Trends in Hydropower

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“The times they are a-changing”

“Decarbonisation has produced high levels of renewable generation which has different operating characteristics, plant dynamics, data quality, flexibility and inertia contribution. This has increased reserve and response requirements and the nature of intermittent renewable generation means that the requirements are more volatile and less predictable.”

Quote from the Introduction of UK National Grid’s Operability Strategy 2018

Trends in Hydro

- Historically hydro was a low-cost energy producer; countries that developed and manged their hydro resources well enjoyed economic prosperity.
- The future of hydro is different: it may not be the lowest-cost energy source, but it should integrate other low-carbon forms of generation.
- Hydro projects are still being designed to suit historic power systems – this has to change.
- Hydro (new and refurbishment) should be designed to provide grid support: balancing and flexibility, energy storage and other essential system services.

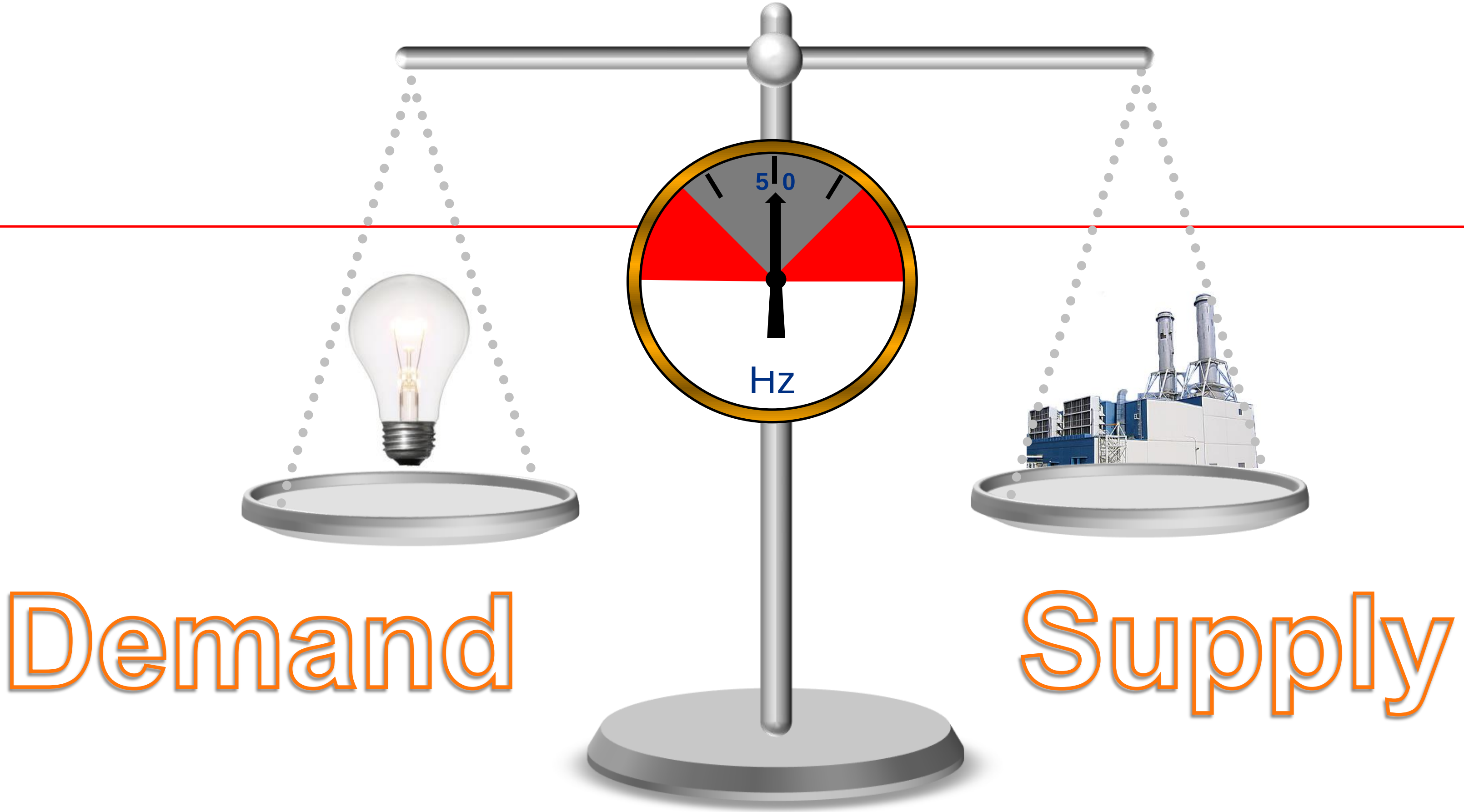
Understanding future electricity systems

- To maximise value we need to configure hydro to provide optimum support to the grid.
- Power systems are changing rapidly: hydro is less about power and energy, and more about stability and security.
- Hydro engineers, developers and regulators must understand the role hydro will play in future energy systems.

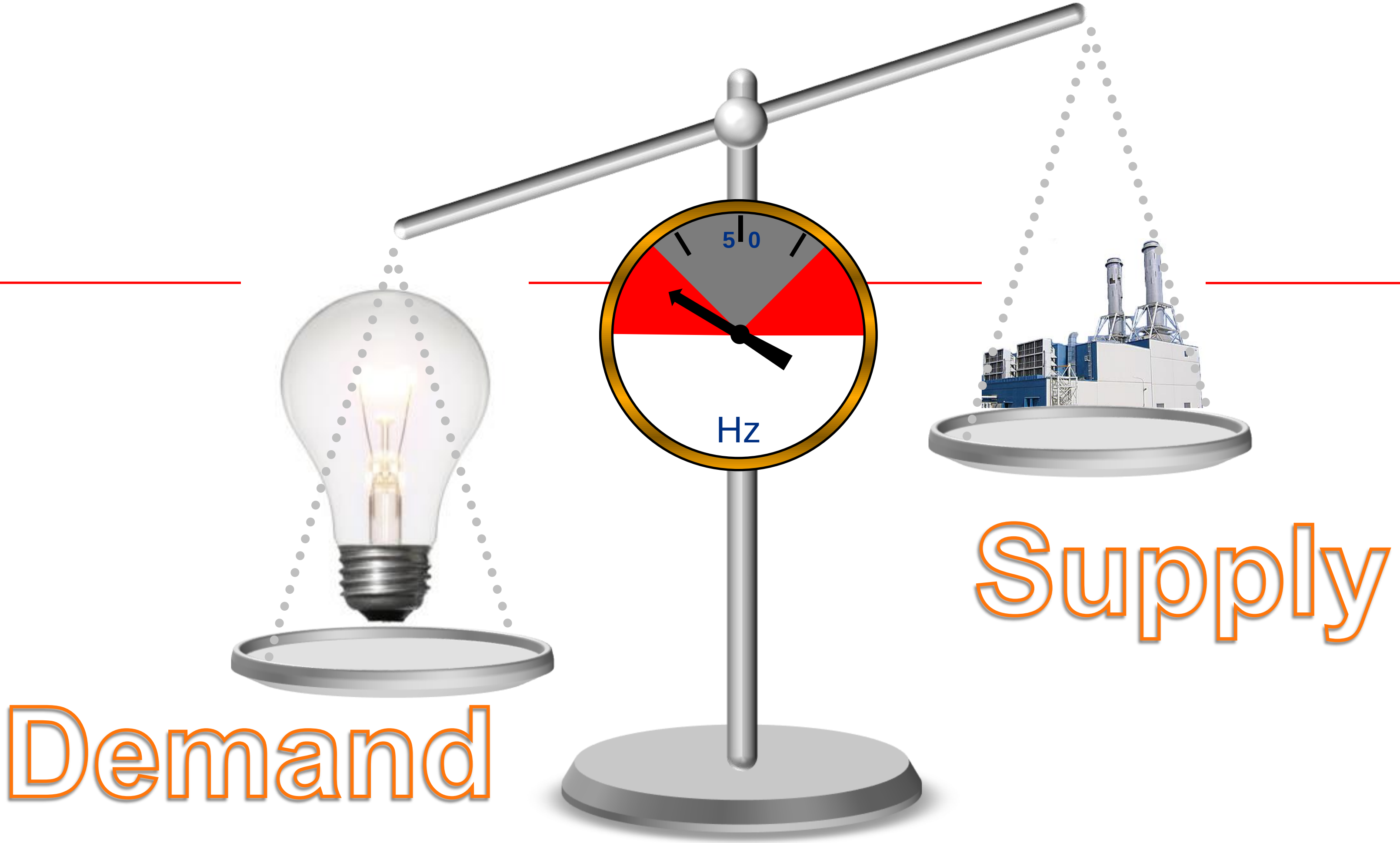
Future generation mix

Technology	Constant	Predictable	Despatchable	Low Carbon
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes
Solar Photovoltaic	No	No	No	Yes
Solar Thermal	(Yes)	No	No	Yes
Wind	No	No	No	Yes
Tidal Stream	No	Yes	No	Yes
Tidal Range	No	Yes	(Yes)	Yes
Biomass / MSW	Yes	Yes	(Yes)	Yes
Geothermal	Yes	Yes	(Yes)	Yes

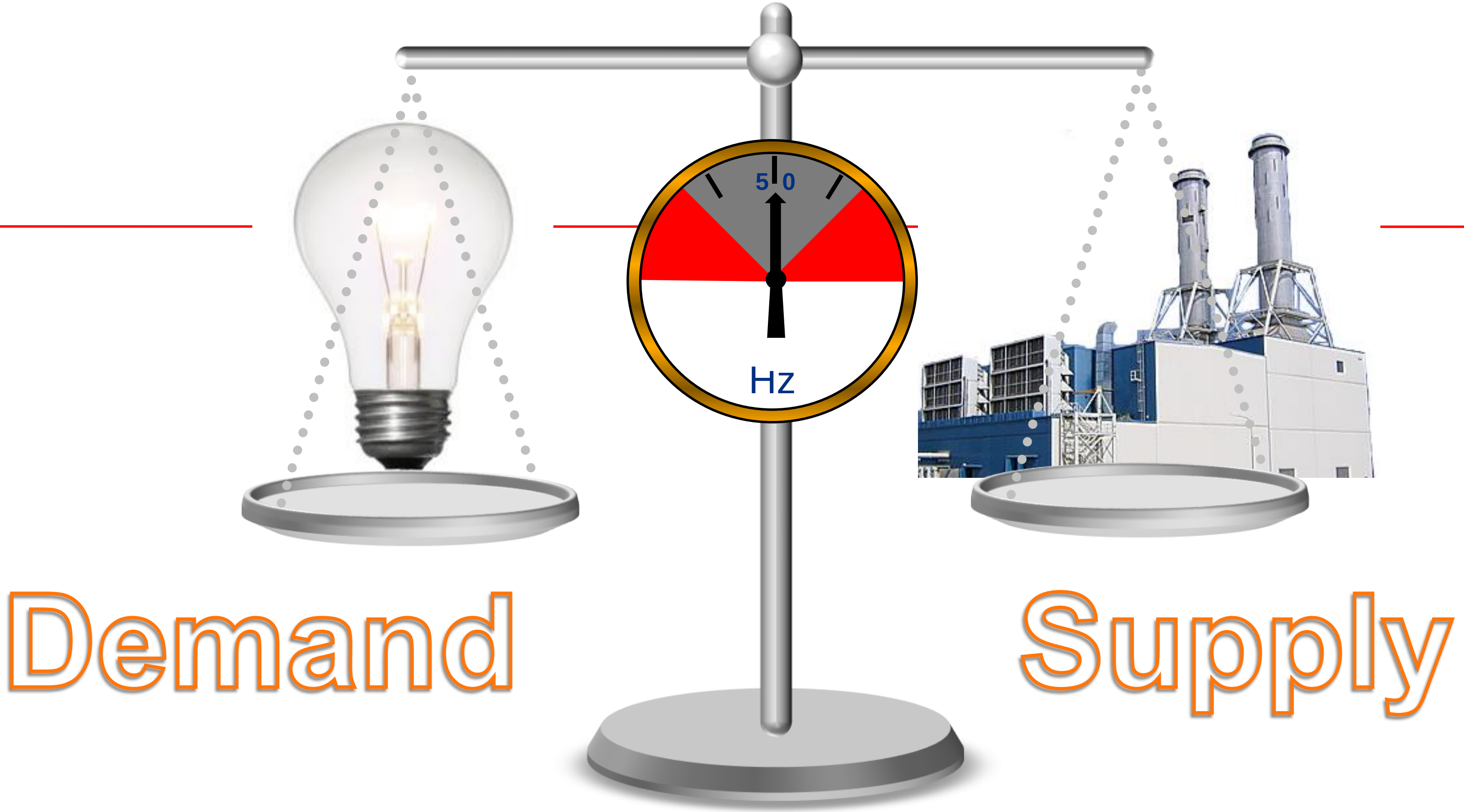
Removing high carbon generation reduces constancy, predictability and most of all despatchability. **The system is difficult to operate**.



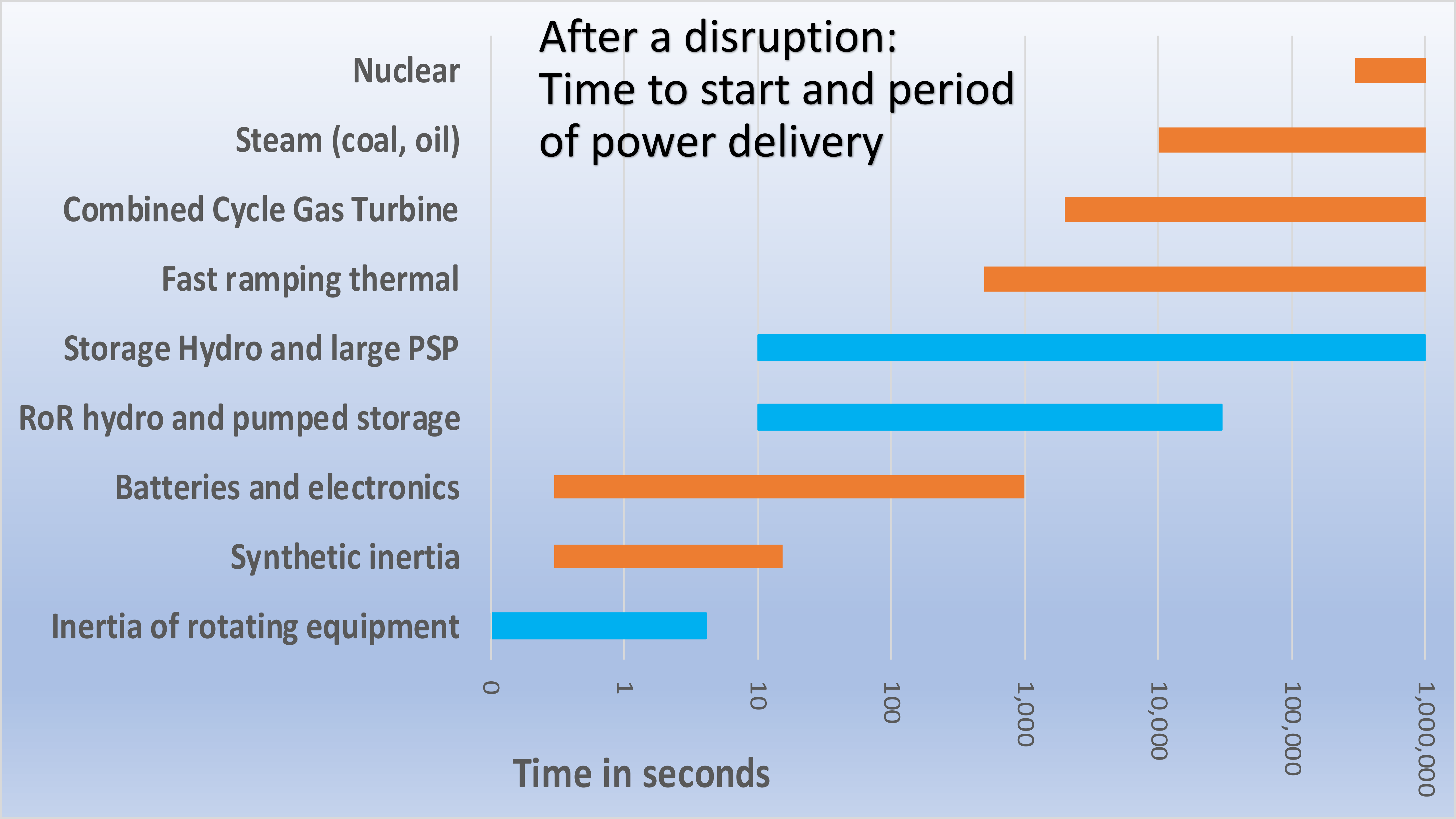
Power demand and supply must be in balance



If power demand exceeds supply,
frequency falls below 50 Hz



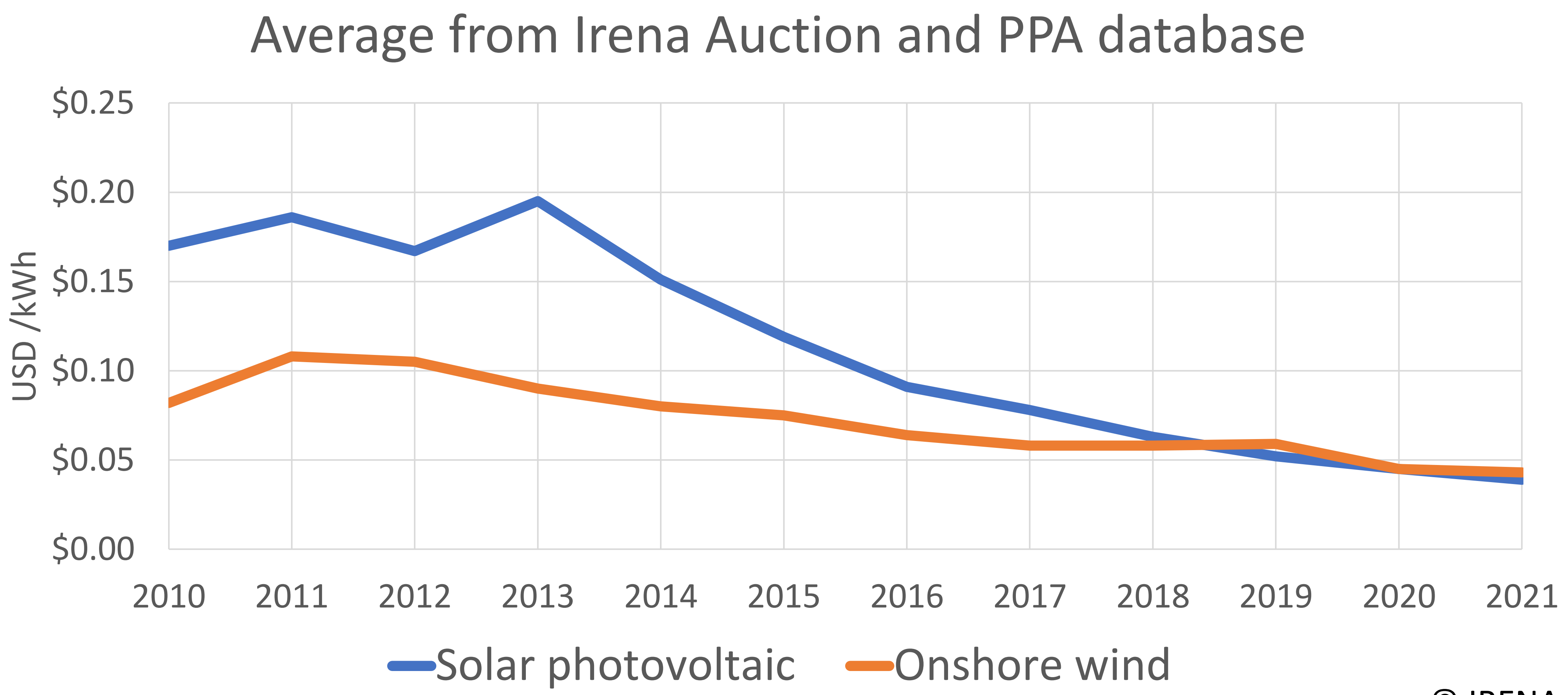
When supply is increased to match demand, frequency recovers to 50 Hz


After a disruption:
Time to start and period of power delivery
Nuclear
Steam (coal, oil)
Combined Cycle Gas Turbine
Fast ramping thermal
Storage Hydro and large PSP
RoR hydro and pumped storage
Batteries and electronics
Synthetic inertia
Inertia of rotating equipment
0
1
10
100
1,000
10,000
100,000
1,000,000
Time in seconds

The energy transition

- Wholesale decarbonisation of electricity is happening.
- Traditional fossil-fuelled generation is on the way out.
- New renewables are taking over, driven by originally by public sentiment but now by economics (sub-US¢5/kWh vRE prices).
- Gas-fired generation may still be needed for back-up, but many nations are committed to “net-zero” carbon.
- Future power systems will look very different.

The falling cost is driving decarbonisation



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The cost of vRE?

- In many countries variable Renewable Energy (vRE) is now the cheapest source of energy.
- In Uzbekistan the Navoi Solar Park is selling energy to the grid at US¢ 2.7 / kWh.
- Prices in the last PV tender in Turkey were ~US¢ 2.5 / kWh
- Few technologies can compete with these energy prices.

Shape of future power systems

- Traditional power systems featured relatively stable demand and predictable supply.
- Most of the generators were capable of supplying continuous base-load.
- Storage hydro could be used for peaking, and pumped storage for arbitrage.
- Hydro is virtually the only despatchable low carbon generation for future power systems.

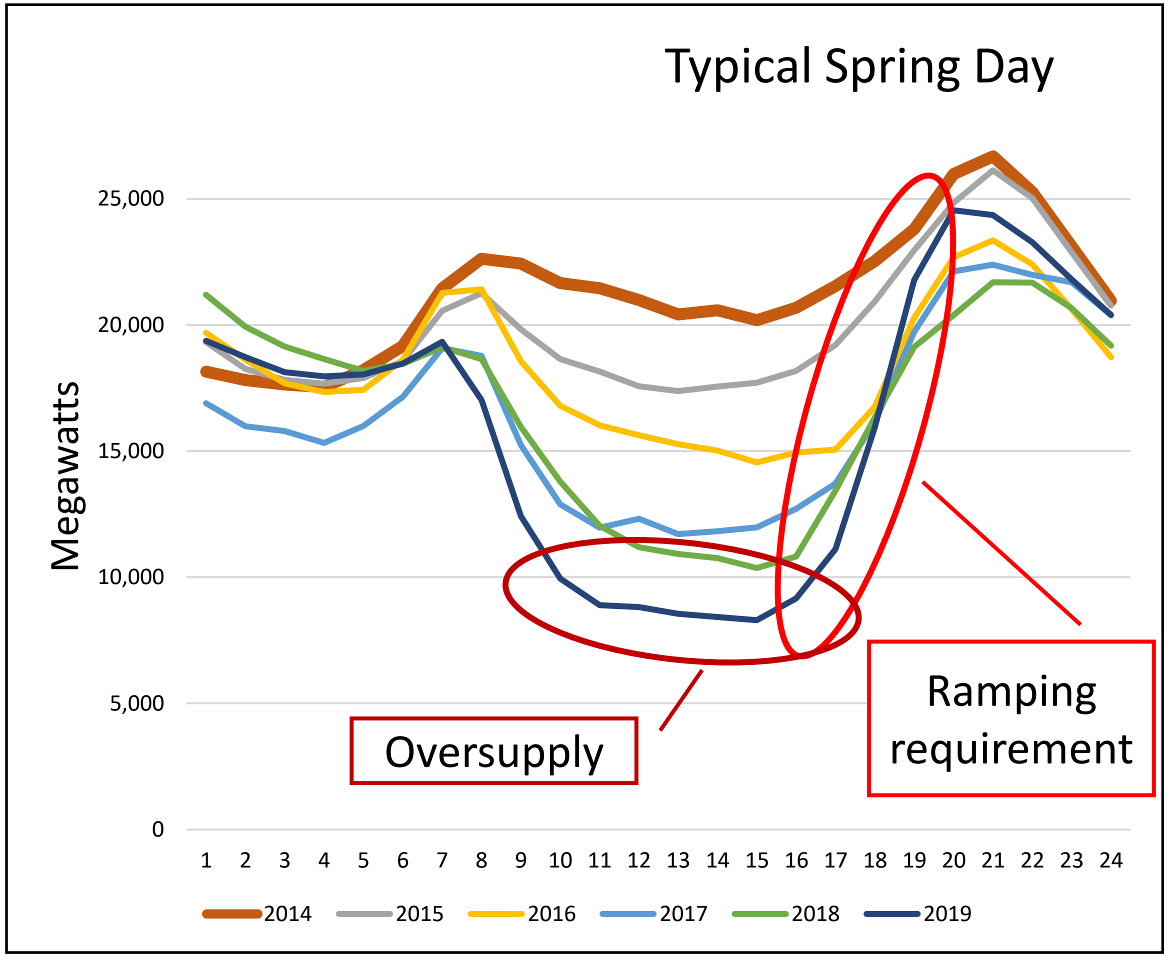
The Duck's getting fatter

In 2013 CAISO* created the duck curve, expecting transmission system demand to drop by 40% in 2020 on a sunny spring day due to distributed solar PV generation.

The duck is getting fatter more quickly than expected: by 2019 demand was already reduced by 57%.

By Spring 2019 maximum ramping rates had reached over 15 GW in 3 hours.

Over-supply is leading to curtailments and negative energy prices.



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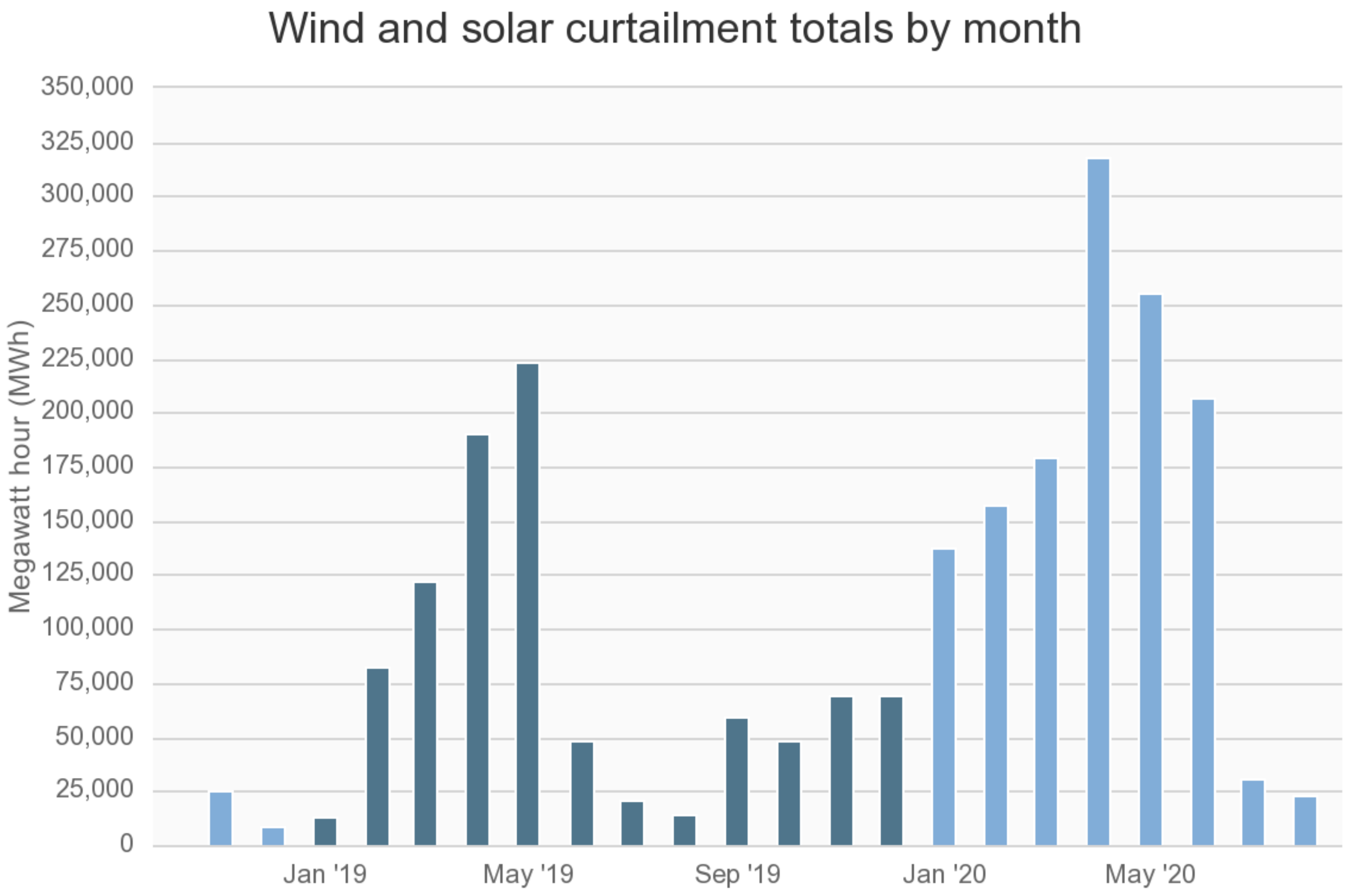
Source: data from IEA / CAISO

*CAISO is the California Independent System Operator

Curtailment of vRE is common…

On CAISO's system curtailment of renewable energy sources due to over-supply has become common, especially in the spring months.



Source: CAISO

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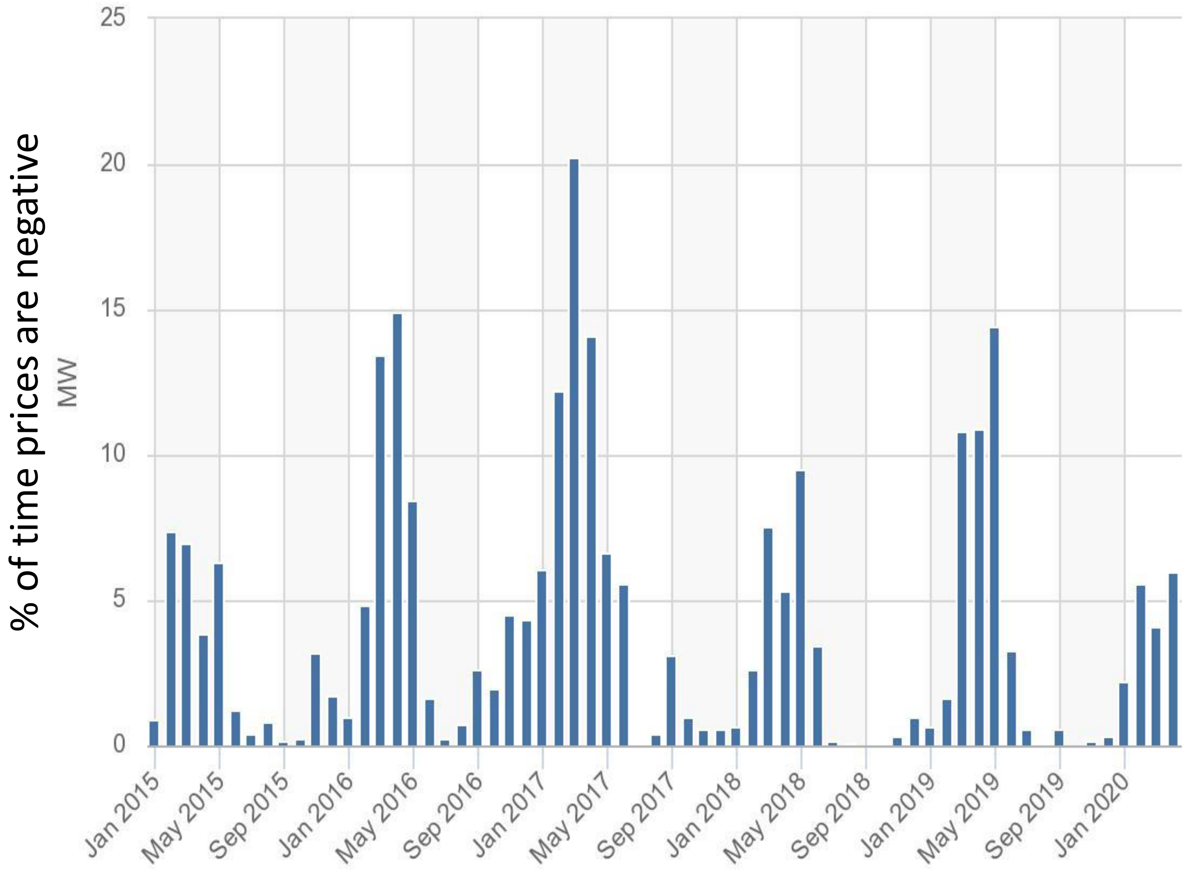
…and prices turn negative

With over-supply and curtailment comes negative energy prices.

In some months prices are negative 10% to 15% of the time.

vRE is becoming cheap, but it is also losing its value.

Energy cost is not a good way of comparing technologies, since the value to the grid depends on when and where energy is produced, and how dependable it is.



Source: CAISO

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History	The future
System planning only for power and energy	System planning for all services and attributes needed by the system
Hydro optimised for energy and revenue	Hydro optimised for system and national benefit
IPP projects on first-come-first served	System planning defines project sequence
Little value given to storage	Energy (water) storage has great value
Oversupply does not exist	Oversupply a problem: footroom and load turn-up needed – major role for pumped storage
Hydro in competition with other generation	Hydro complements other generation – more vRE means greater need for hydro and pumped storage
Hydro prioritised in multi-purpose projects (as primary source of revenue)	Multi-purpose project components prioritised for national benefit
Energy has a real cost (fuel) and value	Energy has no marginal cost and no intrinsic value: prices positive when shortfall, negative when surplus

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Benefits of Hydropower

Activity	Service	Hydro	PSP
Balancing	• Day ahead scheduling • Load following / dispatch • Automatic frequency response • Fast ramping • Arbitrage (intra-day storage) • Bulk energy storage (multi-day) • Footroom (load turn-up)	✓ ✓ ✓ ✓ (✓) (✓) 	✓ ✓ ✓ ✓ ✓ ✓ ✓
Rate of change of frequency	• Inertia	✓	✓
Voltage management	• Reactive power control (location specific)	✓	✓
Transmission management	• Constraint alleviation (location specific)	✓	✓
Reconstruction	• Blackstart • Fine variable control	✓ ✓	✓ ✓

Pumped storage and some hydro can provide many of these services at zero load, hence without displacing vRE

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How should hydro change to respond to system requirements?

Capacity and plant factor

- For most ancillary services power capacity (MW) is more important than energy.
- Most hydro can be built with any desired capacity and plant factor.
- Very low plant factor hydro (5% to 10%) can provide huge system support.
- Existing schemes can be re-built making better use of the site (higher capacity, faster response etc).

Re-purposing example: Kinlochleven HEP, Scotland

Built in 1909 to supply aluminium smelter

19.5 MW, 160 GWh pa – 94% load factor

325m gross head, 8 million m^3 live storage

Scheme could be reconstructed as a peaking HEP, increasing capacity from 20 MW to 300 MW

- 300 MW, 160 GWh = 6% LF (e.g. 2 hrs on weekdays)
- 8 Mm^3 storage = 21 hours generation

Adjacent Lochaber could be re-purposed:

Capacity increased from 90 MW to 1200 MW (6% LF)

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More robust equipment

- Many existing hydros are designed for a single on-off cycle each day (or less).
- Changed role of hydro can require multiple on-off cycles per day, and frequent variation in output.
- Existing plant can be damaged by this changed use (especially generators).
- Robust plant, remote monitoring and failure prediction can allow flexible operation.

Use storage of existing hydros

- Energy storage is critical for decarbonised power systems.
- Existing hydro reservoirs are often used for maximum energy output rather than optimum system services.
- Reservoir operation should change to suit the day-to-day needs of the system and availability of water.
- Conjunctive use – conserving water by using other forms of generation (eg wind/solar) can maximise hydro benefits.
- EG: UK has 1000 GWh of storage in existing hydros that could be used for flexibility services (c/w 30 GWh of pumped storage).

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Increased diurnal storage

- While seasonal storage is of enormous value to the future "net zero" electricity system, diurnal storage that allows daily peaking also has great value.
- Very low plant factor hydro, **perhaps as low as 5%,** will contribute to grid stability and security through fast ramping, frequency response, inertia and other flexibility services.
- A few hours of storage, and a large increase in capacity, can make a much bigger contribution to the grid.

Re-regulating ponds

- Peaking, fast ramping and other modes resulting in rapid flow changes, may require re-regulating ponds to attenuate flows and avoid adverse downstream impacts.
- On- or off-channel ponds can be considered (Pergau in Malaysia has off-channel pond with an automatic syphon spillway).
- On-channel ponds can be equipped with generation (eg Mpatamanga, Malawi and Mphanda Nkuwa, Mozambique) or can have pump-back, giving a pumped storage capability.

Modify waterways to manage hydraulic transients

- Speed of response is often dictated by hydraulic transients.
- For new hydro, sites surge shafts close to the powerhouse will enable rapid change of flow and fast ramping.
- Retrofitting surge facilities to existing stations can be considered, especially underground chambers.

Synchronous condenser operation

- Minimum output for hydros units (other than Peltons) is typically around 40% of installed capacity.
- Hence a 100 MW hydro providing spinning reserve services will displace 40 MW of vRE.
- Blow-down can be provided (or added) for Francis turbines to allow them to spin in air, meaning services can be provided without displacing vRE.
- This mode is normal for pumped storage.

Provision for future capacity increase

- As seen from the CAISO "Duck Curve", the need for flexibility services builds progressively.
- The ultimate capacity (eg very low plant factor) may not be needed immediately.
- Robust planning means provision should be made for capacity increase in future at minimal cost.
- Adding new intakes to reservoirs can be costly and complex (eg Tabela 4th & 5th extensions).

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Blackstart capability

- “Net Zero” electricity systems dominated by variable generation will be increasingly complex to operate and prone to cascade failure.
- Re-building power grids after failure is complex – fine-tuning demand and supply as the system is progressively re-built.
- Hydro is ideal for this function, with the ability to finely adjust output.
- Blackstart capability for hydro can enhance the security of the power grid.

Hybridization: combining technologies

Adding other technologies can extend the operating period of hydro by conserving water and using existing power evacuation and station control infrastructure.

- PV, including floating PV, can operate conjunctively.
- Wind can use existing switchyards and transmission lines.
- Batteries can fill the “ultra-rapid response” gap – hydro provides inertia, batteries provide response within 0.3 seconds, allowing hydro time (10-20 seconds) to ramp.

Does this require new technology?

No: many existing schemes are designed for flexible operation.

Pergau HEP, Malaysia (1996)

- Peaking operation (~10% load factor)
- rapid response (0 – 600 MW in <20 sec)
- weekly storage (empties during week, refills weekends)
- 500 kV line direct to heart of load centre (Klang Valley)

Dinorwig Pumped Storage Scheme (1984)

- Synchronised, spinning in air: 0 to 1320 MW in 12 seconds
- 1728 MW peak output
- 5 hours of storage (9000 MWh)

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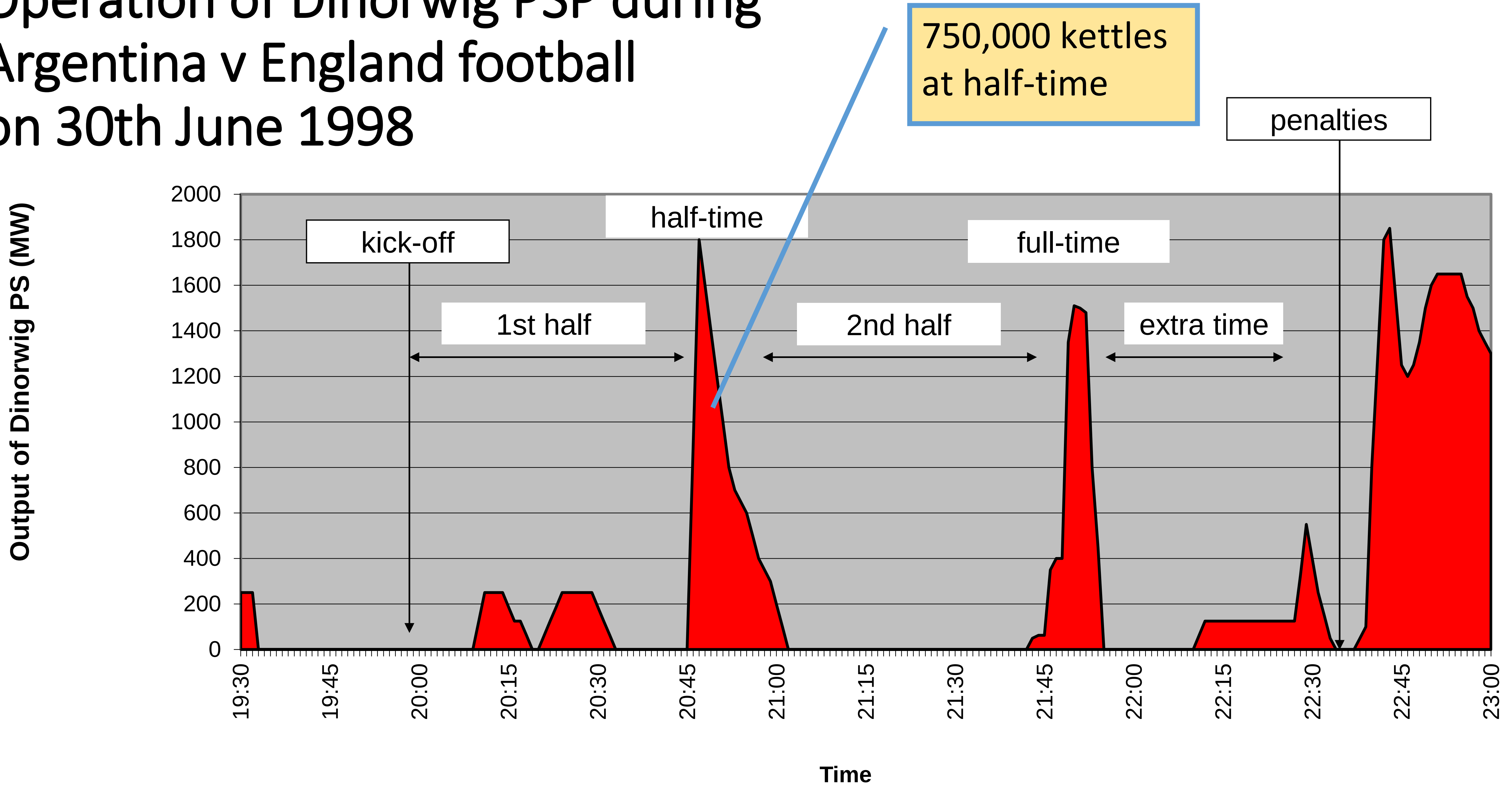
Operation of Dinorwig PSP during Argentina v England football on 30th June 1998



Market challenges

- Markets generally have not caught up with the needs of the future system – still focused on energy prices
- Developers need to finance projects based on the current market – Boards and Banks require revenue certainty
- Projects under development now will face a different market when they are commissioned in 2026 to 2030
- Our projects need to be robust to the uncertainties of the future system

We need to reduce fixation on “cost of energy”

- Historically hydropower competed with thermal power to produce energy, and “cost of energy” (¢/kWh) was critical.
- In future, energy is only a small part of the service provided by hydro; reduction in system cost is the key parameter.
- For example one project under development in Philippines derives 80% of revenue from ancillary services, and only 20% of revenue from energy.

Market structure needs to change

- Future generation will have zero or negative marginal cost.
- Markets based on energy cost need to change.
- For cost-efficient electricity, the system operator needs to define and procure facilities that combine to provide reliable electricity at least cost.
- Procuring services separately is inefficient, and is also makes projects difficult to finance.

"All energy is not equal"

New concession models

- Energy based auctions or concessions are an historic anachronism – dating from when the cost of electricity reflected the cost of fuel.
- New concessions should be based on capacity or availability payments, lease / PPPs or reversion to public procurement.
- De-risking projects for developers will reduce costs and attract financing.
- Consider the ESO buying back sites (with compensation) to change the configuration or mode of operation (or else provide regulatory and fiscal incentives for these changes).

Climate change

- Climate change is driving the energy transition and decarbonisation.
- Climate change may affect the availability of water for hydropower.
- Most grid support services are based on capacity rather than energy.
- Hydros can be operated to provide flexibility services, even when there is little water available.
- Operation needs to change according to availability of water.

In summary

- Power systems are becoming harder to operate due to decarbonisation and vRE dominance.

- Flexible hydro and pumped storage can greatly assist operation, providing vital system services and must be designed to support the future system, and allowed to operate flexibly.

- New regulatory and funding mechanisms are needed to ensure the system operator gets what the system needs **at least cost**.

New-style hydro will be a system service provider and integrator of other technologies, not just an energy generator.

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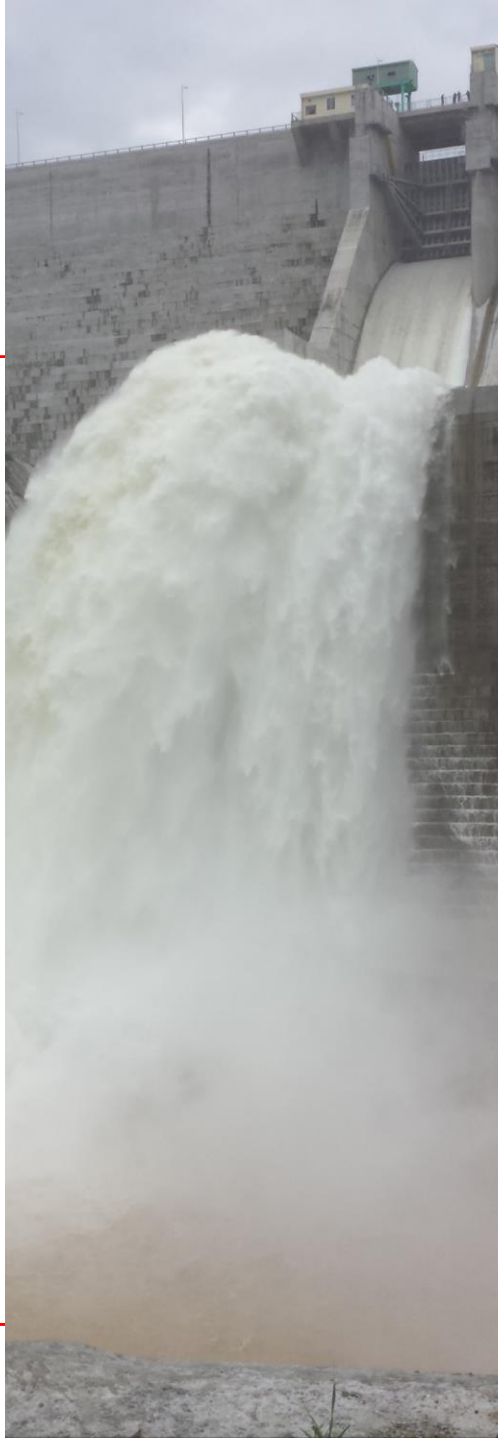

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Thank you

See **www.mcw-e.com** for various papers on flexible hydro and pumped storage, and for innovative financing solutions.

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return

A new concession concept – FELT

Finance, Engineer, Lease and Transfer (**FELT**):

- operator specifies his requirements (to equivalent of EPC tender).
- Developer finances, designs and constructs the facility, and hands over with typical EPC warranties.
- Plant leased to system operator, who operates it for maximum system benefit (3rd party operator if desired)
- Optional transfer at end of lease term
- Focus on de-risking for developer to minimise the cost of electricity by attracting low-cost finance

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