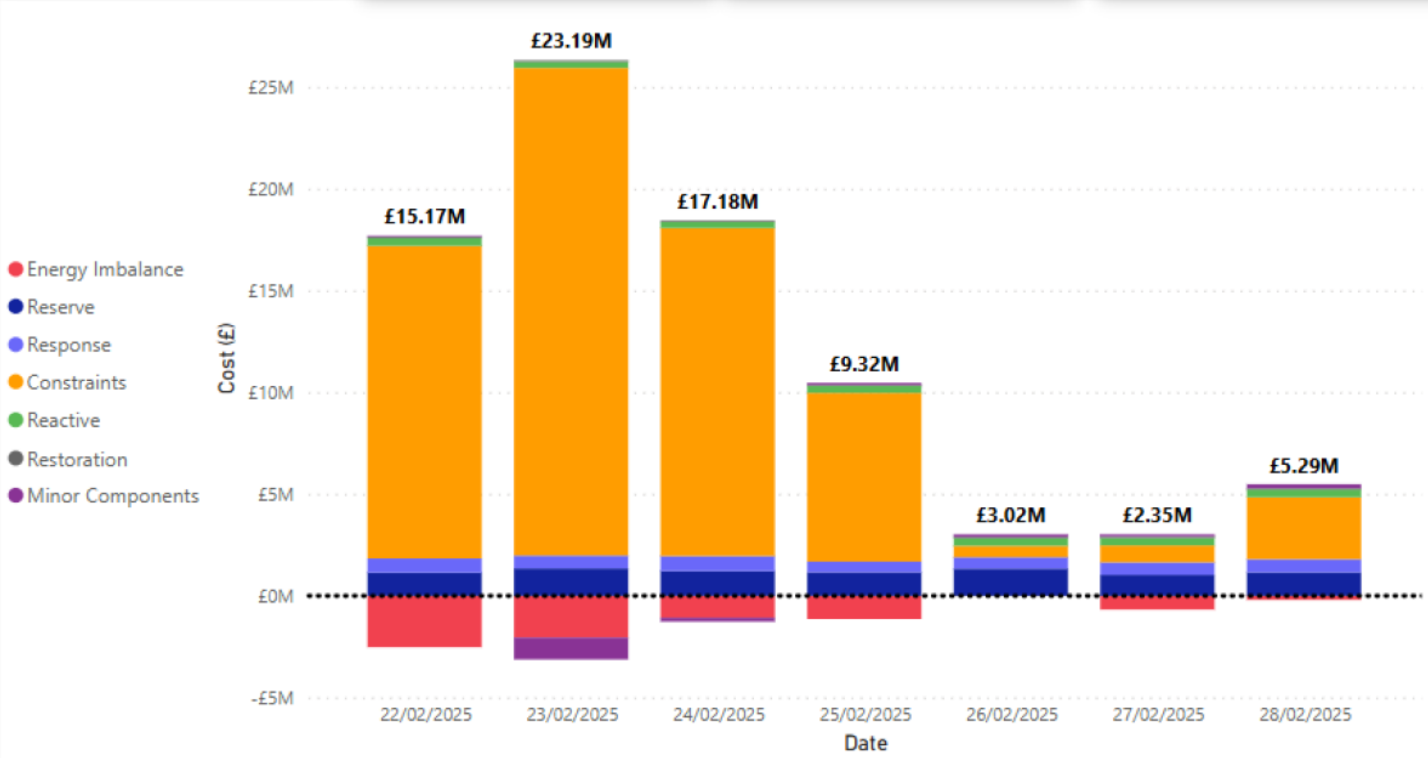
NESO Actions | Category Cost Breakdown

Date	Weekly Total Costs (£)	Last Week Total Costs (£)	Past 30-Day Average Costs (£)
22/02/2025 – 28/02/2025	£75.5M	£83.8M	£9.4M



Current Situation:

1. Wind and even nuclear are often turned down to turn on CCGTs
2. About ⅔ of balancing costs are for lack of inertia when demand is low
3. This has barely changed since I started putting up these charts 5 years ago

- **Except that costs are still increasing**

Energy Transition Plans

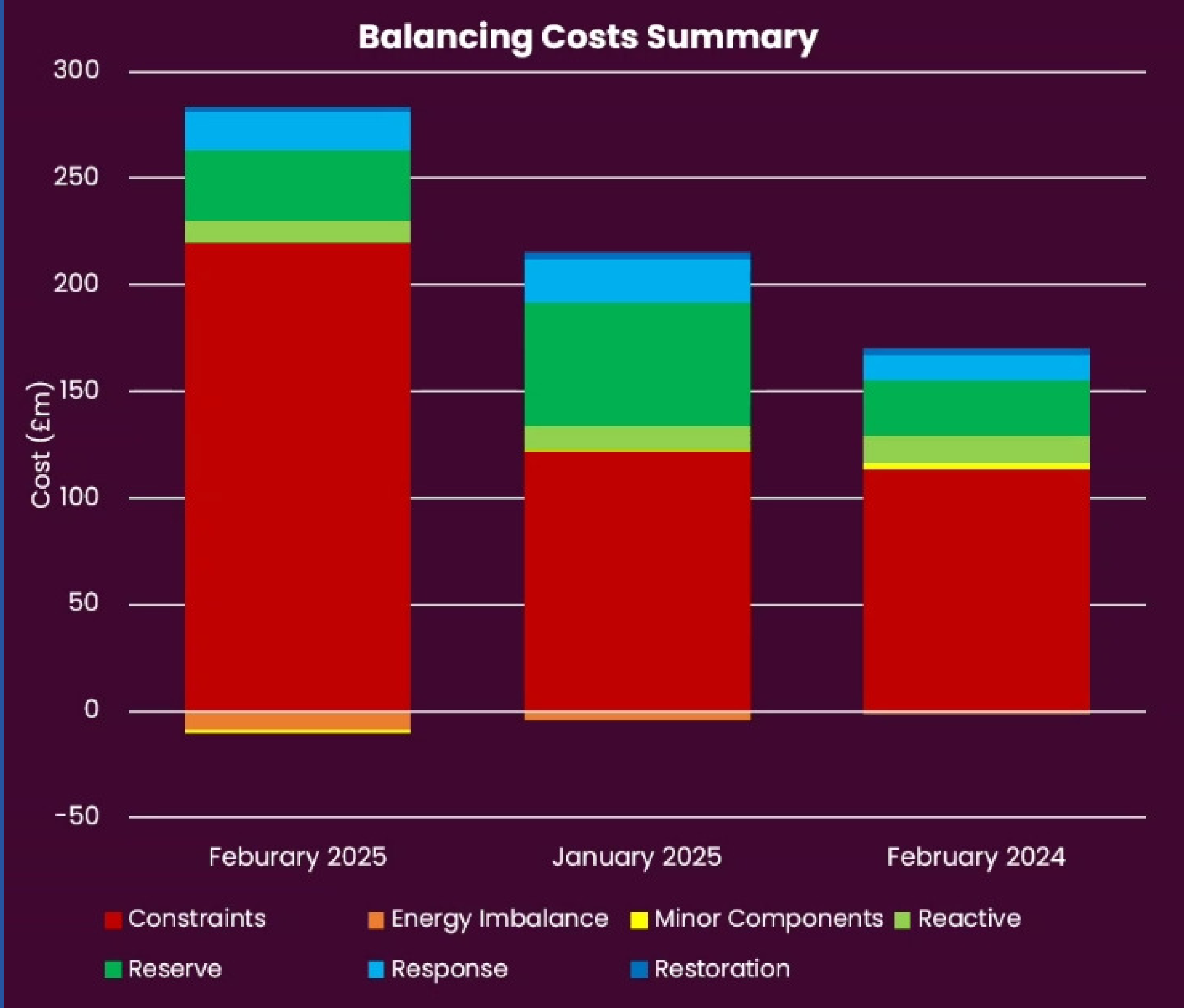
Costs increasing continually because their fundamental causes not addressed, e.g.

1. Sufficient well located large-scale long-duration synchronous storage
2. Appropriate market designs: contract
   - Duration (>⅓ of amortization life of plant)
   - Scope (energy, ancillary services, reinforcement avoidance)
   - Lead time (sufficient to build new)
3. Using storage to avoid reinforcement

This will continue to get worse, with:

1. Increasing renewable penetration
2. Continuing Net Zero switching from gas
3. Powering the H_2 economy through the grid

Balancing costs are only a fraction of the total costs of mis-managing the system and energy transition



Operating a Renewable System Without CAES

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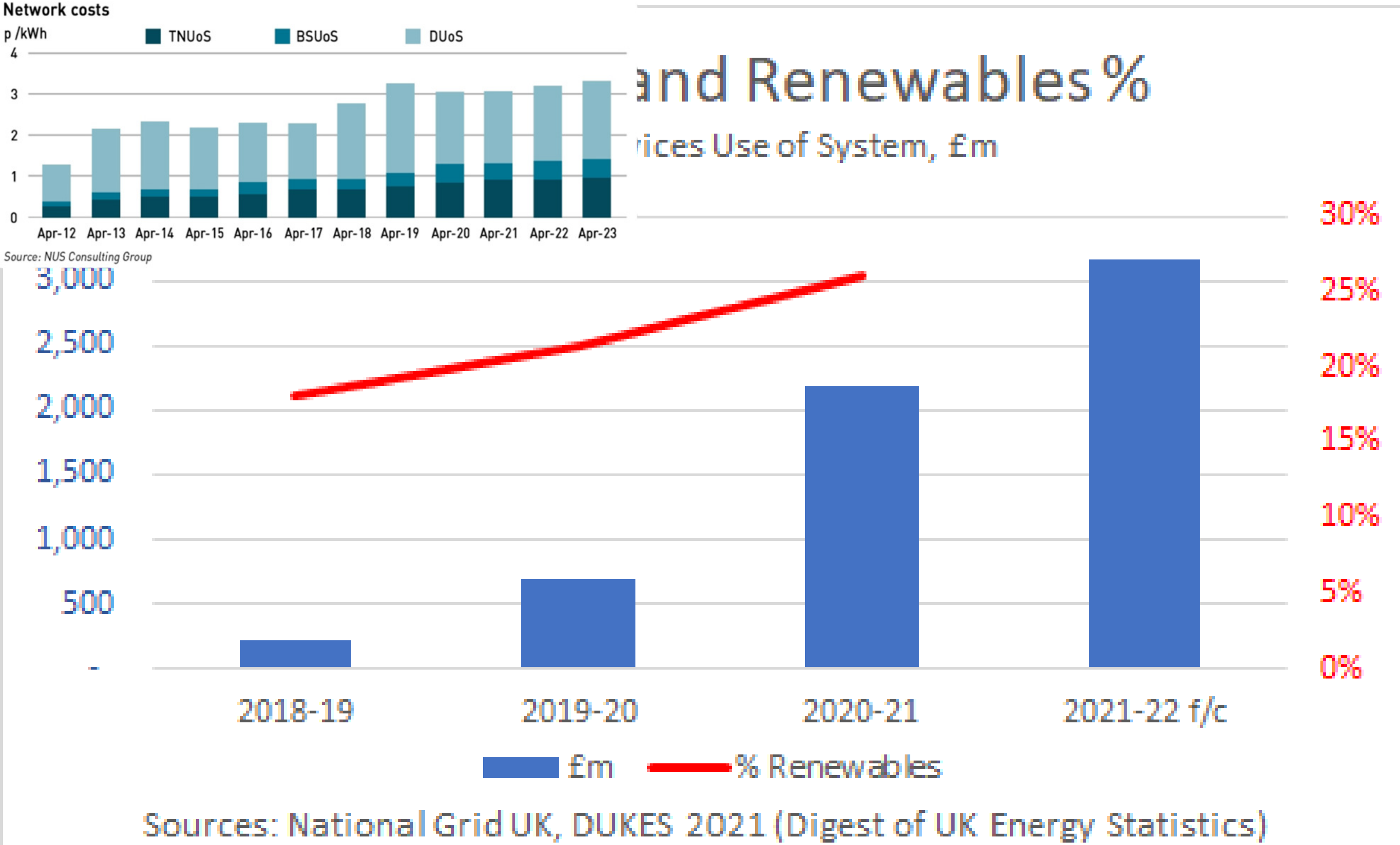

Balancing costs over 14x more in 2021-22 than 3 years before

... and every forecast is exceeded greatly.

2021-22 actuals exceeded the f/c so much that National Grid applied for (and was granted) permission to defer BSUoS charges to 2022-23

Then charges hit the headlines.

Every grid will have these challenges when renewable generation exceeds ~16% of demand.

Building a Renewable Grid Without CAES

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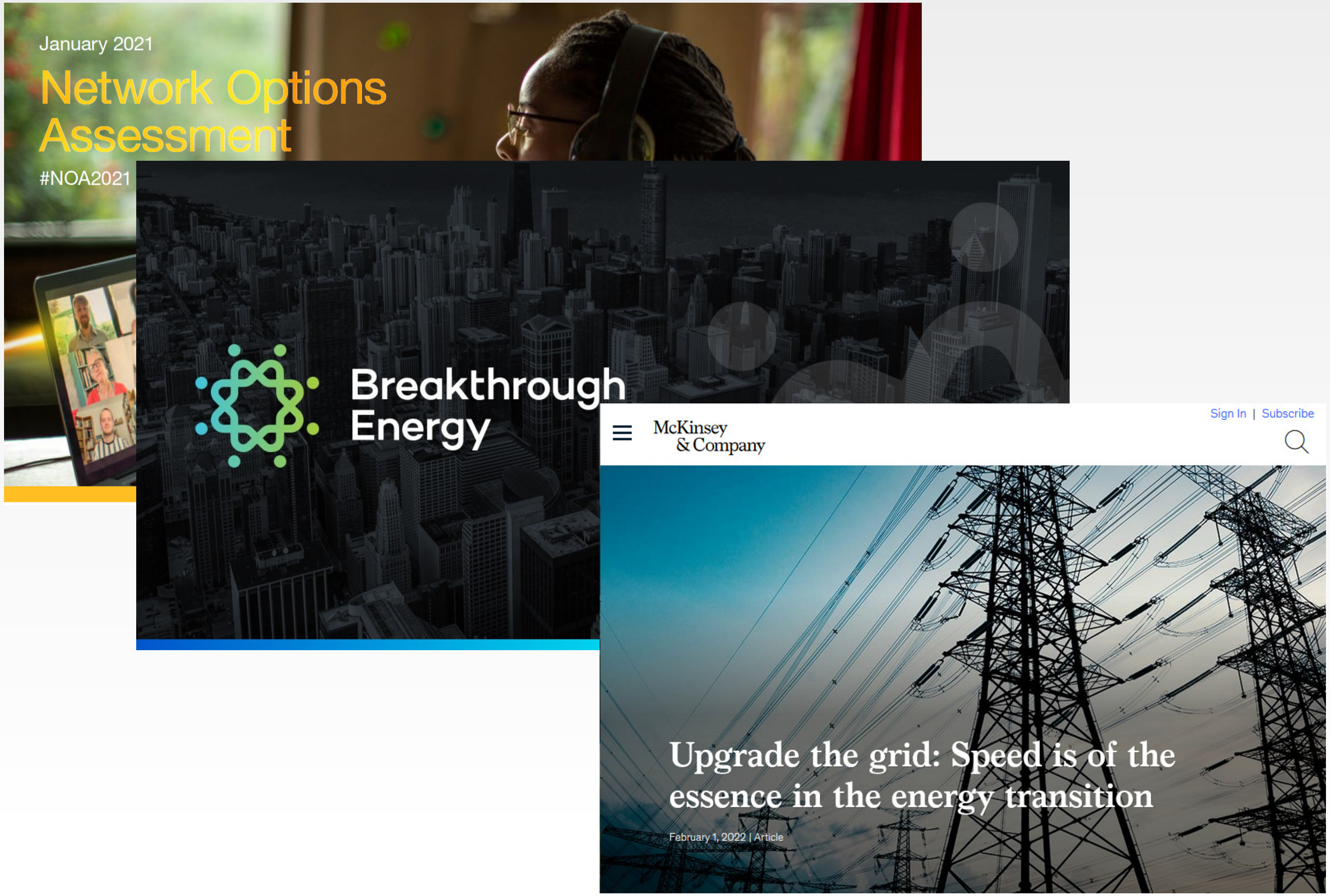


1. National Grid, UK (NOA 2021)
   - NOA = Network Options Assessment
   - $2bn grid reinforcement per GW of new wind connected by 2030
   - Plus procuring and connecting balancing and stability services
   - Plus operation and maintenance = 10% of capex p.a.
   - Increasing for later years
2. Breakthrough Energy, USA (*)
   - Grid needs to triple in size to accommodate renewables
   - Too expensive for USA, so what hope would we have?
3. McKinsey (*)
   - "The energy transition will require a dramatic increase in capital spending on the electric grid, delivered at an unprecedented pace."

The Effect on Bills?

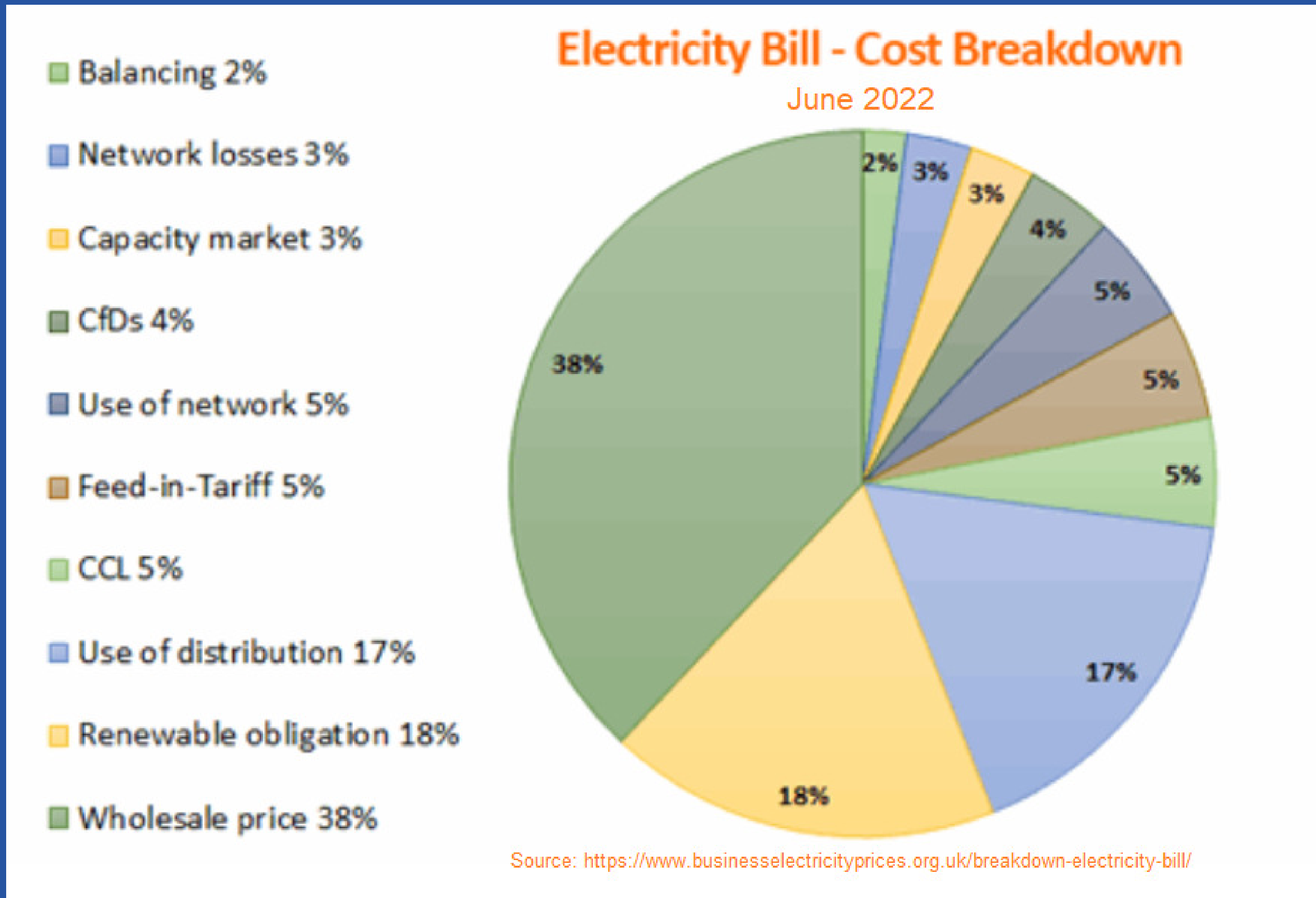
Electricity bills used to be:
- 75-80% wholesale energy
- 20-25% system running costs.

By 2022 they were:
- 38% wholesale energy cost
- 62% system running costs.

BUT wholesale energy also includes similar system charges.

This makes electricity approx.
- 22% wholesale energy cost
- 78% system running costs.

And system running costs are rising exponentially
- Generation costs dropping
- System costs rocketing
- Result: bills rising fast

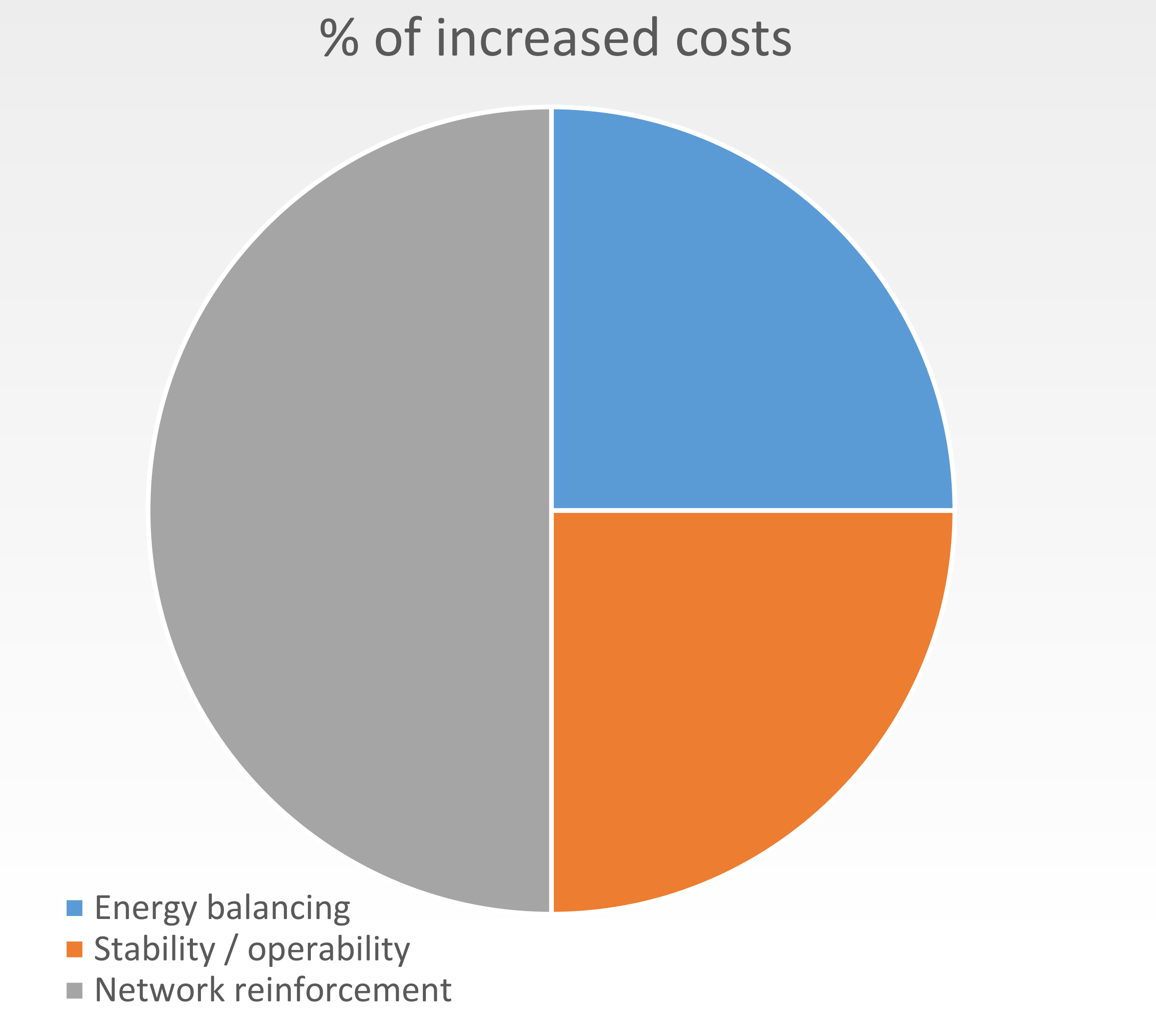


Summary of Increased Costs of the Transition

Very broad-brush: *

1. Energy balancing: 25%
   - Balancing
   - Arbitrage
   - Imbalance pricing
2. Stability / operability: 25%
   - Inertia
   - Voltage / frequency control / regulation
   - Operability services e.g. reactive power / load, phase-locked loops
   - Restoration, Black Start
3. Network reinforcement: 50%
   - More grid
   - Congestion
   - Curtailment

** Will vary by jurisdiction*



Grid Reinforcement: the Solution

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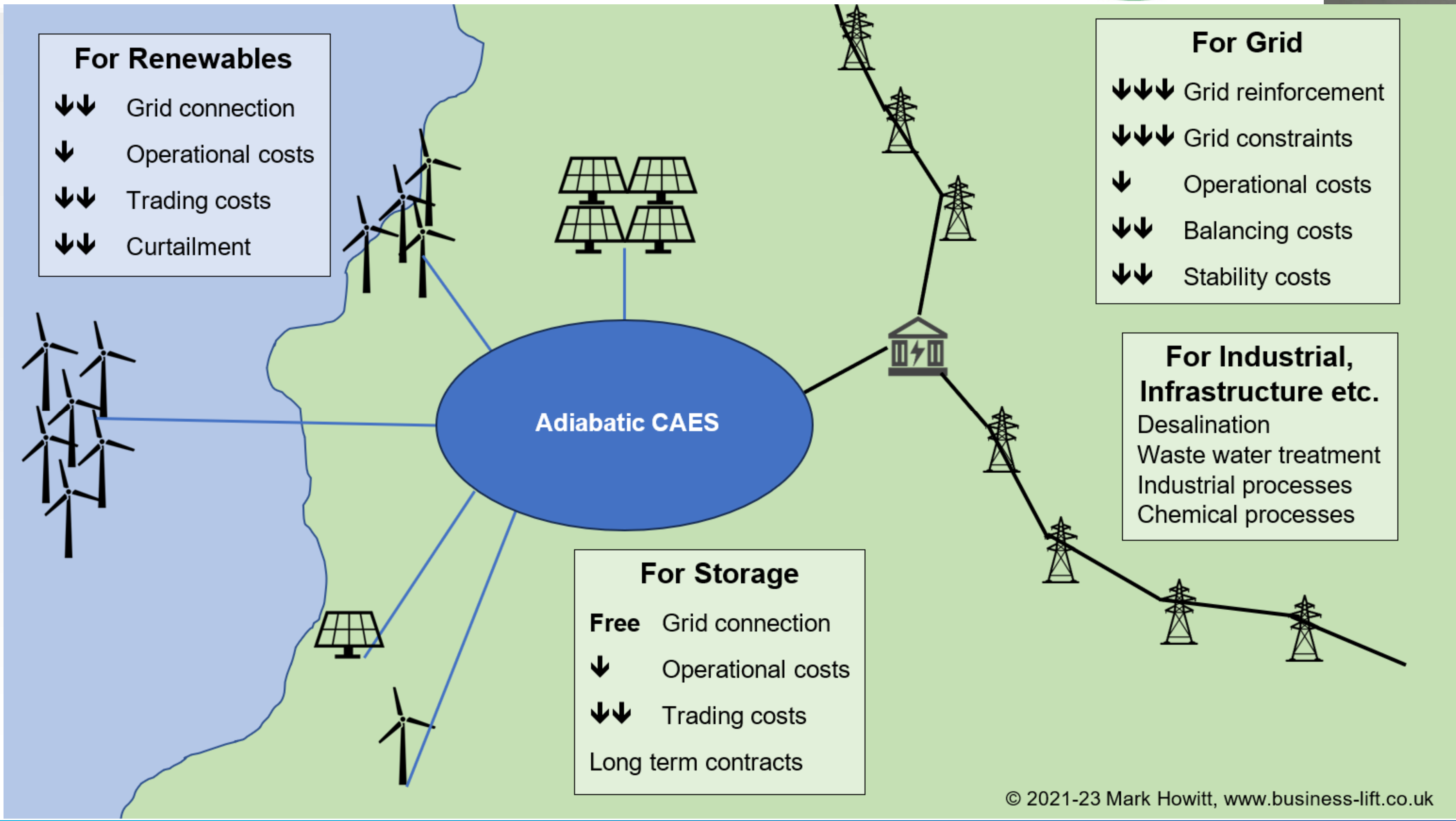

Why Markets Don't Support This

Renewable Generation

1. CfDs don't allow behind the meter (BTM) storage.
2. Quantity of energy is measured at the grid connection.
   - Reduced by the efficiency of storage.
3. Markets reimburse quantity, not quality of energy.
   - 1MWh intermittent, asynchronous electricity requires many MW production plus balancing and ancillary services.
   - 1MWh dispatchable, synchronous electricity does not.

Grid Support

1. No reimbursement for savings in grid reinforcement.
   - Capex and opex.
2. Cannot contract for both grid infrastructure benefits and System Operator contracts.
   - The right storage in the right location delivers both.
3. Short duration contracts are impossible.
   - If contract renewal is lost, there isn't enough grid capacity to take the unabated renewable generation.

Which technology to develop?

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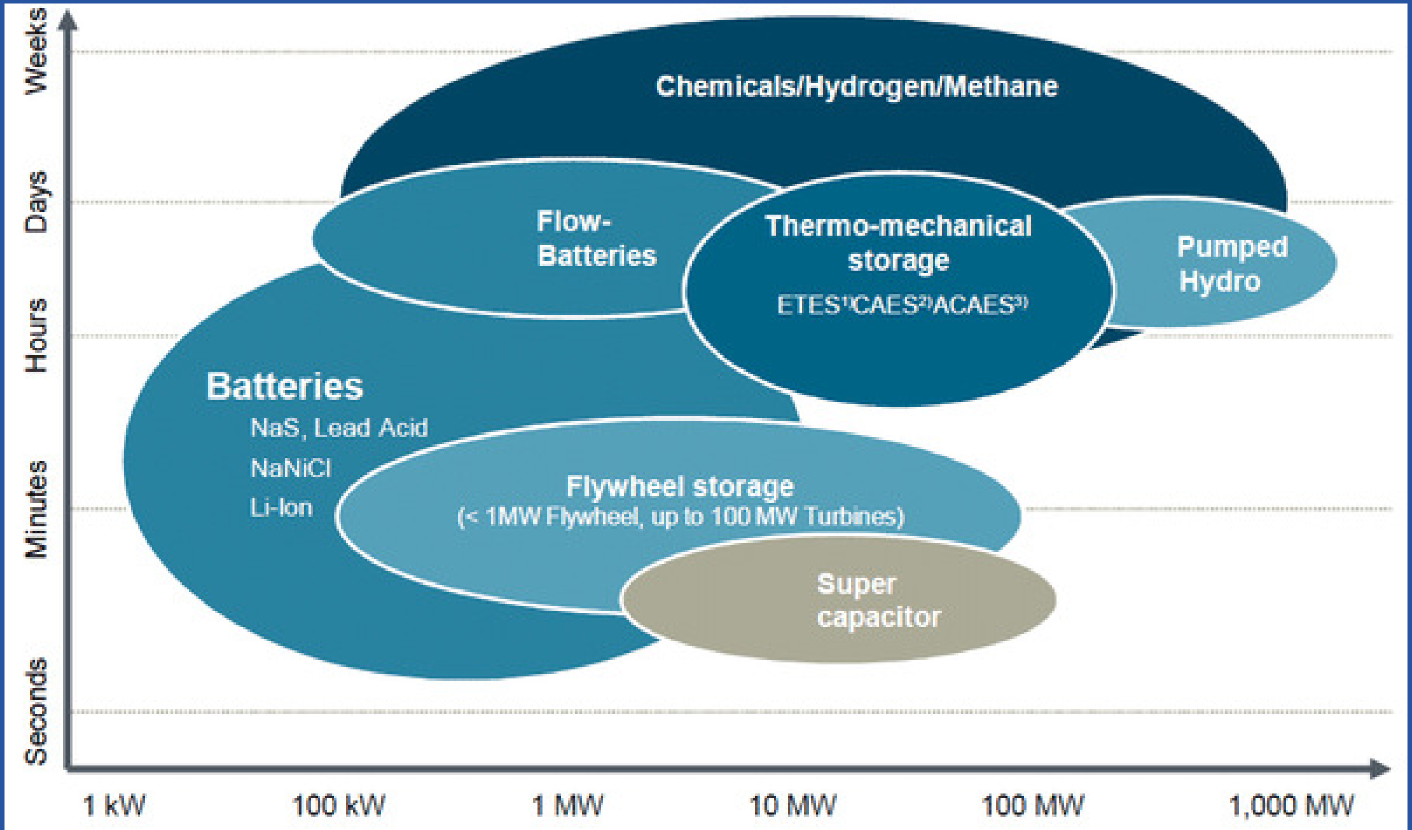


Hydrogen is huge

CAES can be increased in scale and duration

Pumped hydro is expensive & very location limited

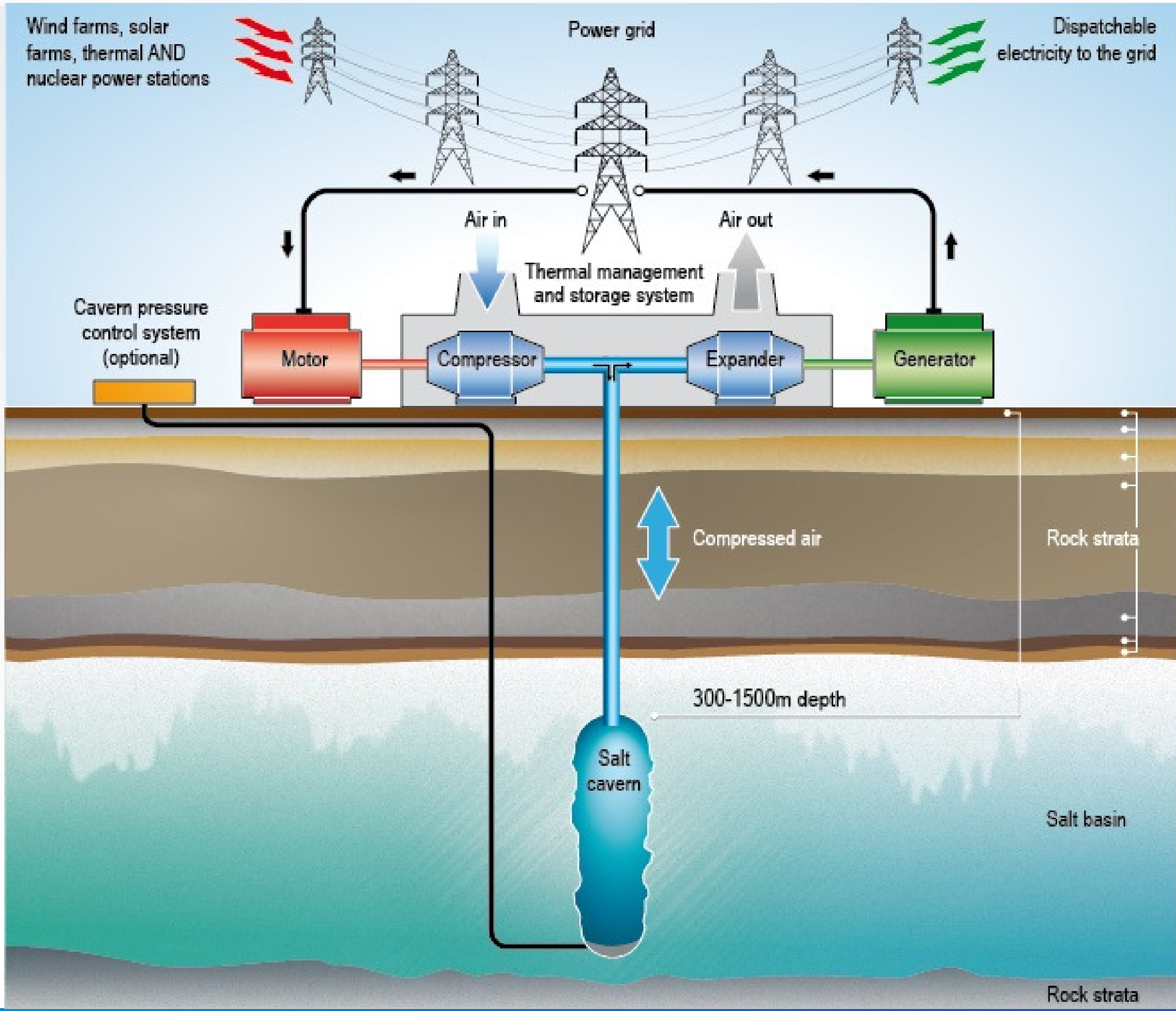
Therefore CAES and hydrogen are the technologies that need developing

Cleanergi CleanCAES TM

Advanced Adiabatic Compressed Air Energy Storage

1. Zero emissions
2. World's most efficient and cost-effective
3. LCOS* ~⅓ of batteries, 5 x plant life, cheaper than gas-fired peaking plant
4. Off-the-shelf equipment
5. Optimal benefits with grids, renewables and Cleantech
6. Can reduce grid reinforcement for renewables by billions

* LCOS = Levelized Cost of Storage, whole-plant



CleanCAES ™ v Batteries

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World's Most efficient *

Huntorf (Germany) 42%

McIntosh (Alabama, USA) 50%

Cleanergi CleanCAES ™ 68-70%

Batteries 50-74%

* Efficiencies measured grid-to-grid, lifetime average, temperate climate

CAES is little affected by high ambient heat and other environments

World's most cost-effective **

Traditional CAES

CleanCAES ™

Batteries

** 500MW 5-hour plant, all-in (i.e. including land, permitting, grid connection etc.)

* Batteries quote 85-92% – but that's terminal-to-terminal, mainly due to cell and controller inefficiencies. Grid-to-grid is 10-15% worse, due to cooling, inverters, signal conditioning etc., dropping the figure to 75-87%. But that's on day 1. By swap-out, these 13-25% inefficiencies roughly triple – of both the cells (mainly the heat generated) and the inverters / signal conditioning – to 39-75%. For average life, the inefficiencies double rather than triple, to 26-50%; round trip efficiency is 100% minus 26-50% = 50-74%.

Plant Life

Batteries 8-10 years

Cleanergi CAES 40-60 years

With mid-life refurbishment

Each does the job of 4-6 batteries

Batteries

Cleanergi CAES capabilities

Each Cleanergi plant can deliver concurrently services that would need 4-6 same-sized batteries (2-4 if with grid-forming inverters):

- Balancing and arbitrage
- Stability services, voltage and frequency control
- Reactive power and load
- Ancillary services, power quality
- Grid constraints, reinforcement avoidance and curtailment
- Resilience, recovery and (with CleanStart™) Black Start

Developments for Hydrogen

Limitations:

1. Electrolysis hates intermittent power
   - Reduced electrolyser efficiency
   - Reduced electrolyser life
   - 3-6x electrolyzers needed per tonne H_2
2. Limited storage capacity
   - 1 lorry carries 3 tonnes
3. Usually considered stand-alone
4. Electrolysis technologies too small

What CAES can Offer:

1. CAES delivers baseload and near-baseload electricity
   - Near-baseload: daily balancing, 8-12 hours storage
   - Baseload: for weather patterns, up to 2 weeks' storage
   - Same benefits for ammonia and fuel synthesis plants
2. Salt cavern storage
   - 1 cavern carries up to 10 million tonnes
3. Best: integrated multi-capability schemes
   - Grid stability, controllability, power quality
4. High temperature electrolysis patent
   - Using the heat of compression to catalyse electrolysis

Supporting Electrolysis etc.

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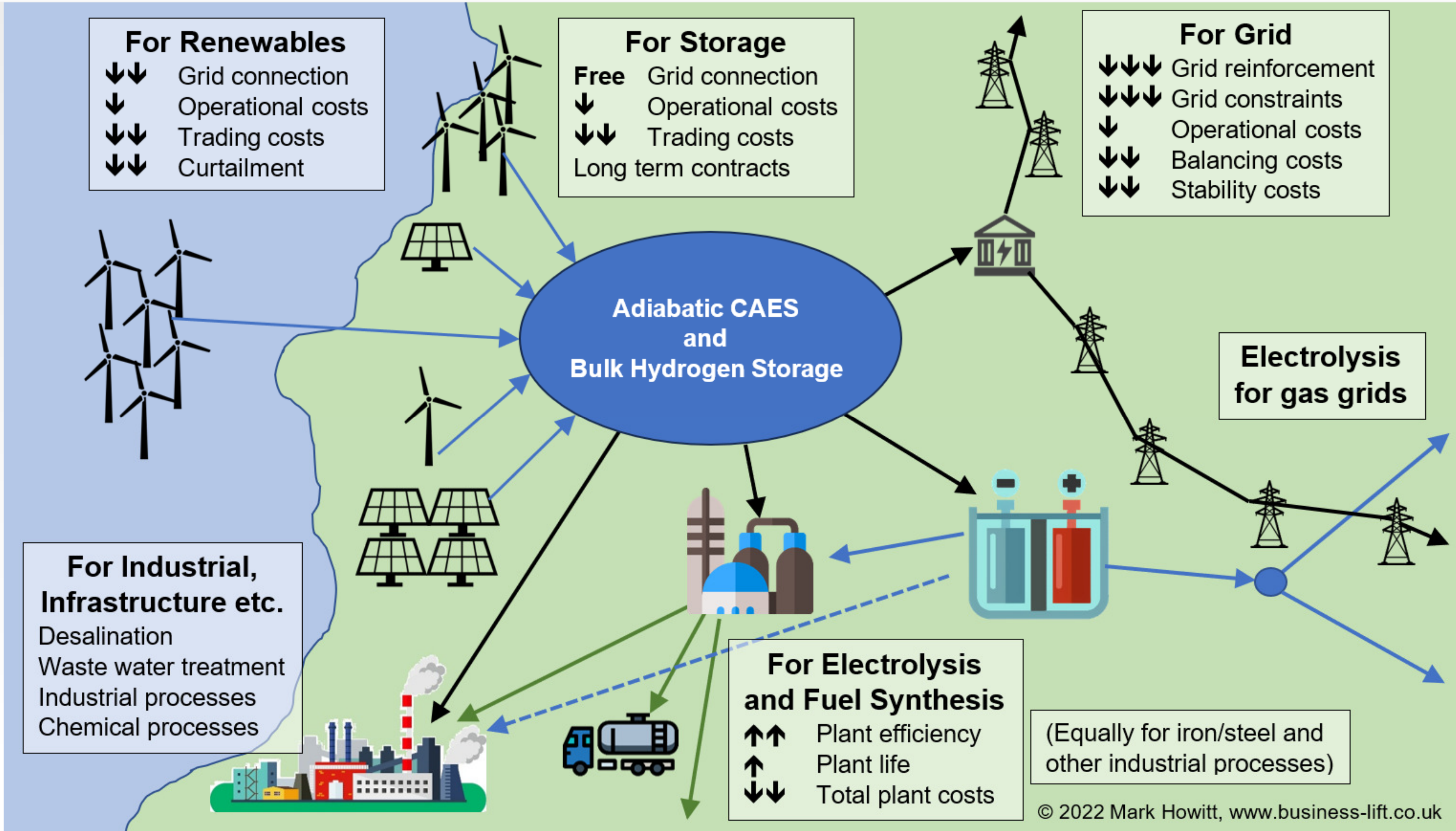

Thank you

For your attention

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