A whole-of-system assessment of the pricing and physical orchestration mechanisms for a smart flexible power system

FlexForum Members[1] have consistently identified that filling holes in the value stack is the top priority for realising the economic benefits of flexible resources and flexibility.

There is quite a lot of activity across the sector on individual holes in the value stack — Electricity Authority workstreams[2], Transpower non-transmission solution procurements[3], and individual network operators, electricity retailers and flex coordinators[4] are exploring commercial[5] (ie, pricing) and physical orchestration[6] mechanisms — but there is not yet a shared view of the overall architecture that ties pricing and physical orchestration mechanisms together to underpin a smart, flexible power system.

At Flex Day 2025 Members highlighted that we need a much better understanding of how the cash and physical signals coming from the wholesale market, transmission and distribution operators practically activate flexibility and how these signals and mechanisms will be practically translated into desirable flexible customer propositions.

A whole-of-system assessment is needed to identify common operational and economic factors, assumptions and design principles for effective and timely development and integration of the suite of pricing and physical signals required by a smart flexible power system.

A range of questions (many listed later in this note) must be answered to identify what pricing and physical orchestration mechanisms are practically required to support the development of smart, flexible power system and empower households, businesses and communities to maximise the value of flexible resources, have a reliable and resilient power supply, reduce carbon emissions and reduce the energy burden.[7]

A deep dive to identify pricing and physical orchestration mechanisms for a smart, flexible power system

FlexForum will use the deep dive process it uses to develop FlexForum Insights (and the Flexibility Plan) to consider pricing and orchestration mechanisms for a smart flexible power system given evolving system conditions,

1 FlexForum is an incorporated society with 49 Members from across the electricity ecosystem. Members include: gentailers, retailers, metering services suppliers, electric vehicle charger manufacturers, energy management software firms, Transpower, distributors, solutions providers, universities, and some real people. Find out more at www.flexforum.nz.

2 Electricity Authority workstreams addressing holes in the value stack include: distribution connection pricing, standardised hedge contracts, mandating retailers offer TOU products, mandating distributors reward export at peak times, and introducing an Emergency reserve scheme.

3 Transpower wants to contract (and pay) for flex resources in the Western Bay of Plenty and Upper South Island.

4 Flex coordinator is our preferred term for 'aggregator', 'flexibility services provider' etc as it most accurately describes the activity and service.

5 Commercial or pricing mechanisms include: contracted flexibility, temporally and locationally dynamic price signals (eg, including scheduled time-of-use-pricing), type of use pricing (ie, extending pricing approaches for flexible water heating to other specific technologies, eg, EV charging, batteries)

6 These involve a range of flexible connection agreements, also known as dynamic operating envelopes.

7 Energy burden is a measure of the share of a household's gross income spent on energy costs. It is a quantitative measure of energy affordability.

technologies and household, business and community expectations. The approach[8] is proven to quickly and transparently produce robust expert advice through a series of structured workshops attended by experts from across the diverse FlexForum membership (and from guests and partners).

The outcome would be an expert whole-of-system view of the suite of pricing and physical orchestration mechanisms expected or likely in the smart flexible power system that Aotearoa New Zealand wants, providing a plausible future state to guide and prioritise policy, regulatory, and learning-by-doing efforts and the enabling investments of the electricity supply chain and by people.

A further, equally valuable outcome, of the deep dive process would be a broader and shared understanding of the issues, opportunities and practicalities, thereby reducing the incidence of people talking past each other or not talking at all.

The main output will be a FlexForum Insights (ie, a report) documenting the observations, conclusions and any advice to decision-makers emerging from the process. There may also be further outputs, eg, guidance or policy documents, identified through the process.

This note provides detailed context and the problem statement for the deep dive. The number and topics of the workshop series, plus any supporting research, will be identified through a co-design process involving FlexForum Members and deep dive participants.

Context: pricing signals and physical orchestration mechanisms underpin power system operation

Electricity prices are intended to signal power system conditions

A suite of electricity prices is the mechanism by which the key links in the electricity supply chain – distribution, transmission and generation – recover their revenues (ideally in the goldilocks range of the costs of supply) and signal to system users the costs of electricity and of network capacity.

The signaling function is a necessary condition of an efficient electricity system as prices both inform system users of the costs of using electricity and network capacity at any time and place across the power system and provides the ability to respond according to their circumstances and preferences.[9]

We see price signals influencing power system operation and performance every day. Electricity generators respond to spot prices in decisions about day-to-day generation output and longer-term generation investment plans (managing revenues). Retailers respond to high spot prices or 'peak' network charges by flexing[10] the use of water heating (lowering operating costs).

The accuracy of the price signal matters. Signals which closely reflect actual costs of providing the service at a given time and place empower system users – generators, network operators, retailers and households, businesses and communities – to make efficient choices given their circumstances, capabilities and preferences about using and producing electricity.

A 2016 report on the Utility of the future from the MIT energy initiative concluded '*Ideally, these prices and regulated charges will reflect all the operating conditions and investment needs of the system, and the markets for*

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[8] FlexForum considers the approach is faster, cheaper, increases participation (particularly from small entities), is more satisfying and productive for participants (including by reducing the time commitment for participants relative to traditional regulatory processes). And produces robust and high-quality advice.

[9] "…in a system in which the knowledge of relevant facts is dispersed among many people, prices can act to coordinate the separate actions of different people…". Hayek, F.A. (1945) "The Use of Knowledge in Society." American Economic Review. Vol. 35, no. 4. pp. 519-30

[10] The electric hot water heating of many households is flexed to shift usage to a different time. The flexing is enabled via ripple control technology managed by local distributors or via metering infrastructure managed by a retailer.

electricity services will allow the participation of all system users.'[11]

Price signals are expected to become more important as flexible resources become more prevalent as… '*moving to a greater reliance on distributed resources (many and small) and demand participators (many and small) leads inexorably to a greater need to have real-time spot prices that send the right price signals. The central control of distributed resources would not be feasible, and prices must provide the needed incentives.*'[12]

System conditions are becoming more variable and less predictable. More granular information is required to enable efficient (flexible) responses

The current suite of price signals is a mixed bag. Spot prices (and associated hedge products) are a highly accurate indicator of the cost of generation electricity by time and location. However, transmission[13] prices and distribution[14] prices are far less accurate indicators of the costs of network capacity by time and location.

These varying levels of accuracy are not surprising. That MIT report noted '*the level of granularity in space, time, and the disaggregation of services reflected in these economic signals will depend on several factors, including: trade-offs among the efficiency gains associated with increased granularity; the availability of communication and computational technologies and implementation costs necessary to increase granularity; and the acceptance of different prices and charges by various agents.*'[15]

Producing the spot price required a small number of large firms to invest in communication functionality and realise the economic benefits of granular signaling of generation costs and transmission capacity. But until recently, it was not practicable to produce accurate information about the time and place of distribution capacity due to the capability and cost of digital and communication functionality.[16]

As importantly, accurate distribution pricing signals were not needed. Networks have seen predictable demand and supply patterns for 2-3 decades. Without a pressing need for more accurate pricing (and the associated flexible responses), there was no pressing need to invest in the communication functionality required to support creating and responding to more accurate price signals.

Granular temporal and locational power system information is less valuable in a predictable environment. For example, network operators can plan and invest based on predictable network usage profiles, and retailers can calculate retail prices based on averaging electricity input costs and predictable electricity usage profiles.[17] This is a key reason why, aside from pricing of transmission capacity, there has been no material change to pricing mechanisms since the wholesale market was established in 1996.

But conditions across the power system – from the transmission to the 400V level – are becoming more variable and less predictable. People are changing how and when they use power. The generation fleet is shifting from highly controllable fossil fuels to more variable sources such as wind and solar. These shifts will increasingly cause system costs to vary more, and more often, by time and location.[18]

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11 MIT Energy Initiative, December 2016, Utility of the future, page 76, available at: https://energy.mit.edu/wp-content/uploads/2016/12/Utility-of-the-Future-Full-Report.pdf.

12 Hogan, William W, Market Design Practices: Which Ones Are Best? [In My View], IEEE Power and Energy 17.1 (2019) referenced by MDAG Price discovery under 100% renewable electricity supply: Issues discussion paper (p64).

13 Transmission prices do not practically signal the cost of transmission network capacity, instead relying on spot prices which are not an effective indicator of actual transmission capacity costs. (see FlexForum, page 7).

14 Distribution prices typically signal the average cost of distribution network capacity for a region or network area across the year. The averaging obscures the time and location-based drivers of actual distribution capacity costs

15 MIT Energy Initiative, December 2016, Utility of the future, page 86.

16 Transmission pricing is not subject to similar technology constraints, but we prefer not to talk about why transmission prices do not closely reflect actual costs

17 More detail on the problems discussed here is available in the FlexForum Insights, Filling holes in the value stack will let people and their flexibility do more, March 2025.

18 An example of one aspect the shift is changing 'diversity' of network use. Distributors have traditionally relied on observed data demonstrating expected levels of demand diversity across connections to provide appropriate levels of network capacity available at each connection point. Increasing use of solar, EVs etc is causing network use to diverge from historical diversity assumptions.

These shifts mean that system users (ie, ranging from large generators, retailers to households, businesses and communities) require more granular information about system conditions to make efficient choices which support a secure, reliable and cost-effective power system. This information can only be provided using granular and dynamic pricing signals and physical orchestration options.

Price signals and physical orchestration mechanisms must work in tandem

Price signals and physical orchestration are complementary. There have always been, and always will be, physical limits to what physical generation and network infrastructure can do and the level of usage or generation that can be managed. Physical orchestration mechanisms have always been used to ensure use of the system occurs within the boundaries set by these physical limits to avoid disturbances or outages.

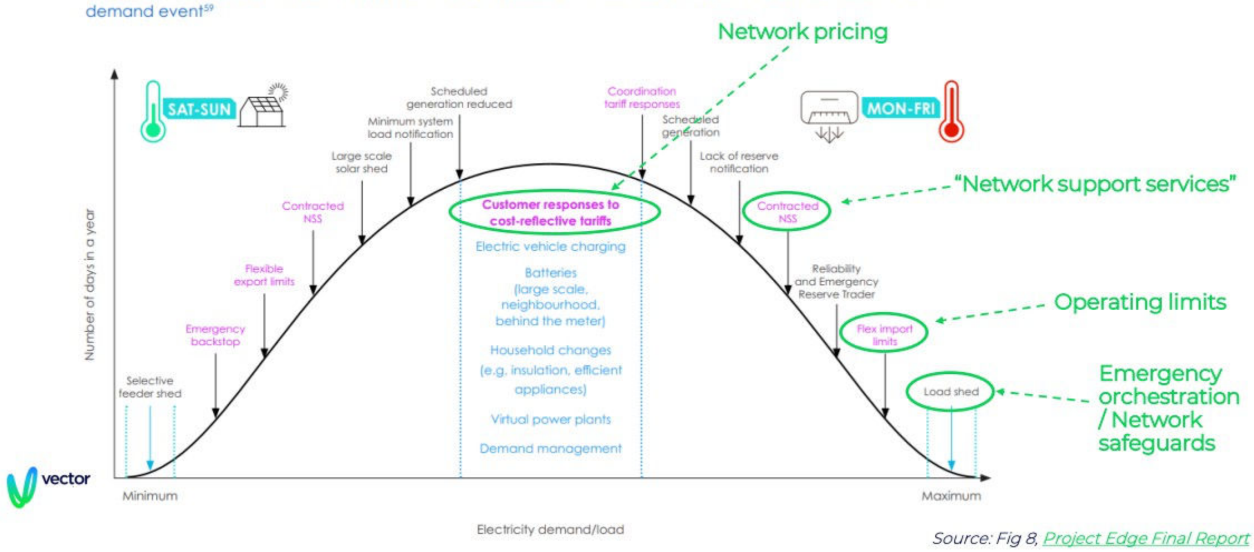
- Performance obligations apply to generators and those directly connected to the transmission network and require assets – generator, network connections – to operate within defined parameters for things like frequency, voltage etc during both normal and abnormal conditions.
- The technical parameters for connecting to a distribution network are set out in connection policies.[19] They have historically been applied on a 'set and forget' basis, but this approach is not sustainable with changing network use.

Physical limits and 'controls' must be complemented by (efficient) pricing mechanisms providing system users with information about system conditions.

An efficiently run power system must have both mechanisms because… '*Central control of distributed resources would not be feasible, and prices must provide the needed incentives. Failure to provide the right price signals will lead to distributed decisions that would undermine efficient operations.*'.8[20]

This graphic (taken from a Vector presentation) on Practical realities of whole-system optimisation of distributed energy resources) shows the spectrum of pricing and physical orchestration mechanisms available to a distribution network. The central insight – which applies for both the transmission network and distribution networks – is pricing signals should carry the load most of the time, but cost-effective reliability and resilience require support from increasingly interventionist physical orchestration.

Figure 8 | Range of available measures for managing minimum demand from peak PV exports, and maximum demand event[59]



Source: Fig 8, Project Edge Final Report

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[19] For example, the network connection requirements for Wellington are outlined in the Wellington Electricity Distribution Code and Network Connection Standard, available at: https://www.welectricity.co.nz/getting-connected/network-connection-standard/

[20] Hogan, William W, Market Design Practices: Which Ones Are Best? [In My View], IEEE Power and Energy 17.1 (2019), page 3.

Price signals and physical mechanisms underpin customer propositions

Households and businesses mostly engage with the electricity sector and their power supply via the customer propositions available to them through electricity retailers.

The retail link in the supply chain packages the price signals into customer propositions[21] which determine the amount of each power bill, perhaps[22] inform choices about how much and when power is used, and, again perhaps, inform a business case to invest in solar, battery storage and energy management capability.

There is no public information on the type and number of customer propositions, however a defining characteristic of most customer propositions is they offer a predictable 'scheduled' price – whether flat or TOU[23] rates – for a predictable 'scheduled' response. This predictability (or schedulability[24]) is a design feature. Pricing signals have been developed around predictable use patterns, and retailers had no pressing need to routinely offer customer propositions motivating people to be flexible.[25]

Flexible resources are well suited to responding to pricing and physical signals

Price signals are information which people can use to decide a response. Physical signals are instructions seeking a particular response, eg, raise or lower usage. Price and physical signals may be provided independently or paired.

Flexible resources – things like electric vehicles (EV), solar, battery storage, water and space heating and cooling equipment – within homes, businesses and communities can modify their generation and usage patterns in response to physical or price signals.

The flex resource is material and growing. Our estimates indicate there is at least 590MW of dependable and deployable flex used in the system today (8% of current system peak demand), and there could be up to 2.1GW of flex available by 2030 (25% of estimated system peak demand in 2030).

This flexibility is expected[26] to play an increasing role in operating the power system and in everyday life and business activities by providing an extra tool to efficiently keep the lights on, and as a way for people to lower their emissions, improve their reliability and resilience and reduce their electricity costs.

FlexForum estimates indicate that existing flex resources provide a range of capabilities useful to day-to-day power system operation. Based on the upper range of the FlexForum estimates:

- About 1,000MW of flex can be deployed within seconds for up to 15 minutes and 240MW able to be deployed for up to 8 hours. This flex can support dispatch and anticipated and unanticipated supply and network capacity shortfalls
- There is currently at least 135MW of long-duration flex contracted to respond to shortfalls of hydro, wind or gas fuels for days to weeks.

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21 A note on terminology. 'Electricity prices and pricing' will refer to prices and signals produced by the various links of the electricity supply chain. Prices experienced by people are referred to as customer propositions.

22 Electricity Authority, 2025 Consumer perceptions and sentiment survey report. November 2025 EA survey, page 48. …26% of respondent reported being on a TOU plan, … with 42% making significant changes to when or how they use electricity, while a further 43% making smaller adjustments. Only a small minority (12%) report no change.

23 Interestingly the EA report (ibid) notes 'Qualitative research shows that some households believe they are on a time-of-use plan when they are not (e.g. attributing hours of power or night rates to TOU products).' We say that hour of power products – and any product motivating people to shift when they use power – are TOU.

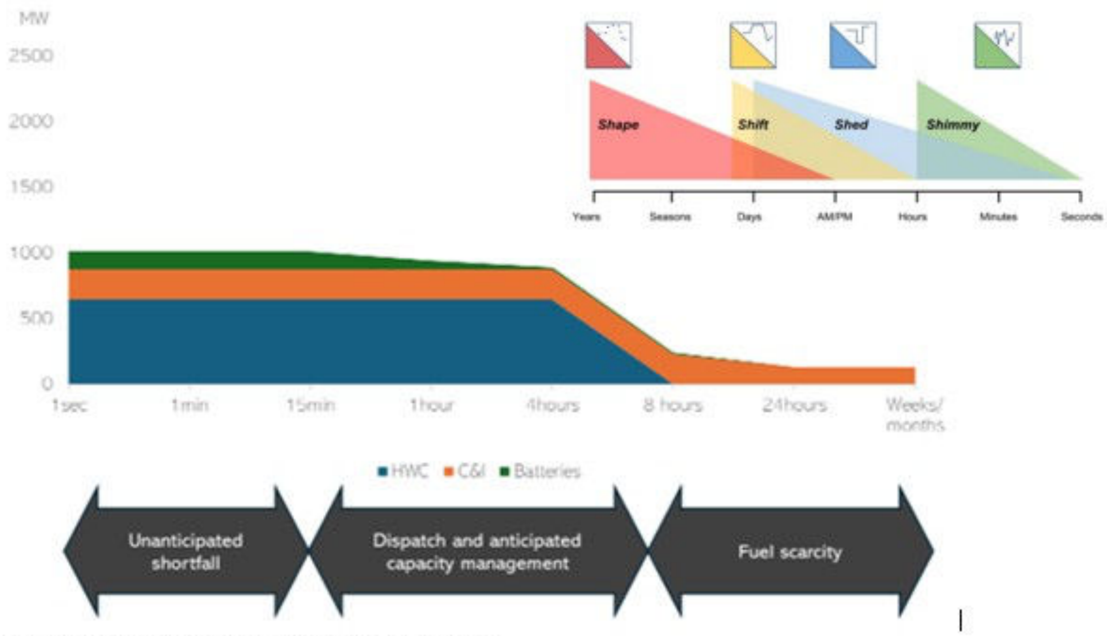
24 Schedulability: the ability to be scheduled.

25 Distributors have controlled (flexed) the use of electricity for household water heating for decades offering a discounted rate for the right to control it to help manage network constraints (and for other use cases). The price signal was typically packaged into a controlled retail tariff as a discount on the variable charge (though not always). Retailers have only recently started using the water heating resource (alongside distributors) to reduce operating costs (and enable lower power bills) by avoiding distribution (peak) peak charges and managing spot price risk.

This September 2020 report for EECA on Ripple control of hot water in New Zealand estimated there was 986.5MW being controlled in 2018 (see table 6). This estimate was considered 'a very approximate figure'. FlexForum recently estimated there was up to 644MW of water heating flex in the system in 2025, while noting that not having an official record means it is not possible to accurately quantify the amount of flex in the system (including water heating flex).

26 The role of flex in the power system has been considered by a range of parties including Transpower, the Market development advisory group, and in the BCG Climate change in New Zealand: the future is electric report.

Figure 2 Size of the flex resource in the system in 2025 able to do each of the four system jobs



Source: FlexForum and Lawrence Berkeley National Laboratory.[12]

There is no technical barrier to making pricing signals more accurate. The required communications functionality is ready and waiting

Economists tell us that pricing mechanisms need to provide the best possible information about the costs of supply and demand for electricity and network capacity across the system.[27]

The information available from pricing has increased over time in step with system conditions and improvements in communications functionality of the electricity infrastructure making up the system.

For example, electricity pricing in the 1970's was largely based on declining-block pricing. The approach encouraged higher usage by lowering marginal prices and reflected a time of energy abundance (lots of easily extracted and cheap oil, coal and gas) and massive investments in network infrastructure following WW2 greatly increasing access to electricity. The oil crisis and rising fuel costs prompted interest in peak-load pricing, aiming to reflect time-varying costs more accurately. But communications technology was limited, so marginal cost-based pricing approaches were difficult to implement at scale.

Marginal cost pricing approaches rely on communication functionality supporting frequent and fast exchanges of messages about system conditions, generation capability, dispatch instructions etc between a range of parties. For example, the spot price provides information about the marginal cost of electricity at 5-minute intervals across the day to underpin day-to-day operating decisions and long-term generation investment planning.

The very large gap between the economic principles and what was possible with electromechanical metering, manual meter reads, and paper (or spreadsheet) based data processing, billing and customer interface capabilities meant marginal cost pricing has not been used right across the supply chain.

This gap has now closed. Digital measurement and communication functionality, data processing capabilities and internet-based customer interfaces enable the creation, processing and instantaneous exchange of granular pricing and physical data and enable pricing signals which closely align to actual costs, and the measurement and

[27] See this quote from the MIT Energy Initiative Utility of the Future report, December 2016, page 75 … 'Acknowledging the importance of designing economic signals that reflect power system costs and serve as efficient signals for distributed decision-makers is not new (Bonbright 1961; Schweppe 1978; Schweppe et al. 1988).'.

coordination of responses to those signals (eg, from flexible resources).[28]

Having pricing signals which more closely reflect costs is not a technology problem. It does however require resolving a set of design, capability investment and implementation questions.

More accurate pricing does not require more complex customer propositions

People do not need or (or necessarily want) to see or directly experience the price signals underpinning customer propositions.

A key function of a customer proposition is to package complex information about transmission, distribution and wholesale market conditions (produced using prices and physical signals) to provide people with hassle free outcomes and benefits (another purpose is to provide a price risk management service).

Price signals **do not** need to be visible in the customer proposition – just available to the retailer, flex coordinator or customer who triggers the flexible response.[29]

Regulatory guidance about distribution pricing has until recently typically included expectations that pricing structures be 'simple' and 'practicable' so they can be explained to end users. This expectation is now unnecessary and counter to future proof tariff designs.[30]

The spread and uptake of propositions designed around autonomous flexible responses is however proving slow:

- there are propositions based on a network price signal and communications functionality enabling autonomous flexing electric water heating without a human doing anything;[31]
- some people automate their response to price signals using a bespoke approach, eg, using timers to manage EV charging.

People should have the ability to choose from a range of flexible propositions reflecting the range of customer preferences and circumstances. For example, retailers could offer subscription-type propositions which provide electricity (or heating) at a fixed cost while autonomously managing input costs (ie, price risk) in the background using the flexible resources of the household or business. Another plausible future state is propositions which pass through 'wholesale' prices and enable the customer to respond to signals given their technology stack and preferences.

All plausible future states (and the states leading up to it) depend on implementing the communication functionality needed to enable autonomous responses and the suite of pricing signals becoming more accurate to give reasons to respond (and invest in the associated communication functionality).

A range of technological choices exist for communicating signals to a home, business or flexible resource; signals can come via a physical home energy management system (HEMS) or directly to the device from a retailer or flex coordinator.

At this point, there is no obvious 'winner' communication technology (and perhaps never will), and progress towards the plausible future states will be accelerated by not imposing unnecessary technological constraints on how pricing and physical signals are communicated and received or greatly increase risks of restrictions to choice and innovation.

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28 This digital measurement and communication functionality is commercially available and is being used in the electricity sector (though not across the board).

29 See FlexForum, March 2025 for more discussion of this idea. Mandated price pass-through is itself impractical; which signal gets top billing? Spot price, network price? If based on value to the customer, the spot price will be top of the value stack most of the time. Further, doing so would *restrict* customer choice – effectively banning the option of subscription-style propositions.

30 For example, the AEMC Pricing Review draft report said… 'Energy service providers are risk managers. They incorporate wholesale electricity prices into retail offers that meet consumers' needs. Rather than energy service providers passing through network tariffs that are designed for customer intelligibility…' (see p38 and recommendation 6).

31 These propositions – sometimes referred to as controlled tariffs – can be underpinned by several price signals, but the primary cash signal is a discounted rate (either to the fixed charge or variable charge) offered by distributors for the right to use the flex. Retailers are stacking value from supplementary cash signals coming from avoiding higher spot prices and to avoid network 'peak' charges. Electricity usage for water heating is coordinated in the background and many households are not aware it is happening.

Several changes in practice are needed for the suite of pricing signals to more closely reflect actual costs of electricity services at a given time and place

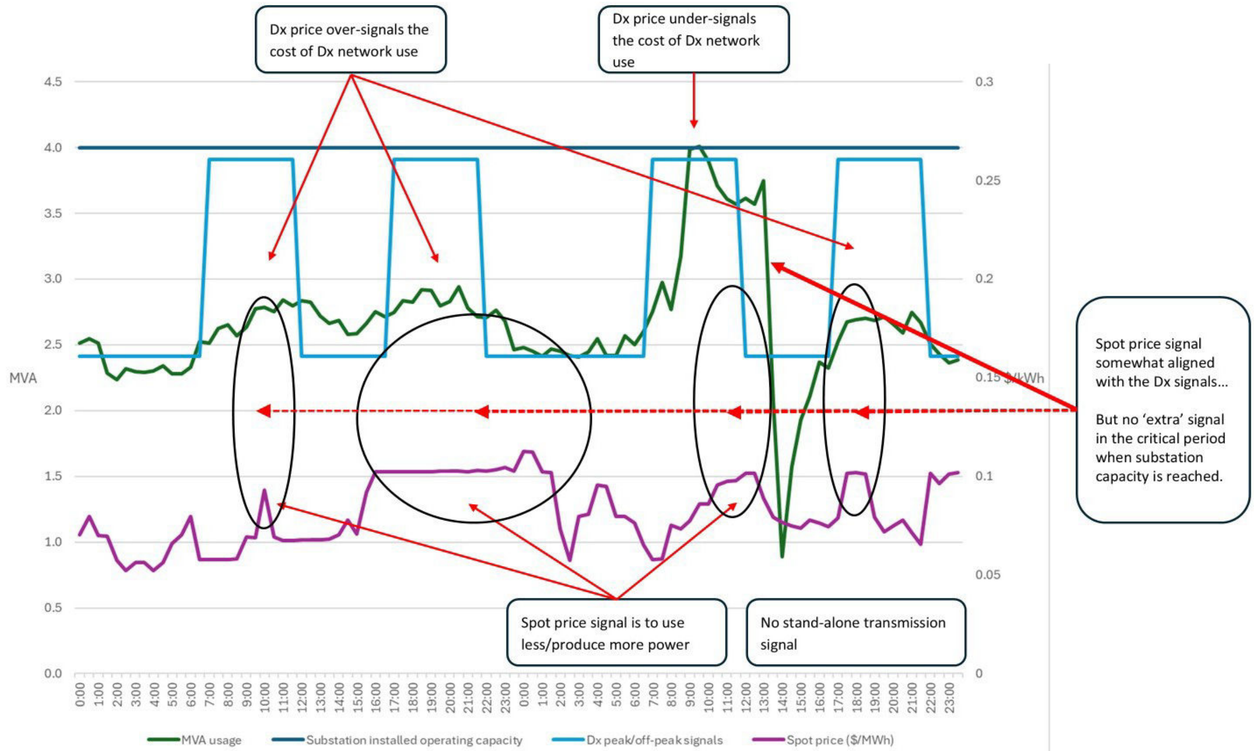
Several changes in practice are needed from across the electricity ecosystem for the suite of pricing signals to more closely reflect actual costs of electricity services at a given time and place and so produce the more granular information required to activate and motivate the flexible responses required for a smart, flexible power system.

In parallel, a suite of physical orchestration mechanisms needs to be developed to complement the pricing signals to create boundaries for optimising a reliable, resilient and efficient power system.

Figure 1 serves to indicate the mismatch in the relationship between system costs and some pricing signals. It charts usage at a substation in the Otago region, including the maximum usage recorded for that area over a 12-month period, and shows the information signaled through the spot price and distribution pricing about the 'costs' of using (or producing) electricity and using the network at that time and place.

- maximum load (4.01MVA) exceeded substation operating capacity (4MVA) for one half hour period in the 2 days shown (and the year). Over the year, the operating capacity was above 3MVA for 3.2% of the half hour periods, and above 3.5MVA for 0.09% of the half hour periods.
- the spot price over the two days ranged between $52/MWh and $113/MWh, with an average price of $82/MWh. The spot price was somewhat aligned to the network price signal, but not consistently. Most importantly there was no 'extra' spot price signal in the critical period when substation capacity was breached.
- local network usage peaked between 0900 and 1330, with maximum usage occurring between 0930-1000. There was spare network capacity in 3 of 4 peak pricing periods. This means the peak charge over-signaled network costs in these periods, while arguably under-signaling network costs when usage exceeded substation capacity.
- there was no explicit signal of transmission capacity. Usage at the GXP supplying the substation peaked later in the evening at 1900-1930 (23.05MW versus a 23MVA firm capacity).

Figure 1: An indicative view of the relationship between system costs and the suite of pricing signals.



Source: FlexForum.

Notes: Figure 1 is indicative. Usage data is from a dataset of HHR data for an Otago region substation. The figure shows usage over 15 and 16 November 2020. This period was chosen because it includes the maximum demand period for the 12 months 1 July 2020 to 30 June 2021. Network pricing is the Aurora Energy 2025-26 pricing schedule for Central Otago and Wanaka (residential customers). It is acknowledged that usage could have been responding to the flat $/kWh signal provided by the pricing structure that applied in 2020/21. Spot price data is for the Cromwell GXP on 15 and 16 November 2020 (from www.emi.ea.govt.nz).

Figure 1 does not show the retail propositions which package up the various pricing signals shown. Based on typically available existing retail offers, the following flexible responses to the price signals may have been motivated.

- Water heating flexibility (if available and if deployed[32]) could have reduced network costs in 1 of the 4 peak periods and could have been used to avoid the costs of higher spot prices across several hours. There are several of these propositions in the market, eg, Meridian Freedom Simple Flexi plan includes a smart hot water product.
- People with a retail daily TOU proposition[33] (aligned to the TOU network price structure) could have responded by shifting usage from the peak to off-peak periods. For example, the Genesis EVHome plan includes 50% of

32 Both retailers and distributors use automated management of residential water heating. Retailers use it to avoid network peak charges and higher spot prices. Distributors use it to manage network capacity, but also to earn revenue from the reserves market etc. A standard household electric hot water cylinder can be flexed (turned off) for up for 4-8 hours a day (we assume based on current practice). The joint use of water heating flex resources by retailers and distributors means the resource may not be available when 1 or the other needs it.

33 Sidenote: information on uptake of TOU products is scarce/difficult to find. Contact Energy advised investors (page 6) that 22% of its household customers were on TOU plans, but the range of retail TOU products includes daily TOU tariffs which mirror the peak/off-peak network pricing periods and hour(s) of power tariffs which provide people discounted (or '$0') power for specified (off-peak) hours (eg, 9-10pm), nights (9-12pm weeknights) or weekends (9am-5pm weekends).

variable day rates from 9pm-7am. The response could have avoided network costs in the single period maximum load coincided with a peak TOU period. Responses in other periods would simply have avoided network charges (and no costs).

- People with flexible sources – solar, stationary or mobile battery storage, space/water heating/cooling – could respond to the spot price signal. There are niche products available from retailers including Ecotricity (ecoWholesale, ecoSolar), Electric Kiwi (MoveMaster) and Octopus Energy (OctopusPeaker, Working on Sunshine) which (more or less) motivate flex-ing in response to the spot price. The response could have arbitraged the spot price to avoid energy costs and may have avoided some network costs when higher price prices coincided with maximum network load (possible in the example as the sun was out and spot prices were rising providing increasing incentives to export solar production).
- People contracted by the local distributor (or Transpower) to supply flexibility (typically from battery storage) as a non-network alternative could respond to an event call. Aurora Energy and Powerco are currently operating flexibility programmes in specific areas (upper Clutha region and Coromandel respectively) which involve availability and performance payments. The response could, if deployed[34], have avoided network costs when network capacity limits were breached.

Each of the proposition types listed are designed to motivate a flexible response, but of the options, the contracted flexibility proposition is the most suited to dependably addressing the atypical spike in network use.

The implication, however, is not just that 'distributors need to make much greater use of contracted flexibility', but that existing customer propositions are not sufficient to motivate flexible responses at the required time and place. This insufficiency of flexible propositions – which is directly linked to insufficiencies in the underlying pricing signals – leaves the local network (and system operator) to rely on physical orchestration mechanisms, eg, forced outages, to avoid harm to network assets.

Harking back to the 2016 Utility of the future report from the MIT energy initiative which said '*the level of granularity in space, time, and the disaggregation of services reflected in these economic signals will depend on several factors, including: trade-offs among the efficiency gains associated with increased granularity; the availability of communication and computational technologies and implementation costs necessary to increase granularity; and the acceptance of different prices and charges by various agents*.'

Ten years on we observe…

- Increased granularity is a necessary condition for realising a chunk of the efficiency gains expected from a smart flexible power system.[35]
- The communication and computational technologies required for increased granularity are commercially available. There is no technical barrier to creating more accurate pricing signals.
- There are clear calls from 'agents' – intermediaries, flex aggregators, retailers, humans etc – for prices and charges to more closely reflect system costs and provide the motivation and reward for flexibility.

But we are still some way off the ideal.

- Distribution network prices (charges) and distribution network costs are not closely related, and a similar uncertainty exists with the relationship between transmission prices and costs.
- Spot and network price signals do not consistently align. Sometimes the signals will conflict and ask people for different, diverging responses. The conflict could easily lead to generation or network investment that would not

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[34] Deployment would depend on the contract terms. For example, the Aurora programme has procured flexibility to respond in winter. There may be no obligation for flex to be available to respond outside the periods specified in the contract.

[35] See footnote 26 for references to views on the efficiency gains of a smart system.

be necessary in a system which efficiently orchestrated and optimised system use.

- There is a limited range of retail propositions designed around an autonomous flexible response to underlying pricing signals requiring low/no customer effort.
  - a low/no customer effort and autonomous response is typically available for the flexible hot water resource. This product exists because the communication infrastructure connecting device to flex user was mostly in place, and only incremental investment was needed.
  - other flexible resources rely on customer-initiated action involving high effort and a manual response. (See Huels Test.)[36]

The overarching opportunity is to identify a suite of pricing and physical signals which accurately reflect system costs (ie, provide good information on system conditions) and underpin customer propositions which motivate people to say yes to flex.

There are four sets of questions to be considered during the deep dive.

Customer experience + Proposition design	Price and physical signal design	Interaction between price signals	Interaction between price and physical signals
How are signals and mechanisms practically translated into customer propositions which better motivate people to invest in flexible resources and say yes to flex?	How accurately do existing pricing and physical mechanisms signal the operating conditions and investment needs of the system?	What is the reasonable balance between pricing signals, discounts for 'control' (a type of allocation of costs) and payments for response (opex)?	What physical orchestration mechanisms are required to complement pricing signals?
Are there technological and implementation limitations?	What are the opportunities and benefits of more closely aligning pricing signals with system costs (including adding any missing signals of system costs)? Are there technological and implementation limitations?	What are the use cases and limits of each mechanism?	What is the interaction between pricing and physical mechanisms? What are the implications of these interactions for coordinating (orchestrating) system use and allocating limited network headroom?
How are the customer 'responses' to these propositions accounted for as part of investment and operational decisions?	What is the reasonable balance between pricing signals (allocation of system costs and residual costs), discounts for 'control' (a type of allocation of costs) and payments for response (opex)? Which use cases are each of these approaches most suited to, and are there overlaps?	What is the interaction between various pricing mechanisms? What are the implications of these interactions for coordinating (orchestrating) system use?	

36 There are 4 levels to the Huels Test. Level 1 = demand response. Level 2 = active load shaping and locational dispatch. Level 3 = full grid integration capabilities and the ability to automatically respond to market signals. Level 4 = the ability to autonomously provide fully locational grid services on the distribution level. … the collective Aotearoa New Zealand power system is probably at level 1, though a few participants have defeated the boss to reach level 2.

Customer experience + Proposition design	Price and physical signal design	Interaction between price signals	Interaction between price and physical signals
	How can contracted flexibility potential be used to create more opportunity for price-based optimisation?		
	What is a reasonable measure of marginal system (network) costs at a time and place? (ie, the costs avoided by a response that prevents a network asset exceeding maximum capacity today). Is a long-run marginal cost signal needed?		

This is not a comprehensive list of questions, but does list questions routinely raised by FlexForum Members and across the electricity ecosystem.

Appendix. An overview of the accuracy of existing pricing mechanisms

Spot prices accurately signal marginal electricity costs by time and place

Spot prices are set every 30 minutes for about 285 points around the country and accurately reflect the cost and scarcity of fuels used to generate electricity. Spot prices are lower when there is abundant water, wind and solar (zero or low-cost fuels).

Spot price volatility is managed using financial instruments (hedges) and owning generation. Hedges traded on the ASX provide a forward price curve which signals expectations for future spot prices. The forward price is closely linked to forecasts of fuel costs, eg, water storage levels, snow/rainfall forecasts, gas and coal prices.

Hedging (and generation) insulate the buyer/owner from very high (and low) wholesale electricity costs. A fully insulated retailer will be less motivated to reduce purchases (usage) in response to very high spot prices.

Conversely, an uninsulated retailer will be very motivated to reduce purchases to avoid higher input costs.

Transmission charges do not accurately signal marginal transmission costs

Transmission costs are signaled to industrial users directly connected to the grid and distributors through three charges.

- connection charge – a fixed $/year rate
- the residual charge – a $/kW historic maximum gross demand or an estimate
- benefit-based charge – $/MWh total annual offtake and injection. This charge applies to 'beneficiaries' of specified assets.

None of these charges signal the marginal cost of transmission capacity or provide any information about upcoming transmission investment in an area. The expectation is the spot price signals transmission congestion. However, this expectation rests on two assumptions which are not being met.[37]

- retailers will forecast and expect to experience an increasing frequency of scarcity prices ($10,000+/MWh in the worst case) in each location. Retailers hedge against scarcity prices and will be incentivised to wait for their competitors to incur the costs of responding to scarcity prices and claim the benefits a delayed grid investment for free.
- the grid owner will hold back a transmission investment until scarcity prices are experienced. Scarcity prices are rare due to N-1(or higher) transmission reliability standards and the system operator and grid owner will not be doing their job if they occur often enough to be predictable.[38]

The EA appears to be arguing that the administered investment approval process is the problem, not the pricing

[37] A post-implementation review of the TPM completed for Transpower identified similar issues, eg, ' The reliance on nodal prices to signal transmission constraints was described as "all you can eat, until it is too late" – reflecting a concern price signals were not being received and therefore could not be acted on.' [section 3.4].

[38] The Electricity Authority attempts to counter this conclusion saying… 'The Authority is aware of an alternative view that argues spot prices would not be able to get high enough to appropriately compensate DG for avoiding transmission costs or supporting reliability. … One concern is that Transpower builds capacity ahead of constraints being reached, so nodal prices will never get high enough. This concern is not one about the efficiency of electricity prices, but the efficiency of grid and local network investments.' [emphasis added].

mechanism. It's a difficult argument given the fundamental role of pricing signals for efficient investment in electricity markets and not strengthened by suggestion that any problems are minor due to the untested assumption that the costs of 'early' (or unnecessary) transmission investments are offset by lower wholesale prices.

Transpower (grid owner) has made several requests for proposals for non-transmission solutions (NTS – including flexibility), with upcoming requests for the WBOP and upper South Island. A NTS would establish an explicit price signal (payment) for flexible responses to transmission conditions.

Singular reliance on NTS to signal marginal transmission costs may not be ideal, and makes it worth understanding the reasonable balance between pricing signals (allocation of system costs and residual costs), discounts for 'control' (a type of allocation of costs) and payments for response (ie, for a NTS)?

Further, any signal emerging from the transmission charge can be highly processed passing through the local distributor and then a retailer. As such, there is value in also considering which party gets the price signal.

Distribution charges approximate marginal network costs.

Distribution costs are signaled to retailers and larger connections through a range of pricing structures. Typical structures are:

- A fixed daily charge ($/day) plus a variable scheduled TOU charge ($/kWh) which varies the rate for daily peak (higher $/kWh) and off-peak (lower $/kWh) periods.
- A fixed daily charge ($/kWh), plus a capacity charge ($/kW/day) and a demand charge ($/kVA/day).

These charges are set using accounting-based measures of the cost of capacity or are highly averaged LRMC-based measures. As such, they do not accurately signal marginal network costs and do not establish a clear relationship between the price signal (either $/kWh or $/kVA) and actual network conditions.

The daily scheduled TOU charge establishes an approximate relationship with network conditions (and costs) because network usage has predictably increased in the morning and evening (0700-1100 and 1700-2100 and permutations thereof). However, there is a weak relationship between higher usage and any capacity shortfall which would require a response. As such, the higher 'peak' rate typically over-signals network costs by applying when there is a surfeit of network capacity (which is most of the time; you could easily argue these peak rates penalise efficient use).

Existing distribution pricing structures do not routinely provide a price signal which motivates people to respond to the high-cost unanticipated events outside the TOU schedule or to provide a high value dependable response to events.[39]

[39] There are however green shoots of progress, eg, in Auckland, with distributors pricing structures which more accurately target actual peak network usage.

Filling this gap would involve providing a price signal when the network (or network assets) actually faces a capacity shortfall which motivates the desired flexible response (usage or generation).

- eg, for anticipated (forecast) capacity shortfalls, the distributor could provide retailers/flex coordinators etc with notice a day ahead, and confirmation an hour ahead, that usage in that part of the network is at levels that trigger a critical peak price (symmetrical – charge for use and payment/discount for export or vice versa depending on the conditions).
- eg, for unanticipated events, the distributor could provide a 'please respond within 15 minutes, it'll be worth it' signal that triggers a payment/discount for the desired response. However, responses to such unanticipated events may be more effectively obtained directly via contract, not implicitly via charges.

Dependable flexible responses are the most valuable. A network operator needs to know that their chosen tool(s) will reduce the risk of and resolve a capacity constraint.

The surest tool has been poles and wires, but it is not economic to have N-1 redundancy for an entire network. Next surest tools have been static and dynamic physical limits, eg, flexible connection agreements[40] enabling the distributor to direct someone to reduce usage or generation in particular periods, of limits on the size of solar installations.

Flexible resources have been dependably used for years; flexible water heating, sometimes referred to as 'ripple control' has been deployed by most distributors for managing distribution or transmission capacity constraints, avoiding transmission charges or supplying the reserves market. As noted in various footnotes, distributors procure flexible water heating via controlled tariffs which offer a discount to either[41] the fixed or variable usage charges. The discount is effectively an availability payment allowing unrestricted access to the resource (subject to service level agreements[42]).

The dependability of flexible water heating – from the perspective of distributors – reflects long experience, direct control (via the ripple relay communication functionality) of the on/off switch and unrestricted access to the resource. However, these circumstances are changing due to control increasingly being available through metering infrastructure and shared use of the resource with retailers.

Shared use of flexible resources would be facilitated by more accurate pricing signals indicating the relative value of responding to separate requests. And the availability, or not, of flexible resources will inform consideration of the suite of physical orchestration mechanisms which would efficiently complement pricing signals.

There is no evidence-based position on the type of pricing signal to use – price or contract activated and increasing levels of control or dependability of response – for a given outcome.

When some people hear 'flex markets' they often relate that to UK-style network support services / contracted services (ie, contracted flex).[43]

Flex can also be motivated via network pricing structures to respond and defer specific network investments. This approach was advised by the Australia NEM review (recommendation 1D[44]) and reflects the direction of travel (draft

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[40] Flexible connection agreements equivalent to dynamic operating envelopes.

[41] Practice varies it seems, eg, Vector and Orion discount the fixed daily charge. Aurora discounts the variable ($/kWh) charge.

[42] For example, … "For peaks, we aim to limit control to no more than 4 hours in any 8 hour period (and no more than 8 hours per day). Generally off for up to 250 hours per year during the coldest winter weekday mornings and evenings."

[43] The terms flex market and flex services are quite unhelpful to the conversation. There is no flex market and no flex services. Rather flex is a resource which can be used in a market established by pricing signals, eg, the spot market (with a spot price), or reserves market, or distribution capacity market. The market exists when there is a price signal.

[44] In short, distributors should use dynamic operating envelopes and dynamic network prices (SRMC-based) to activate flex and achieve what's required to effect deferral. (See page 84).

recommendations 5 and 6[45]) being taken in the AEMC pricing review.

We need to identify the boundary between what you could/can use pricing to achieve, and when you need to move on towards contracted services (which ideally would just provide a premium on top of the SRMC-based signal). And the choices about which type of pricing signal to use when need to occur with explicit understanding of the role of physical orchestration mechanisms (eg, dynamic operating envelopes).

[45] Draft recommendation 5 is 'Amend the rules to focus network tariff design on efficiency, supporting a lowest-cost grid and a fairer sharing of costs among consumers.' Draft recommendation 6 is Amend the rules to ensure networks design tariffs for energy service providers, rather than directly for customers, to promote more flexible and innovative retail offers. (See pages 35-40).