RACE for 2030

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B4: Opportunity Assessment

Flexible demand and demand control

Final report October 2021

RACE for Business Program

Flexible demand and demand control

Final report of opportunity assessment for research theme B4

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What is RACE for 2030?

The Reliable Affordable Clean Energy for 2030 Cooperative Research Centre (RACE for 2030) is a 10-year, $350 million Australian research collaboration involving industry, research, government and other stakeholders. Its mission is to drive innovation for a secure, affordable, clean energy future.

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Executive summary

The RACE for 2030 Cooperative Research Centre (RACE for 2030) has commissioned an opportunity assessment on flexible demand and demand control (Research Theme B4). The opportunity assessment aims to identify priority research areas to accelerate adoption of Flexible Demand (FD) in Australia's electricity system.

FD is a resource in the electricity system that involves energy end-users modifying their electricity demand in response to an incentive. This shifts demand to times of low price and/or away from periods of stress on the electricity supply infrastructure. Using FD is a win-win-win; businesses pay less for electricity, electricity network operators reduce infrastructure costs, and electricity supply becomes more reliable. Enabling FD gives businesses increased choice and control over their costs.

The opportunity assessment identified large untapped potential for low-cost FD across industrial and commercial energy end-use applications. Activating these FD opportunities would put downward pressure on electricity prices for *all* electricity consumers. However, a number of barriers are impeding uptake of FD. Research is required to address these barriers and to develop tools to support FD deployment.

What is flexible demand and why is it valuable?

FD includes moving electricity consumption to a different time of day or switching off equipment altogether. The former is attractive when there is some form of storage (including inventory management) in the end-use process and flexibility to schedule equipment operation for different times of day. It is less feasible for processes that operate continuously at high capacity. Switching off equipment may be attractive when electricity is expensive or unreliable, or if paid incentives outweigh the corresponding costs of production.

Four forms of FD are generally recognised:

- **Shape**—Moving demand routinely according to a standard long-term pattern.
- **Shift**—Moving demand sporadically in response to an external signal.
- **Shimmy**—Moving demand over very short timescales in response to an external signal.
- **Shed**—Switching off equipment.

These four forms of FD have relevant use cases across different components of the electricity supply system. For example, *Shift* can be used to reduce demand and reduce pool price in the ***wholesale electricity market*** during high price events. *Shape*, *Shed*, and *Shift* can reduce demand on ***electricity networks*** during peak demand periods, reducing the need for infrastructure upgrades and increasing network security. *Shed* is the dominant provider in the ***Australian Reliability and Emergency Reserve Trader*** (RERT) scheme. *Shimmy* can be used to provide short-term supply and demand balancing in the ***Frequency Control Ancillary Services*** (FCAS) market.

FD has its own technical and operational characteristics distinct from those of traditional electricity supply-side solutions (generators, network poles and wires). These FD characteristics can add value across each component of the electricity system. AEMO (2019) found that 8.5% of forecast peak demand is a reasonable contribution from FD resources.

While FD is not a drop-in replacement for traditional solutions, existing electricity supply industry rules were designed on the implicit assumption that customers would have little interest in participating actively in the market. National reform to better integrate and value FD capability for a more efficient electricity industry is a work in progress.

What and how much flexible demand is viable and untapped?

Excluding traditional load control of residential hot water, the main existing application of FD is in the RERT scheme. Over the last two years, 1422 MW of FD was contracted, delivering 5223 MWh of FD at a benefit-to-cost ratio of almost 2:1. While robust information is not available, participation of loads in the wholesale electricity market (either directly or through wholesale market exposure in retail contracts) appears limited.

A literature review on the techno-economic viability of a range of sources of FD identified a wide variety of relatively untapped, cost-effective FD technologies that could be deployed in the Australian electricity system. There are particularly large FD opportunities for technologies and businesses whose facilities and operations can provide energy storage.

Sectors and loads were ranked for suitability based on a qualitative HUFF matrix scoring framework, prioritising those FD sources that are **H**omogeneous, **U**biquitous, **F**easible (techno-economic) and **F**easible (fit well with industry practices and priorities). The analysis found that the most prospective technologies and sectors are:

- commercial buildings, with a focus on Heating, Ventilation and Air Conditioning (HVAC)
- water/agriculture, with a focus on water pumping
- food and beverage manufacturing, with a focus on refrigeration and cold storage

Preliminary modelling identified the indicative scale of untapped FD resources. The potential of FD from air-conditioning was determined by top-down disaggregation of the temperature-dependent load on electricity networks. The potential for (i) completely switching off air-conditioning (*Shed*) as an emergency measure is distinguished from (ii) reducing air conditioning by nudging thermostat settings up or down (*Shift*). The latter is more suitable for regular flexing in response to price signals. An interactive Tableau visualisation tool is available to identify the quantity, location and timing of available FD from air conditioning from both commercial and residential buildings (Air conditioning demand response atlas v1.04).

The FD potential of domestic hot water and swimming pool pumps was determined by bottom-up stock modelling of appliances in homes. Similarly, an interactive Tableau visualisation tool can be found at Residential end use demand viewer v0.1.

The potential of industrial FD was estimated by assessing the load flexibility exhibited by over 200 known market-exposed companies. This was taken as being representative of their respective industrial sector, allowing for extrapolation across each sector.

The estimated quantity of FD available in the built environment (commercial and residential) and in industrial applications is summarised below:

Sector / load	Coincident with peak demand		Coincident with minimum demand
	Emergency FD resource	Market participation FD resource	Indicative estimate only
	(MW *Shed*)	(MW *Shift*)	(MW)
Built environment			
Residential hot water	450	450	4,900
Residential swimming pool pumps	170	170	450
Residential air conditioning	6,900	970	970
Commercial HVAC	1,500	190	190
Total	**9,020**	**1,780**	**6,510**
Industrial			
Other (non-coal) mining[1]	unknown	1,044	unknown
Food, beverage & tobacco manufacturing	unknown	224	unknown
Other transport, services & storage	unknown	22	unknown
Water, sewerage & drainage services	unknown	83	unknown
Agriculture, forestry & fishing	unknown	140	unknown
Total (32% industry consumption)		**1,511**	

[1] Given the size of loads involved in this sector, it is assumed that these FD resources are already participating to the extent that they are cost-effective and able to participate.

There are several other FD resources that could also put downward pressure on consumer electricity bills, but are outside the scope of this opportunity assessment. These are largely addressed by other RACE for 2030 research programs. They include:

- standby generators (mainly diesel): ~2000 MW (but possibly included in the table above)
- batteries: 5000 MW by 2025 (AEMO)
- electric vehicle battery management
- voltage tapping: a United Energy trial suggests 450 MW of FD potential
- solar PV curtailment (for managing minimum demand or voltage excursions).

The review also excluded the substantial volume of load shaping that could be achieved through improved energy efficiency during peak times.

Comparing the scale of potential FD resources above with peak demand on the NEM (~35,000 MW), this study concludes that there is ample FD resource potential to materially contribute to the reliability and efficiency of the Australian electricity system.

How much could flexible demand be worth to Australian consumers?

We analysed the potential value of 1000 MW of 'market participating' FD resource for the purpose of estimating the value of the national FD opportunity. This target is seen as modest and hence eminently achievable. This 'last GW' resource would effectively dampen the worst impacts of infrequent but high cost events in the electricity system.

Unlike much of current FD participating in RERT (deployed only when there is an emergency), this FD would be continuously and actively engaged in various segments of the electricity system (wholesale, network, FCAS etc.) and responsive to signals (price or non-price). Thus, it would harvest revenue from multiple value streams (value-stacking).

Preliminary estimates of the system wide value of this 1000 MW of FD are tabulated below:

Source of value	Value
	(million $/year)
Wholesale market	290
Network augmentation	100
RERT	35
FCAS	30
Total	**455**

These estimates are conservative compared with several more detailed modelling studies conducted elsewhere and other sources of comparative information. Importantly, the structure of Australia's electricity system is such that the reliability needs of the industry (and concomitant benefits of FD) are poorly recognised.

Even with relatively expensive sources of FD (costing ~$155/kVA/year), it appears that 1000 MW of FD could provide around $300 million per year of bill savings for customers. Detailed research should be conducted to develop more rigorous estimates for Australia.

Why isn't more flexible demand already being dispatched?

Barriers to current adoption of FD were investigated with both a literature review and industry consultation. Consultation included nine energy-user interviews, three industry roundtables and a barriers workshop, with the latter two involving 38 industry stakeholders. The majority of barriers to FD relate to:

1. **Lack of reward for participation.** Price signals for energy users (providers of FD) are both muted (not fully cost reflective) and uncertain. This makes building a business case difficult. The structure and market design of the electricity industry have a major influence on the financial viability of FD. For example, processes and requirements for providing FD in network applications are opaque, making it difficult to simultaneously derive value from different components of the electricity industry. This makes obtaining fair and full value from FD resources difficult.
2. **End user engagement issues.** These include (i) lack of awareness of the opportunity, (ii) perceptions of risk/risk aversion, (iii) disinterest, confusion, and competing priorities for time and resources, and (iv) a lack of trust amongst energy users (providers of FD) in both the electricity industry (buyers of FD) and rules of markets where FD can participate.

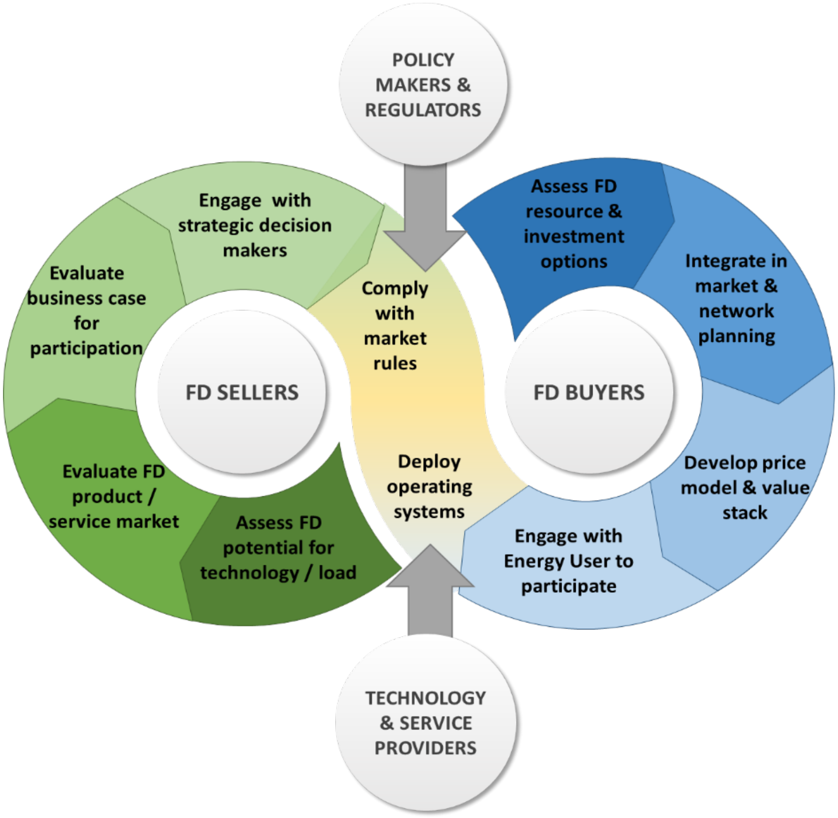
Stakeholder consultation found that these barriers overlap. The ability to convince energy users to adopt FD depends on the right economics and risk profile, which depends on workable industry structures and market design. While some energy users are gradually working through the complexity of current industry structures, most of those interviewed considered the risk of FD to far exceed any possible reward.

For many energy users the effort to even bother considering FD requires fundamental integration with business models and business strategy. The opportunity for strategic board-level attention may best be linked to 'net-zero' and renewable energy investment considerations. Successful engagement with energy users will likely follow when FD is:

1. easy and trustworthy
2. relevant, and
3. financially visible and viable.

What are the flexible demand research priority areas?

A series of research propositions were developed to address the identified barriers to FD, particularly in the context of the decision-making steps required of actors involved in trading FD (FD sellers, FD buyers, policy makers and technology providers).



The research propositions were used as stimulus for a research opportunities workshop attended by 40 experts. The workshop discussed and prioritised the propositions and invited additional ideas for research. Participants noted that many of the research propositions are interconnected (not mutually exclusive), addressing similar barriers from different perspectives. The resulting prioritised research list is outlined in the table below.

Economics and incentives	Priority
Investigate alternative tariff structure models, price signalling mechanisms, and impacts on customers. This research would inform business models for trading FD as a resource and help to understand price sensitivities.	High
Investigate options to drive FD in a way that addresses network issues (including minimum demand). This research would aim to influence regulatory support for networks to engage with FD providers and encouraging network service providers to procure FD.	High
Investigate options for appropriately valuing the contribution of FD to each component of the electricity system (wholesale, network, RERT, FCAS) and rules by which FD could be paid from multiple sources to achieve *value stacking* and higher returns for FD providers.	High
Investigate aggregator models and the potential for the electricity market to simplify FD by recognising FD as a separate market; e.g. offering something akin to a feed-in-tariff for FD resources (proven market transformation model).	Med
Review the early operation of Wholesale Demand Response mechanism.	Low

Technology

Conduct feasibility studies and technology demonstrations that prove up new FD loads (EVs, batteries, HVAC etc.) and share knowledge on implementation approaches.	High
Develop data management tools and interoperability/data standards for streamlining information exchange between electricity markets, FD providers and other actors. This would reduce transaction costs and enable new business models to scale.	Med
Examine options for improving real-time metering of supply and demand in distribution networks. This could include (but not be limited to) monitoring low-cost Internet-of-Things technologies that reduce reliance on expensive billing meters.	Med
Develop metering and verification baselining tools, guides and settlement procedures, with the aim of standardising technology and procedures to reduce transaction costs. This could include artificial intelligence techniques for more rigorous baselining.	Med
Review options for uniform technical standards.	Low

Cultural and behavioural

Study customer decision-making and participation triggers to identify factors that would increase interest among energy users and overcome internal non-financial barriers to participation.	High
Develop strategies to improve energy user awareness and understanding of FD; this would include case studies and media collateral to communicate the opportunity to energy users and step them through the journey.	High
Work with purchasing departments to better understand the contracting process and increase trust by developing standard independent terms and conditions for FD contracting.	Low
Research cultural barriers within the electricity supply industry that prevent stakeholders (retailers, networks, market operators etc.) from prioritising FD.	Low

Other

Investigate methodologies and benchmarks for demonstrating FD supply firmness, including simplified but robust FD capacity registration, compliance tools and technical requirements guidelines.	Med
Identify opportunities for creating more transparency and certainty for FD providers.	Med
Identify FD potential in specific end-use sectors through case studies and knowledge sharing. Conduct resource assessments to identify the size of the FD resource in various sectors, and target barriers and opportunities for unlocking it.	Med
Investigate costs and benefits of governance reform to encourage demand-side activity.	Low

Implementing a flexible demand research program in RACE for 2030

The priority research areas identified by stakeholders and experts in this project were categorised into three investment streams as follows:

Strategic barriers and solutions stream	Sectoral transformation pathways stream	Industry partner enablement stream
These projects take a strategic perspective, helping to identify a better fit between (i) electricity industry structures and markets, and (ii) FD characteristics and opportunities. The aim is to help create the right market structure/ framework for trading FD. Four research opportunities are prioritised for the first tranche of projects: 1. methodologies for network FD 2. pricing trials 3. technical, communications, information and data standards 4. consumer participation in FD.	This stream is open for partner consortia to submit proposals that identify a credible national pathway for increased adoption of FD in priority sectors. Proposals would address specific barriers (or opportunities) relating to the sector, with focus on new FD resources becoming realisable under *existing* market conditions. Proposals would ideally create a strong *community of practice* where energy users can learn from each other and share knowledge. Three sectors and technologies are prioritised for immediate work: 1. Commercial buildings (with a focus on HVAC) 2. Water/agriculture (with a focus on water pumping), and 3. Food and beverage manufacturing (with a focus on refrigeration and cold storage).	This stream invites individual RACE for 2030 industry partners to nominate projects that have targeted benefits and strong utilisation pathways. This may include research involving technology trials and technology feasibility studies. It could also include other project ideas that may not otherwise have been fully captured in the B4 Opportunity Assessment project.

Next steps for implementing this research program are illustrated below.

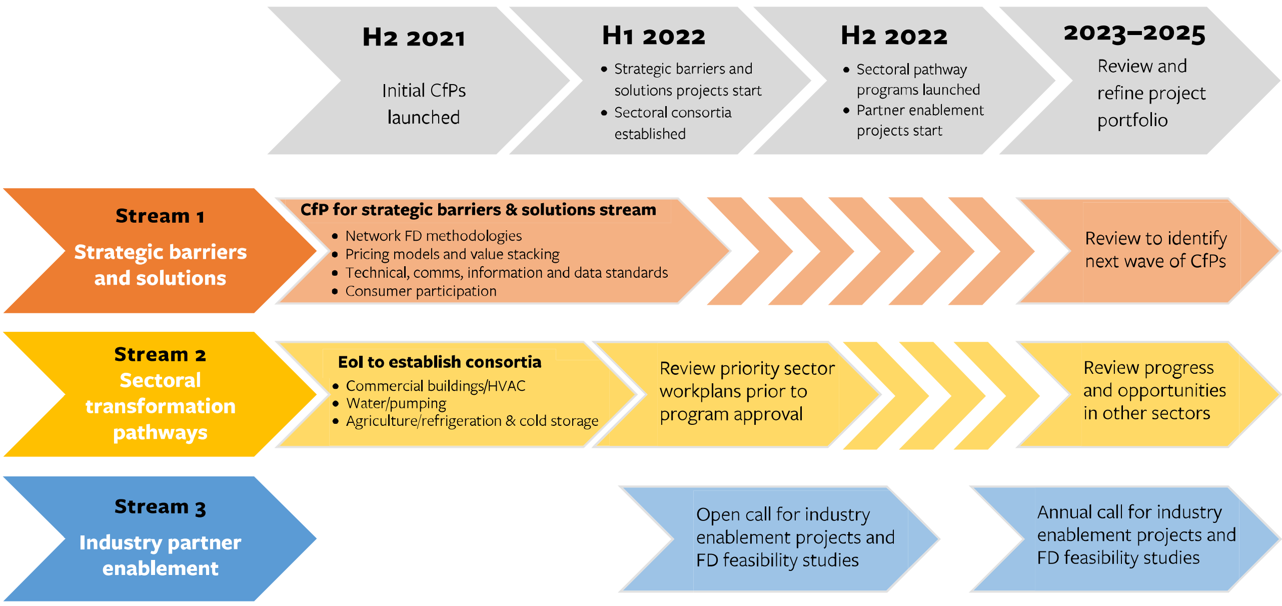


Figure. Research implementation roadmap for the RACE for 2030 research theme B4—Flexible demand and demand control.

Contents

1 Introduction

This document is the final report of an Opportunity Assessment project for the RACE for 2030 Cooperative Research Centre (Race for 2030), Research Theme B4—Flexible demand and demand control.

The goal of Research Theme B4 is to enable business to voluntarily adjust its demand for energy in response to conditions within the electricity market. Enabling businesses to take up **Flexible Demand** (FD) will give them far more control over their energy costs and better align their consumption of energy services with the value that it generates. Increased FD by businesses will also deliver benefits to the whole electricity system, including supporting faster penetration of renewables in the electricity supply system, improved grid reliability, enhanced competition, and more affordable electricity for all users.

Unlocking the potential for flexible energy demand will require energy market reform, more cost reflective pricing of electricity, development of hardware and software solutions, development of service models and improvements in the energy literacy of businesses.[1]

The Opportunity Assessment was a short-term (six month) investigation to guide where RACE for 2030 should focus its efforts for the B4 theme over the next few years. It provides a framework for developing and tracking research activities over the whole life of RACE for 2030.

Supporting documents produced for this project are listed in Table 1. These documents have been used as the primary source material for this final report and are referenced throughout. For each document the sections of this report that summarise or discuss the contents are also listed in the table.

RACE for 2030 can be contacted to discuss possible access to any of the documents not directly published by RACE for 2030.

1 racefor2030.com.au/race-for-business/ (RACE for business website)

Table 1. Supporting documents.

Reference	Title	Final report section(s)
D0	Contract: 20.B4.0132 Opportunity Assessment: B4—Flexible demand and demand control technology and development	A.2
D1	CSIRO, *RACE for 2030 Opportunity Assessment Project Theme B4: Flexible demand and demand control technology & development Detailed Project Plan*	B
D1a	CSIRO, *Inception Workshop Presentation*	A.2
D2	RMIT, *Techno-Economic Review of Flexible Demand in Australia Discussion*	2.2, 4.1, 5.5
D3	CSIRO, *Flexible Demand Barriers and Behavioural Factors Literature Review Discussion Paper*	2.1
D4	CSIRO, *RACE for 2030 B4 Opportunities Assessment Technical—potential and barriers literature review discussion paper summaries*	2
D5	CSIRO, *Flexible Demand Policy, Pricing and Incentives Literature Review Discussion Paper*	2.3, 5, 5.1
D6	RACE for 2030, CSIRO, RMIT, *State of the Art Research*	2.2.6, 2.2.2, 4.3.1, 4.4.1, 5.1
D7	CSIRO, '*Combined Results*' PowerPoint presentation, B4 Flexible Demand 'Barriers' Workshop	5.6
D8	A2EP, *Feedback from Energy End Users Barriers & Opportunities*	3, 5.5.1
D9	CSIRO, A2EP, RMIT, EEC, RACE for 2030, *Key Barriers to Flexible Load Management*	2.1, 5.6
D10	Energetics, *Overview of the demand response market in Australia*	4.1
D11	Energetics, *Valuation Methodologies of Demand Response*	4.2, 5.1
D12	RMIT, *Industrial Flexible Demand in the Australian Energy System: Resource Potential*	4.3, 5.1
D12a	CSIRO, *Built-Environment Flexible-Demand Resource Assessment Discussion*	4.4, 5.5
D14	CSIRO, *B4 Flexible Demand 'Barriers and Opportunities' Workshop: Summary*	5.6
D16	UTS, *Research Roadmap*	6
D17	*Flexible Demand B4, Opportunity Assessment Final Report* (Draft)	
D18	*Flexible Demand B4, Opportunity Assessment Final Report*	1–6, A–C

2 Literature review summaries

2.1 Barriers and behavioural factors

Document D3, produced for this project, is a literature review on FD barriers and behavioural factors. Key identified barriers from the literature are listed in Figure 1.

Economics and incentives

- Muted price signals
  - fixed price retail tariffs
  - no market for network services
- Uncertain business case
  - split incentives
  - uncertain price, uncertain baseline
  - duration of contract and/or incentive
- Upfront cost
  - transaction/customer acquisition costs
  - equipment/technology costs
- Lack of access to capital

Cultural & behavioural

- Electricity industry inertia
- End-user disinterest and lack of trust
  - awareness
  - perceived risk
  - complexity and competing priorities
- Lack of capability and capacity
- Purchasing processes and incentives
  - contracting
  - individual site versus portfolio perspective

Technology

- Lack or poor quality of metering data
- Difficulty with information management
- IT, cyber-security and interoperability issues
- The industrial process isn't able to flex

Other

- Arduous regulatory requirements to participate
- Achieving scale and firmness at specific locations
- Operational control of assets when value stacking
- Market transparency/lack of competition

Figure 1. Summary of key barriers to flexible demand.

The literature review provided the background to an industry workshop on Flexible Demand Barriers and Opportunities, held on 16 March 2021. The outcomes of the workshop and literature review were combined into Document D9.

The literature review, and consultation with various stakeholders across the Australian energy sector, found that a majority of barriers to FD can be summarised as:

1. **Lack of reward for participation**. Price signals for energy users (providers of FD) are both muted (not fully cost reflective) and uncertain. This makes it difficult to build a business case. Of particular note is the difficulty for providers of demand flexibility to access value from network applications and in bundling incentives to obtain full value from demand flexibility.
2. **End user engagement issues**. These include (i) lack of awareness of the opportunity, (ii) perceptions of risk/risk aversion, (iii) disinterest, confusion, and competing priorities for time and resources, and (iv) a lack of trust amongst energy users (providers of FD) in both the electricity industry (buyers of FD) and rules of markets where FD can participate.

2.1.1 Flexible demand stakeholders

Section 2.3 of D3 identifies relevant stakeholder roles as including:

- electricity account customers, electricity supply end-users
- electricity retailers, intermediaries (aggregators), and wholesalers
- energy management advisors
- electricity generators
- distribution and transmission network service providers
- market operators and system operators. (While this is the same organisation (the Australian Energy Market Operator, AEMO) in the two main Australian electricity markets—the National Electricity Market (NEM) and Wholesale Electricity Market (WEM)—there is emerging potential for distinct roles for distribution system operation and distribution market operation).

Role-specific barriers to FD are identified and analysed in Section 4 of D3. Barriers to FD that are specific to customer market segments are covered in Section 5. The market segments considered are industrial and large customers, commercial and medium customers, and residential and small customers.

2.1.2 Common barriers

Barriers to FD that are common to all roles and market segments (D3, Section 7) do not affect all roles and market segments to the same extent or in the same way (see Table 5 of D9). They include the following:

- **Technical and technology barriers:** More (and improved) metering is required for network visibility, verification, and financial settlement. Additional communications connectivity, decision and control integration, and automation is required to integrate end-user devices with markets for firm FD capacity. A high proportion of loads with the capability to flex is needed to service the various applications of FD in the electricity industry.
- **Economic barriers:** Every stakeholder called for more certainty of favourable returns to justify investment in demand flexibility. More clarity is also required on how to determine demand response baselines. For high capital cost interventions access to the required financial capital may be a barrier.
- **Market structure and regulatory barriers:** Many markets (network savings, emergency reserve, distribution operation, non-FCAS ancillary services) that would support demand flexibility are either absent or lack transparency, and so potential buyers of FD lack strong incentives to realise that potential. What is required is more clarity on the role and priorities of regulators and better coordination of the activities of regulatory bodies. Existing regulations including technical standards tend to favour historical and incumbent technical solutions. Various energy policy targets could support demand flexibility. More clarity on the registration of FD capacity in markets would improve market transparency and thereby commercial certainty of returns to investment in FD.
- **Cultural barriers:** Significant cultural biases exist in the electricity industry. These are not necessarily well recognised by regulators, who are working on the assumption that market behaviour is economically rational. Inertia or status quo bias can affect customers, retailers, networks, market operators, and regulators. Institutional structures by definition impose some degree of inertia. Furthermore, the relationships and interactions among stakeholders will tend to become somewhat institutionalised as a way to manage coordination complexity. Cultural and institutional inertia are mutually reinforcing.
- For all **customers** (potential providers of FD), including residential customers, accessible savings may not be material relative to overall financial considerations. A range of behavioural factors impact on

customer perceptions and willingness to explore demand flexibility, including long-evolved, persistent patterns of behaviour. Choice and information overload rather than lack of awareness can be a barrier in some circumstances.

2.1.3 Industrial and commercial energy users: Barriers and behaviours

Barriers to FD that are particularly relevant for industrial and commercial energy users are discussed in Sections 5.1 and 5.2 of D3. For **industrial customers** commercial terms for electricity supply that are offered may not be sufficiently cost reflective. Hence the value of FD passed through to the customer may be a small proportion of the value created. Load flexing in the industry sector can impact on production, and many customers are constrained by the limitations of legacy capital equipment and operational logistics that were designed for least cost rather than operational flexibility to enable agile business strategies. Because industrial processes are relatively heterogenous, FD solutions are more commonly bespoke. Many industrial customers are not aware of the financial savings that can be achieved through demand responsiveness and may overestimate the disruptiveness to business operations or overlook flexibility opportunities beyond production processes.

In the **commercial sector** smaller energy savings from smaller site loads makes the business case more difficult. Behavioural factors, misaligned incentives, and perceived risks of disruption are also significant barriers. Although the end-use processes in the commercial sector may be more homogenous than in industry, lack of technical standards and interoperability issues impact on the scalability of FD-enabling technology. Government building portfolios could influence the market but must overcome internal purchasing and other barriers associated with decision making.

2.1.4 Residential energy users: Barriers and behaviours

Barriers for residential and small energy users are discussed in Section 5.4 of D3. The **residential sector** may require lifestyle typologies and demographics to segment and attract customers; individual customers will tend to be too small to justify developing bespoke FD options or suitable energy supply tariffs, or to justify deploying costly technologies. Changing consumption patterns is difficult without automation or changes to lifestyles over the longer term. Financial benefits, trust, perceived risk and perceived control, complexity of energy decisions, and effort are important factors for consumers.

2.1.5 Electricity supply industry participants: Barriers and behaviours

Section 4 of D3 addresses FD barriers to other energy industry stakeholders. **Network service providers** lack a supportive regulatory framework to unlock potential savings offered by FD solutions. **Retailers and Intermediaries (aggregators)** face high transaction costs, end-user lack of interest, and time scales for FD investment returns that exceed typical energy supply contracts. Intermediaries also face competition from existing electricity supply companies with established customer relationships and would prefer a level playing field with other actors in the market.

2.2 Techno-economic assessment of load flexing opportunities

Document D2 produced for this project is a literature review on techno-economic assessments of load flexing opportunities in Australia. Documents D2 and D3 were summarised into document D4.[2] These documents introduce a taxonomy of four categories of FD capability, including *shift*, *shed*, *shimmy*, and *shape*, as distinguished by their time scales. *Shift* moves demand on hourly timescales (suitable for arbitrage and renewables exploitation). *Shed* is foregoing electricity consumption altogether, typically infrequently and at short notice (suitable for system peaks, contingencies, and reserve). *Shape* is moving demand on a consistent or permanent basis. It is always implemented as either *shape as shift* (regularly moving load across periods) or *shape as shed* (a regular reduction of load). *Shimmy* is changing demand on frequency control ancillary services time scales.

2.2.1 Attractive technologies for flexible demand

Energy end use technologies that offer attractive sources of FD are discussed in Section 3 of D2 (and detailed in Table 4 of van der Laar, Vreuls and Kofod[3]). They include heating, ventilation and cooling (HVAC), hot water systems, pool pumps, other domestic appliances, electric vehicles, electrical energy storage, thermal energy storage, industrial processes, embedded generation, material or inventory storage, and conservation voltage reduction.

An aggregation of some quantitative estimates of FD potential from Sections 3 and 5 of D2 are shown in Table 2 and Table 3 below. They summarise the estimates of technical or economic potential by technology and FD capability.

Key statistics of the NEM and WEM are provided in Table 3 for comparison. Across the three sectors—industrial, commercial and residential—the technical potential of FD is estimated at some 10–30% of peak demand but only at a relatively coarse disaggregation; more detailed information is incomplete. By FD capability, very limited information was found on the quantitative potential of shape and shift capability and likely cost.

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2 Alstone, J. Potter, M. A. Piette, P. Schwartz, M. A. Berger, Laurel N. Dunn, S. J. Smith, M. D. Sohn, A. Aghajanzadeh, S. Stensson, J. Szinai, T. Walter, L. McKenzie, L. Lavin, B. Schneiderman, A. Mileva, E. Cutter, A. Olson, J. Bode, A. Ciccone, and A. Jain, 2017, 'Final Report on Phase 2 Results 2025 California Demand Response Potential Study,' Lawrence Berkeley National Laboratory, Energy and Environmental Economics; Inc.

3 E. van der Laar, H. Vreuls, and C. Kofod, 'INDEEP Analysis Report,' International Energy Agency, 2004.

Table 2. Flexible demand technical potential estimates by technology (Section 3 of D2).

Technology	Cost		Quantity	Est. % of peak (%)
Heating, ventilation & cooling	$120–140 per initial activation	$10–30 per device $25/MWh in UK	Commercial: total max. demand relative	1.1–4.0
			Residential: total max. demand relative	5.0–15.3
Pool pumps		$75 per pool pump	13% of population 1.1 million pool pumps ~1.1 kW 1.2 GW / (31 + 4 GW)	3.4
Other domestic appliances	$25 year running	$31 per appliance	48 MW Qld 430 W per household midnight, 65 W per household peak c.f. 10 GW Qld peak	0.48
Electric vehicles		Parity with ICE by 2030	40–100 kWh per vehicle, >50% market share of vehicles (2050)	
Electrical energy storage	w/o PV	$276–874/kW-year $524–761/MWh capacity		
	with PV	$500–650/kW-year $320–410/MWh capacity		
Thermal energy storage			15–20% peak refrigeration shift 30% shed	
Industrial processes		$200–1000/MWh energy $140–700/MWh in UK	1.7–3.8 GW	4.7–10.5
Embedded generation		$45–60/MWh PV (non-flex) >$300/MWh diesel (flex)	2 GW available (Energy Synapse)	6.4
Material or inventory storage			Data not available	
Conservation voltage reduction			30 MW United Energy, 660,000 customers 45 W/customer 10 million customers NEM Scaled to NEM: est. 450 MW	1.45
Total			% of peak	10.8–29.8

Table 3. Flexible demand technical potential by capability (Section 5 of D2).

	Quantity	% (relative basis described below)
NEM	Installed cap: 51 GW, Max demand: 31 GW Consumption: 192 TWh	
WEM	Installed cap: 5.8 GW, Max Demand: 4.0 GW Consumption: 18 TWh	
Shape		Cost: 2–30% (TOU savings on small sample) 70% increase to 80% decrease on larger sample
Shift	7.7 (2021) to 16.4(2025) GWh in Victoria C&I 44.3 TWh consumption in 2020/21	Electricity consumption relative 0.017–0.037%
	5.3 GWh per day Consumption: 260 TWh pa (California)	Electricity consumption relative 0.74%
Shed	42% of industrial peak 3.1–3.8 GW	Maximum demand relative 8.8–10.8% of 35 GW
	total: 4.3 GW industrial: 0.86 GW residential: 1.2 GW	Maximum demand relative total: 13.8% industrial: 2.8% residential: 3.9%
FCAS	~100–300 MW in each of eight FCAS markets ~0.6 GW lower, ~0.9 GW raise	Energy consumption relative Lower: 2.7% Raise: 4.1%

2.2.2 Flexible demand potential: International comparisons

Document D6 further summarises literature reviews that survey FD potential in the United States and Europe. The literature for the United States is also covered in D2. Europe has load reduction potential of 93 GW (on average over time) as well as load increase potential of 247 GW (the increase potential being largely from residential loads). In most countries investigated, the average load reduction potential over time is between 10% and 20% of that country's peak demand. Of the load shedding resources (again on average over time) by end-use sector the largest are estimated to be from steel (9%), refrigeration (8%), pulp and paper (7%), and cement (6%). The potential for load shedding from HVAC in the commercial and residential sectors comprises more than 20% of the anticipated total shed resource. Within the commercial sector in Europe significant potential was identified in 'cross-sectoral' processes (e.g. HVAC, electric water heating, and refrigeration) that do not directly interfere with production processes and could be aggregated easily due to their homogenous distribution. For this reason, the highest practical potential was found to be in restaurants (28% of total practical potential) and food retail (25%), noting that practical potential was defined as 'companies that show willingness to conduct DR measures.'

For the provision of shimmying services, the key likely industrial loads and sectors are:

- electrolysis in aluminium production (though only for load shedding due to high utilisation)
- steel melt shops (though limited to half an hour)
- cement grinding mills (as demonstrated in South Africa)
- refrigeration using thermal inertia, especially when Auto-DR is in place
- electrochemical processes (e.g. chloralkaline, which is well-documented in the literature)
- temperature adjustment in data centres, noting their high reliability requirements

2.2.3 Cost to energy users of providing flexible demand

While cost information for Australian industries is limited, an investigation in the UK into industrial process demand-side participation estimated activation costs for a number of different industrial sectors (Figure 2). Cost data was provided originally in 2016 GBP and converted to 2016 AUD at 1 GBP = 1.825 AUD. Quantity data was provided originally in MW and converted to percentage of 2019 peak demand at 48,230 MW, down from 53,485 MW in 2016.[4]

[4] AER State of the Energy Market 2020

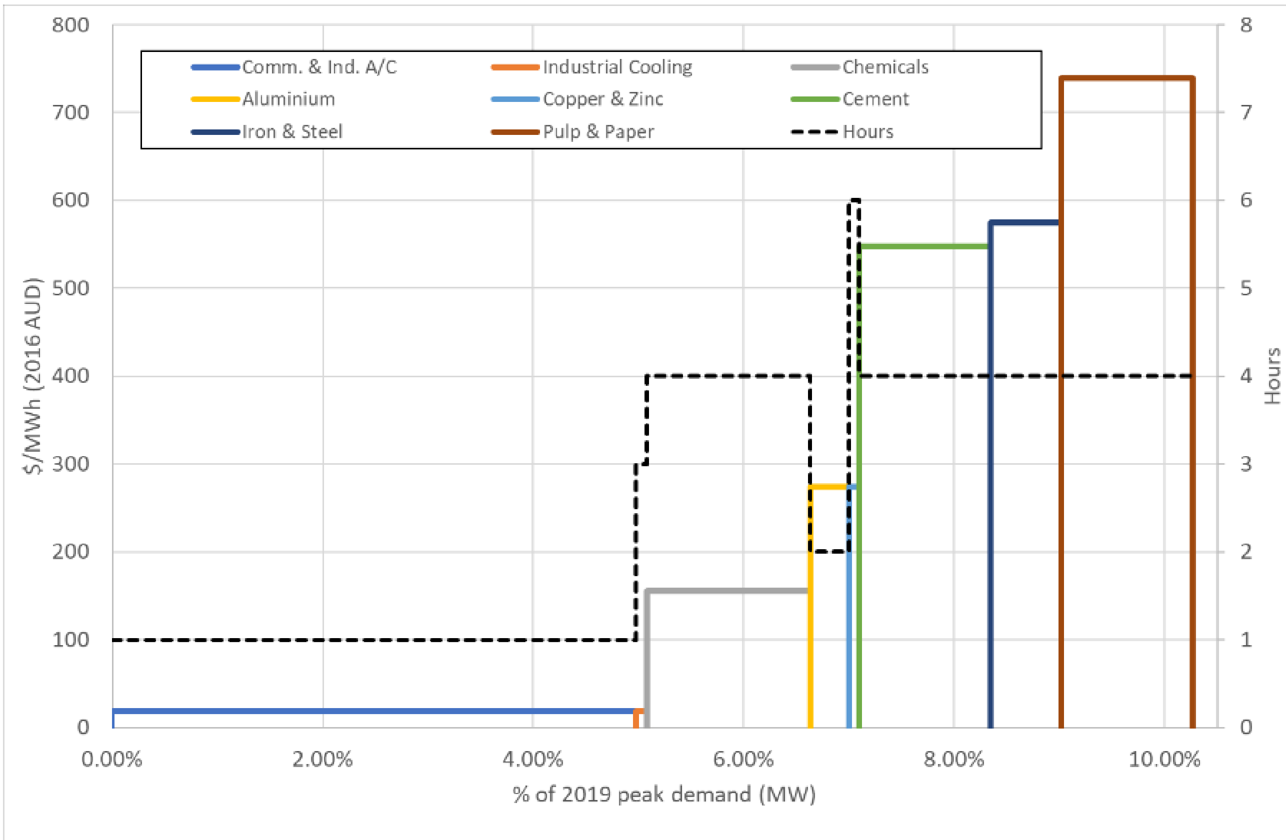

Figure 2. Estimate of industrial and commercial turn-down demand technical potential in the UK (using data sourced from Figure 19 of Charles Rivers Associates, 2017[5]).

2.2.4 Flexible demand value to customer: The business model canvas

In order to consider FD deployment opportunities from the energy customer perspective D6 applied the business model canvas, a widely accepted framework for understanding value propositions, to five industrial and three commercial case studies from the international literature that align to priority sectors previously identified. The business model canvas framework entails three dimensions: value proposition, value creation and delivery, and value capture (Table 4).

Table 4. Business canvas model framework.

Dimensions	Elements
Value proposition	Product-service Customer segments Customer relationship
Value creation and delivery	Key resources Key activities Distribution channels Key partners
Value capture	Revenue model Cost structure

5 Charles River Associates (2017). An assessment of the economic value of demand-side participation in the Balancing Mechanism and an evaluation of options to improve access.

The case studies are as follows:

- Industrial
  - Cement production: This accounts for 1.5% of industrial electricity demand in the UK (and a similar proportion in Australia). Silos and stone stores that do not interfere with production could result in reductions of an estimated 4.3% in costs and 4% in carbon equivalent greenhouse emissions.
  - A thermal energy storage (TES) system (glycol chiller and buffer tank) in food manufacturing (cost savings of 2–3.3% of total bill).
  - Complex processes (anaerobic sludge digestion) and side-processes (CHP) in wastewater treatment plants—which account for approximately 1% of Australia's total electricity demand—that can drive network peaks and account for 25–40% of operating costs.
  - Irrigation pumping, which is generally the largest consumer of electricity in agriculture.
  - Stockpiling and delayed processes in paper manufacturing, of which there are 679 businesses in Australia.
- Commercial
  - HVAC, CHP, equipment, chillers and pumps, and home appliances on university campuses in the UK with a well-established FD market (cost savings 3–5% of bill plus incentive revenue of 7–10%), and Romania with an emerging FD market (5–10% cost savings).
  - Heat pumps and equipment in French offices in a well-established FD market (cost savings 2–4% of bill plus incentive revenue of 5–8% of bill).
  - Chillers, trigeneration, and food carts in an Italian hospital, which has limited access to FD markets through solely implicit (pricing) schemes (5–10% cost savings).

Considering FD deployment options with respect to the business model canvas framework provides a useful confirmation that the proposed FD option provides value not only to the grid but also to the customer. Table 5 of D6 provides a demonstration of how to explicitly identify how these dimensions apply for the selected case studies and hence guidance on conducting similar checks on other FD prospects. Where the case studies included indication of potential quantitative financial value to the FD provider, the range is 5–12% of the electricity bill.

2.2.5 Technology and market platforms for enablement

Section 4 of D2 discusses the current technological development status of various FD enabling technologies. An overview is provided in Table 5 below (Table 5 of D4).

Document D10, also produced for this project, describes existing enabling technologies in Section 4.1. In addition to end use technologies mentioned above (on-site generation, thermal storage—including chilled water and ice demand, and hot water), enabling technologies such as demand-response-enabled devices (DRED) for other appliances, and ripple control for hot water, are also described.

Table 5. Flexible demand enabling technology development status.

Technology	Status
Smart Meters	100% penetration in Victoria with limited capabilities; limited rollout elsewhere
Building Energy Management Systems	Commercial deployment at small scale; technology improving
Digital User Interfaces	Commercial deployment at small scale; technology improving
Automated Demand Response	Demonstrated
Virtual Power Plants	Australian residential trials
Artificial Intelligence, Machine Learning, Block Chain	Few demonstrated applications; some academic applications

Section 4.2 of D10 discusses additional emerging enabling technologies. These include EnPot™, which is designed to increase operational flexibility in aluminium smelting, voltage reduction, battery storage, virtual power plants (VPP), and data science and smart controls. Data science and smart controls could facilitate improved load and price forecasting, load scheduling and control by customers or aggregators, design of incentive and rewards, and segmentation of customers and/or loads.

2.2.6 Industry 4.0 solutions to enable flexible demand

Document D6 observes that some technical and transaction cost barriers to FD could be overcome by improved data and data analytics and greater autonomy for loads to flex themselves. These solutions can be described as **Industry 4.0**—the fourth industrial revolution, the digital transformation of industry.

There are four key Industry 4.0 technology functions relevant to the electricity industry:

1. **Data capture**: Internet of Things (IoT, including new sensors)
2. **Data management**: Linking diverse data, time-series data management, naming conventions and digital machine to machine interfaces, behind-the-meter aggregation (e.g. Virtual Net Metering Infrastructure [NMI], peer-to-peer trading via blockchain)
3. **Data analysis**: Applications of artificial intelligence (AI) such as forecasting or production schedule design or pricing scheme design
4. **Decision and action**: Energy and building management systems (EMS/BMS), Distributed Energy Resource Management Systems (DERMS, which are largely commercial), digital twins of loads, sites and customers, Automated Demand Response (ADR), and transactive control

IoT solutions create a communication platform within a local network of devices—e.g. loads, generators, sensors—that can enable energy management applications for monitoring and control. The key design trade-offs that need to be considered are range, power consumption, interoperability, bandwidth, and cost.

Aggregating devices, sites and/or customers behind the meter may enhance the deployment of FD. There are Australian case studies of businesses that have aggregated loads and generators (e.g. wastewater treatment, refrigeration, onsite generation) under a 'Virtual NMI' to maximise FD benefits such as by 'soaking up' more onsite solar. Similar solutions are technically possible for multiple business sites or different customers (e.g. peer-to-peer trading through blockchain) but are hampered by existing barriers such as market regulations.

Building and energy management systems are already commercially available. However, much of the information is inaccessible and not linked with energy markets and other business systems necessary to orchestrate FD. Thus, more fruitful research areas appear to be in the linking of data utilising IoT approaches with the integrated management of data among energy industry stakeholders' information systems, enabling of AI for system-level optimisation and supervisory-level control of devices after data capture and analysis (e.g. ADR, market platforms).

Digital twins are "a virtual representation of rare or real-life assets such as services, products, or machines with the models."[6] They allow real-time data to be integrated, analysed, and manipulated prior to real-world implementation (e.g. alternative process schedules can be tested on the digital twin to maximise FD benefit). They can be used to forecast the results of control action, thus allowing system optimisation.

Artificial intelligence and machine learning have been applied to many fields including the energy sector particularly for more accurate load and price forecasting and/or improved (including more granular) control of loads. Four categories of AI approach include:

1. **Reinforcement learning** (a subset of machine learning) for dynamic data-driven control (e.g. ADR) of aggregated assets without detailed knowledge of each asset. This is more applicable to smaller, distributed, and often heterogeneous residential and commercial loads.
2. **Multi-agent systems** have been used to design pricing and non-price incentives for similar groups of disaggregated entities.
3. **Nature-inspired algorithms** have also been used to design pricing and non-price incentives as well as for task scheduling.
4. **Artificial Neural Network** are also used for FD applications, especially in forecasting.

There is also a significant gap in research focused on the commercial and industrial (C&I) sector as most research has been conducted on residential customers. AI learning methods for developing energy management automation rules (as opposed to bespoke, customer-specific design methods) are more suited to smaller loads such as residential and commercial customers (because they are lower cost and can take advantage of economies of scale), provided they are reasonably homogenous.

Much AI research for the electricity sector relies on Automated Demand Response, which is still far from becoming reality. Without automation, the full potential of FD is limited by human intervention response times, precluding applications such as *shimmy* FD. Most examples of ADR have been in either HVAC or lighting, so there are options for applications to other end uses in pilots or demonstrations.

There are also opportunities to remotely control and coordinate a disaggregated suite of DER via automated market transactions, which requires *transactive control* solutions. While there are many versions of transactive control that have been implemented, many commercial demonstrations of transactive control use simpler, non-iterative market clearing. Emerging research is investigating iterative options, particularly for EV smart charging. A particular pilot demonstration in Australia is the 2017 development of the decentralised energy exchange (deX).

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6 A. E. Onile, R. Machlev, E. Petlenkov, Y. Levron, and J. Belikov, 'Uses of the digital twins concept for energy services, intelligent recommendation systems, and demand side management: A review,' *Energy Reports,* vol. 7, pp. 997–1015, 2021, doi: 10.1016/j.egyr.2021.01.090.

2.3 Sources of value: Pricing, policies, and incentives

2.3.1 Existing sources of value

The key system benefits of FD are provided in Section 1 of D5 and summarised below.

1. Accommodating generation and demand variability at slower time scales (hours)
2. Accommodating generation and demand variability at fast time scales (minutes, seconds, and faster)
3. Accommodating transmission and distribution network limitations, including:
4. capacity limits, which change on capital investment time scales
5. congestion, losses, and quality of service at all time scales, and
6. Accommodating outage emergencies (generation or network) fast time scales.

Table 6 summarises the potential for each type of FD capability to contribute to each value stream.

Table 6. Contribution of flexible demand capability to value stream.

	Wholesale Market & Grid- scale Renewable Support	Network Investment Savings	Contingency & Emergency Reserve	Distribution Network Support	Frequency Control Ancillary Services
Shift	H	MH	L	ML	NA
Shape	MH	MH	L	ML	NA
Shed	ML	H	H	L	ML (Lower only)
Shimmy	NA	NA	NA	H	H

Key: H = high, MH = moderately high, ML = moderately low, L = low, NA = not applicable.

2.3.2 Tariffs and retail offerings

Document D5 is a literature review on pricing, policies, and government incentive programs for FD. Section 2.1 of D5 describes price-based programs, and Section 2.2 covers non-price incentive programs. Table 7 below summarises a range of customer incentive types for over two-hundred (200) demand-side management programs analysed in 2004 for the International Energy Agency.[7] Direct financial rewards such as rebates and cash inducements cover the majority of programs. A smaller proportion of programs are based on tariff-based (or price-based) incentives. Other incentives include subsidised improvements to customer energy efficiency and gifts or merchandise. The United States Federal Energy Regulatory Commission reviews national energy efficiency programs annually[8] and recognises six categories of categories of price-based programs and eight categories of FD programs described as (non-price) 'incentive-based' (see Table 8). Depending on how these pricing and non-price incentive programs are designed, the financial risk and energy availability risk are

7 See reference in footnote 3.

8 For example: Federal Energy Regulatory Commission, '2020 Assessment of Demand Response and Advanced Metering: Pursuant to Energy Policy Act of 2005 section 1252(e)(3),' 2020.

variously shared between the FD service provider and purchasing counterparty. By contrast, in programs involving subsidies and non-financial inducements, the risk of non-delivery is typically borne by the purchaser of the FD service.

Table 7. Price and non-Price Incentives for demand side management programs.

Category	Incentive	Proportion of programs (%)
Tariffs and pricing	Tariff reduction	9
Financial rewards	Rebates and cash awards	52
Other subsidies, discounts, or free of charge improvements	Financing, loans and leasing	13
	Bulk purchasing	9
	Direct installation	7
Non-financial inducements	Gifts and merchandise	4
	Other	14

Table 8. Price-based and non-price incentive-based energy efficiency programs.

Time-varying energy price-based programs	Non-price incentive-based programs
• Time-of-use pricing • Peak time rebate • Critical peak pricing with control • Critical peak pricing • System peak response transmission tariff • Real-time pricing	• Demand bidding and buyback • Direct load control • Interruptible load • Load as capacity resource • Regulation service • Non-spinning reserves • Spinning reserves • Emergency demand response

Where the price for supplied energy provides the encouragement for discretionary customer deployment of demand flexibility, those prices must be dynamic (time-varying). Dynamic prices are suitable for incentivising demand flexibility to balance supply and demand on hourly time scales and to reduce peak aggregate (or increase minimum) demand on the network. However, they are not suitable for encouraging faster time scale energy balance (frequency control ancillary services) or emergency demand response.

2.3.3 Business models that maximise value

Several documents in the literature review (D5: Sections 2.2, 2.2.1, 2.2.3) systematically investigate numerous mechanisms, schemes, or programs designed to promote energy efficiency, demand-side management, or energy-use behaviour change. Many such schemes investigated were not found to have publicly available information on costs and impacts that was sufficient to perform accurate cost-benefit analysis. However, for those schemes where cost-benefit analysis was performed, the majority showed very attractive returns: One study of energy efficiency programs found 73 of 122 programs had costs that were no more than 30% of benefits. Unfortunately, from the studies reviewed there were few strong recommendations for successfully cost-effective programs or business models. One common finding is that larger schemes tend to me more cost effective than smaller ones, mainly due to fixed costs being spread over a larger number of customers.

For price-based interventions there is strong evidence that dynamic prices encourage a larger demand response, with a larger relative difference between peak and off-peak prices. Consequently, critical peak pricing, which provides a typically larger price premium, encourages a larger response than time-of-use pricing. Of dynamic pricing schemes, those found to be most popular in a survey of United States industrial customers were also those pricing schemes (like critical peak pricing) with a larger relative difference between peak and off-peak prices and shorter peak price periods. Installing enabling technologies has been shown to increase responsiveness to dynamic pricing as devices such as monitoring, displays, and automatic load control devices can increase both the value of FD and provider rewards. The preference for pricing schemes with a larger dynamic range among US industrial customers appears contrary to observations in the household sector, which suggest that given a choice, (Australian) residential consumers generally prefer a flat energy tariff over dynamic tariffs. However, moderately dynamic tariffs (that is, not including real time pricing) are preferred by some households and are almost as popular as a flat tariff if accompanied by an automation device or a money-back guarantee of a lower overall bill.

One reference recommended that intervention schemes should include at least one feature from each of the following three categories: i) offering rewards, ii) providing information, and iii) employing social influence. Another reference observed that numerous schemes combined subsidies with other features such as competitive tender, formal savings agreements, or education and training.

2.3.4 Government policy options

The structure of the energy industry and design of energy markets constrain the type of energy tariffs and other incentives that energy suppliers can commercially-viably offer to FD providers (Section 3 of D5). Australia has markets and other payment mechanisms that reward provision of some of the benefit streams delivered by FD, including wholesale electricity markets with generators and retailers independent of network operators, the wholesale demand response mechanism, frequency control ancillary services markets, and payments for emergency reserves.

However, there is further potential for market regulatory reform to facilitate additional FD deployment. Although there are regulatory mechanisms such as the Demand Management Incentive Scheme (DMIS) to reward network operators for demand management schemes that deliver network infrastructure investment savings, these incentives may be underutilised by network operators and are not directly accessible by other market participants. As natural monopolies, network owners are not subject to strong competitive pressures to pass through incentives for FD to providers. This is reflected in network tariff pricing structures accessible to customers that do not strongly encourage deployment of, and investment in, demand flexibility although there is increasing encouragement from the regulator for Australian networks to develop tariffs that are reflective of long run marginal costs of capacity investment. However, as yet there are limited incentives to recognise the full potential contribution of FD to the operational performance of low voltage distribution networks through management of network losses, by control of reactive power flows, regulation of voltage magnitudes, and suppression of harmonics.

Greater certainty for providers of demand flexibility could result from incentives that also reward capacity (availability) rather than deployment only—as through the Reserve Capacity Mechanism of the Wholesale Electricity Market (WEM) in Western Australia, and as is permitted by regulations—but not necessarily at the discretion of providers—through the Reliability and Emergency Reserve Trader (RERT) scheme. Market regulations could be investigated to confirm that retailers and intermediaries engaging in demand flexibility are not overly disadvantaged compared to network operators, and that emerging intermediary market participants are not overly disadvantaged compared to incumbent retailers with existing customer relationships. Market regulations could be investigated to confirm they do not present unnecessary barriers to the formation of FD trading markets. Market regulations could more explicitly assign responsibility for collation and storage of, and access to, energy market relevant data and information.

Section 4 of D5 reviews government policy instruments to encourage FD. Beyond energy market regulatory policy, the spectrum of other policy instruments includes mandatory directives, mandatory provision of information, facilitation, and other information provision initiatives. One report[9] reviewed develops and proposes more than two dozen measures for demand-side management and assesses how well the measures address each of more than twenty policy and program barriers. It provides tables that can be used to look up suitable measures to address them provided that the barriers for a specific context are known (see Table 9 and Table 10). Other recommendations to encourage FD from the literature (and the Barriers Workshop; see D14, D7, D9) are classified in D5 based on location, the policy spectrum, and the target value stream.

Many of these recommendations aim to reward FD providers for contributing to network investment savings. Most other measures that promote FD generally but do not explicitly emphasise any particular benefit stream also support network investment savings. Many recommendations are for market regulatory reform, pricing reform, and the provision of information (both mandatory and voluntary), with the aim of enhancing transparency in energy market-related decision making and enhancing competition in energy markets. Recommendations from a European Union report on FD emphasise regulation—energy market legislation, codes governing networks, and market rules—with some reliance on co-ordination, information dissemination, and further studies. A significant proportion of recommendations from that report are intended to promote the development of FD markets. A modest number of recommendations identified in D5 are to encourage the role of intermediaries, mostly through regulatory reform. Fewer recommendations aim to improve incentives for FD for ancillary services, distribution network performance, and emergency generation capacity.

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9 D. Crossley, M. Maloney, and G. Watt, Developing Mechanisms for Promoting Demand-side Management and Energy Efficiency in Changing Electricity Businesses, International Energy Agency, 2000.

Table 9. Policy barrier to mechanism class map from Table 5 of Crossley *et al.* 2000 (Footnote 9).

	Policy barrier identifier	Integrated resource planning	Mandatory EE sourcing	EE licence conditions for electricity businesses	DSM and EE as alternatives to expansion	Revenue regulation	Public benefits charge for EE	Financing of EE by electricity businesses	Energy performance contracting	Cooperative procurement (EE appliances)	Competitive sourcing of demand-side resources	Competitive sourcing of energy services	Communicating pricing & other information for EE	Energy performance labelling	Developing an EE brand	Demand-side bidding in competitive markets	Taxes on energy	Tax exemptions and incentives for EE	Consumption info on customers' electricity bills	Developing the ESCO industry	Aggregating electricity purchasers to achieve EE	Voluntary agreements for EE	Sustainable EE training schemes for practitioners	Energy centres	Creating entrepreneurial energy organisations	Promotion of EE by industry associations
		C3	C1	C2	C4	C5	F1	F2	M8	M7	M10	M9	M4	M5	M6	M11	M1	M2	M3	S4	S6	S7	S1	S2	S3	S5
No EE valuation paradigm	10	*	*	*	*		*		*		*	*		*	*	*	*	*		*	*					
No EE opportunity awareness by policy makers	6	*	*	*	*		*	*	*	*	*	*	*	*	*	*		*		*	*	*	*	*	*	*
No EE expertise (in transition)	13	*	*	*	*		*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*
Restricted access to customer information	7		*		*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Lack of market transformation experience	12	*			*		*		*	*	*	*		*	*	*				*	*	*	*	*	*	
Customer instability	9		*					*	*	*			*		*					*	*					
Inadequate competition	8		*						*		*	*			*	*				*	*					
Split incentives to energy providers	3		*	*		*		*			*								*		*	*				*
Separation of energy policy process	11	*		*	*		*			*				*			*	*								
Short-term perspective	2	*			*				*	*				*	*		*	*	*							
Pricing	4															*	*		*							
Utility price setting process	14	*	*			*																				
Excess capacity	1				*	*																				
Import tariffs and duties	5																									

Table 10. Program barrier to mechanism class map from Table 6 of Crossley *et al.* 2000 (Footnote 9).

	Program barrier identifier	Integrated resource planning	Mandatory EE sourcing	EE licence conditions for electricity businesses	DSM and EE as alternatives to network expansion	Revenue regulation	Public benefits charge for EE	Financing of EE by electricity businesses	Energy performance contracting	Cooperative procurement (EE appliances/ equipment)	Competitive sourcing of demand-side resources	Competitive sourcing of energy services	Communicating pricing and other information for EE	Energy performance labelling	Developing an EE brand	Demand-side bidding in competitive markets	Taxes on energy	Tax exemptions and incentives for energy efficiency	Consumption info on customers' electricity bills	Developing the ESCO industry	Aggregating electricity purchasers to achieve EE	Voluntary agreements for EE	Sustainable EE training schemes for practitioners	Energy centres	Creating entrepreneurial energy organisations	Promotion of EE by industry associations
		C3	C1	C2	C4	C5	F1	F2	M8	M7	M10	M9	M4	M5	M6	M11	M1	M2	M3	S4	S6	S7	S1	S2	S3	S5
Lack of information to end users	2	*		*	*		*	*	*	*	*	*	*	*	*	*			*	*	*	*	*	*	*	*
Product/service unavailability	7		*	*	*		*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*
Lack of experience of impacts	5						*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*
Information/search costs	3								*	*		*	*	*	*				*	*	*	*	*	*	*	*
Lack EE investment habits or custom	4								*			*	*	*	*				*	*				*	*	
Financial barriers	6							*	*	*			*					*		*						
Inseparability of product features	8																			*						
Organisational (institutional) barriers	9																			*		*				
Low cost of energy to end users	1																									
Split (misplaced) incentives	10																									

3 Industry attitudes and barriers

3.1 Stakeholder survey findings

Interview summaries from 18 people about FD across a range of sectors and organisations appear in Document D8. Sectors investigated include basic chemical-, and chemical, polymer and rubber product manufacturing, food and beverage manufacturing, pulp, paper and printing, basic non-ferrous metals, mining, agriculture, water and sewerage services, built environment, resource recovery and recycling, and gas production. Energy users without energy 'batteries' in their facilities (e.g. water storage, cold storage, batteries) were consistently found to consider the risk of load flexing to far exceed any possible reward.

Opportunities may exist to exploit on-site power generation in a more integrated way to support the grid and to further increase the amount of FD from thermal (cold) storage at many sites. The water and sewerage services sector appears most progressed in their use of FD, with other high-use energy sectors such as paper and pulp, aluminium, built environment, and agricultural irrigators investing in load shifting trials.

3.1.1 Challenges: Industry-identified barriers

While each sector, organisation, and operations were unique, some common themes and barriers emerged. These include:

1. Production assets are usually not designed to be agile, and businesses are often locked into integrated, highly complex multivariable asset and production plans that impact the full supply chain. This makes short term response to demand markets structurally difficult to accommodate.
2. Access to FD enabling technology is variable. Some businesses have the relevant technology (if not necessarily to scale) but it is not being implemented (e.g. not a strategic priority), while for others the enabling technology doesn't exist and seems distant from viability.
3. The energy market is seen as a key barrier to further deployment of FD. There is a lack of transparency and trust in networks and retailers. The spot market is highly volatile, the value proposition requires aggregation of capacity from multiple FD providers to become viable, behind-the-meter generation is disincentivised, and it is commonly perceived by end users that flexible generation and network investment would deliver better outcomes than end user driven FD.
4. Internal behaviour and culture change are challenging but possible if there is a business case. There is a general lack of recognition of the time and resources required to learn about FD and to perform feasibility studies.
5. Organisations are increasingly targeting net zero carbon emissions or 100 per cent renewable inputs and this will provide more encouragement for FD than the imperatives of the wholesale market alone.
6. There is concern, even amongst strong advocates of FD, that batteries will diminish the FD market (risking stranded assets for FD investments).

For many production processes, energy is the primary input and far less interchangeable than other inputs. This results in a tolerance for high energy prices (unless there is a low margin environment) and a low appetite to expose either production or production assets to risk. For many businesses, the low risk tolerance is embedded in decision-making processes and culture. Stakeholders were clear that it was not strategically feasible for key processes that use large quantities of electricity (e.g. aluminium; paper and pulp; glass; mining;

LNG) to shift demand—except for infrequent reliability events—without making large capital investments and/or implementing complex production process chemistry.

3.1.2 Industry identified opportunities: Conditions that could activate flexible demand

For many businesses, engagement in FD does not require a strong business case but rather integration into the business model. Current business models are largely based on energy that is reliable, continually available, and affordable in proportion to its value to production.

Table 11. Load-flexing barriers, opportunities and 'readiness' for interviewed industrial sectors from D12.

Industrial end-user	Sector	Primary barriers	Key flexible demand opportunities	Load-flex readiness
Agriculture	Agriculture, forestry & fishing	Tariff options; Scheduling constraints; Weather conditions	Water pumping for irrigation; Cold stores; Lots of unexplored sites/ customers	High
Water supply, sewerage & drainage services	Water supply, sewerage & drainage services	Tariff options; Metering & monitoring; Human resource limitations	Integrating weather/renewable output forecasts; Exploiting negative pricing; Automation	High
Aluminium	Basic non-ferrous metals	Risk to smelters; Long-term financial certainty	Determining value of smelters to the grid; Improving potline thermal insulation	Medium
Beverages	Food, beverage & tobacco	Production constraints; Operational awareness; Asset suitability	Flexing cold stores; Thermal batteries to buffer refrigeration; Electrifying gas boilers	Medium
Pulp & Paper	Pulp, paper & printing	Long shutdown times; Energy costs low priority; Financial certainty	Automation and risk mitigation; Optimisation/flexing of cogeneration	Medium
Gas Extraction	Oil & gas extraction	Production constraints; Regulatory standards	Flexing gas pipeline pressures; Varying/modulating compressor outputs	Medium
Bauxite & Alumina	Other Mining/basic non-ferrous metals	Process chemistry; Production constraints Asset suitability	Electrification of digestion process using MVR; Optimisation/ flexing of cogeneration	Low
Chemicals	Basic chemicals & chemical products	Risk of damage to electrolysis membranes; Long shutdown times	Limited—new tariff structures could reveal more.	Low
Minerals Processing	Other mining/non-metallic minerals	Production constraints; Metering & monitoring; Operational awareness	Flexing electrowinning process; Use of embedded generation	Low

Barriers do not appear to stakeholders all at the same time during the implementation journey but act as sequential *gates*. Organisations and sectors that have had some success in implementing FD projects commonly have (in sequential order): an electricity market and grid that incentivises and supports the desired behaviour, project alignment to the business model and strategy, available technology that is effective, scalable, affordable and does not risk production, an aware culture and supportive internal behaviour, automation that reduces workload, and FD opportunities to leverage/ add value and minimise risk.

Several specific technical opportunities identified for further consideration include:

- scaling up existing successes—exploiting inherent storage (e.g. water utilities and cold stores), adding low cost thermal storage to large refrigeration/chiller plants, and increasing on-site energy generation
- aggregation to achieve economies of scale

- following macro trends—adoption of 100% renewables and circular economy principles, energy storage in gas pipelines, electrified compression and energy recovery, off grid or behind-the-meter/micro-grid electricity and energy generation, and
- improving data for forecasting production cost and benefit. Often sites can feasibly reduce load, but as this requires effort and planning the rewards must be reliable.

In summary, while there was some appetite for further uptake, further industry assessment of the viability of FD is critical to align the technology to:

- The organisational purpose, structure, business model, and strategic priorities
- The business planning and capital expenditure assessment processes that competitively assess investment risks and opportunities, and
- Project planning, which often requires a small amount of initial funding for scoping studies to assess viability and business value, before investing in new projects.

Further detail of these key themes across the conversations and by sector can be found in D8. Additional feedback from industry representative stakeholders can be found in Section 4 of D12, with results summarised in Table 11 above.

3.2 Case studies

A small number of case studies were investigated to better understand individual participants.

3.2.1 Sydney Water—FD provider

Representatives from the business development team of Sydney Water (SW) were interviewed by RMIT to gain insights into the success of their demand management program. For SW engaging in FD is seen as a strong, low-cost opportunity to generate new revenue streams from existing assets.

Developing a demand resource

The initial stages of SW's demand response program focussed on curtailing load at waste water treatment plants (WWTP). The principle flexible load assets at these sites include water pumps, blowers, and aerators. These loads can be turned down or off to reduce electricity consumption, or where there are modular systems, a subset of loads can be left running (e.g. running one blower of four).

By manipulating these assets at their six largest WWTP sites (out of 29 total), SW is able to provide 4–5 MW of load-shed capacity. The six sites represent the 'low-hanging fruit' of flexible capability but a larger reserve could be made available if further WWTP sites were engaged. The demand response for these assets is operated manually by on-site managers who are signalled by SW's operations centre when an event occurs. As these sites have been used to provide response for several years already there is significant process maturity and operator confidence.

At the end of 2020 SW was looking to extend its portfolio of DR assets by commencing DR at potable water pumping stations. These sites are traditionally operated during the night to capitalise on off-peak TOU power tariffs, pumping water up to storage tanks which gravity feed end users based on water demand. Incorporating approximately 20 of these sites into their demand response portfolio resulted in an additional 5 MW of load-shed capacity, bringing total capacity to 10 MW. This capacity increases further to 13–14 MW on weekends, resulting from reduced water service constraints, and SW expects this weekend response to reach as much as

18 MW of load-shed. Compared to an average total portfolio demand of 40 MW, this represents load-shed capabilities varying from 25–45% of total load.

There is also a large number of diesel generators within SW's asset portfolio which are being investigated as an option to provide additional response. However, there are concerns that increasing the utilisation of these generators would reduce their reliability during contingency events such as blackouts. Other options considered include BTM solar and battery systems; these systems would be predominantly aimed at increasing energy security, with provision of FD as a supplementary component of the business case.

Contracting and operational specifics

The provision of demand response by SW is contracted through a third-party aggregator distinct from their energy retailer (Origin). Response activations are signalled by the aggregator on an event-by-event basis, with 10am notifications on the day of the event. Often SW is given 2–3 days advanced warning if there are forecast weather events (i.e. heatwaves) or planned grid maintenance, which gives the on-site operational staff ample time to prepare for events in a way that limits the impact to critical services.

Activations of SW response are typically called upon for a duration of two hours and this length of response is 'very comfortable' to accommodate. It is possible for response to be provided continuously for up to 4 hours before impacts to services would become significant and this defines the maximum length of their contracted response activation. The level of response is highly dependable, with delivered load-shed consistently falling within a 10% margin of contracted response. The only significant exterior influence on response provision is heavy rainfall, during which SW's service constraints are much tighter due to the resultant higher volumes of water to process.

Revenue and costs

Through its provision of load-shed response via an aggregator SW receives around $1 million of annual revenue, although this amount is quite variable. When compared to its ~$20 million annual energy bill, this represents 5% of total annual energy costs. The cost of implementing the response program is less than 10% of the annual revenue, with most costs associated with initial enablement such as training operational staff and programming control strategies. The program is now essentially self-sustaining and incurs minimal running costs; these relate to overtime payments or rescheduling, with the potential need to draw electricity at a higher tariff rate. Overall, participating in demand response is seen as a very profitable endeavour for SW and a way for it to amplify the value of its assets.

Future opportunities

Energy is provided to SW by Origin on fixed price tariffs: peak, shoulder, and off-peak. As a result, there is no inherent financial incentive to flex loads beyond the relative price difference of the fixed tariffs and this incentive is not dynamic in the way it reflects electricity market conditions. SW currently has no wholesale spot-market exposed sites in its portfolio, although there have been internal discussions regarding the opportunities and risks presented by this option. Interest was expressed in the opportunity to exploit negative pricing through spot-price exposure, indicating that case studies of successful implementation would be highly valuable to support the pursuit of such opportunities.

SW is also looking to increase its revenue through participation in different response markets, in particular the frequency control ancillary services (FCAS) market. SW expects that participating in FCAS could potentially increase revenue by up to 50%, although the barriers to engaging in this market are more significant. These barriers include the requirement for increased automation to provide the response times necessary (seconds to minutes) and the current cultural hesitation to remove human oversight from response operation. There are also concerns that FCAS as a revenue stream will dissolve in coming years as market participation reaches saturation, particularly from new battery and VPP projects.

3.2.2 Energy Queensland—Network FD

A representative from Energy Queensland's (EQ) Demand & Energy Management team was interviewed to gain insights into the success of their demand management program. For EQ, engaging in FD is seen as a relatively low-cost opportunity to support the management of network assets.

EQ has broad-based residential demand response programs (PeakSmart air-conditioning and hot water load control) and a targeted commercial demand response program (Cashback Rewards).

The Cashback Rewards Program is targeted at constrained network areas. Consequently, there is a relatively small number of contracted FD providers under this program. Many of these FD providers have gensets that can be switched on to provide flexible demand at very competitive rates ($20 to $100/kVA). This is particularly financially attractive when much of the cost is borne by someone else for other purposes (e.g. standby gensets) and the network only pays an incremental portion of the cost of enablement.

The Queensland Government is also hosting a large-scale, network-connected battery trial aimed at supporting the state's continual uptake of renewable energy; 40 MWh of battery storage is being installed across five locations in Queensland.

The PeakSmart Air-conditioning Program has connected over 136,000 home or small business air-conditioners, providing up to 150 MW of diversified load under control during peak demand events. The air-conditioning controls use a Demand Response Enabling Device (DRED) as part of an Australian Standard for Demand Response in Appliances (AS/NZ 4755.3.1). The DRED can cap energy consumption of an air conditioning appliance to run at 75% or 50% of capacity. Note, 50% capacity can be called without householders noticing/reacting, thus providing a dispatchable resource.

The DREDs are activated via audio frequency load-control (AFLC) and randomly grouped into 1 of 5 channels. These can be staggered at the start and end of the FD event to prevent sudden large loss or gain of load. The DRED is supplied by EQ, installed by industry providers, and can attract a $50 incentive per device (paid by EQ) claimed upon application. A one-off cash incentive of either $200 or $400 is provided to the home/business owner after which the air-conditioner is available to be managed by Energex/Ergon during peak demand events. Participants can leave the program by opting out and disabling the DRED device, although that must be done by an electrician or air-conditioning installer at the homeowner's expense. EQ attempts to then recover the removed device.

Customers and/or installers must confirm installation to receive the one-off cash incentive. This is done to ensure that the device is installed. A small number of installations are spot-audited to ensure adequate level of compliance.

For the 2021–22 financial year Energex intends to operate its broad-based program, which includes the PeakSmart Program, at $244/kVA or lower. This includes DRED procurement, cashback reward payments, resourcing, marketing, and other linked functions that help facilitate this demand management program. The Ergon Broad-based Program intends to operate at $/kVA in the 2021/22 financial year and is marginally more expensive as this market is less mature. These program operating costs have reduced greatly since the program/s inception (and now steadied) as more experience has been gained.

EQ's targeted programs include various Regulatory Investment Test for Distribution (RIT-D) or Request for Proposals (RFP) programs where demand management solutions are proposed and compared to the cost of deferral of capital augmentation projects. Energex RIT-D consultations can be found here and Ergon RIT-D consultations can be found here. In 2021/22 these projects are forecast to operate at $79/kVA for Energex and at $98/kVA for Ergon.

In comparison, the broad-based nature of the program means that the cost of the FD capacity in constrained areas is more difficult to directly link to deferral of capital projects. Attempting to deliver a more geographically-targeted PeakSmart program through channel partners (air-conditioning sales stores) was problematic as some customers were eligible for the program and others were not.

The AFLC DREDs involve one-way communication. Therefore, it is not possible to know whether the controller has responded in a given home, whether the air-conditioner was operating (load cannot be reduced from an air-conditioner that is not switched on), or how much FD was delivered from a given home. However, metering at substation level provides an aggregated view of achieved load reduction (where sufficient PeakSmart air-conditioners are connected to that substation). Significant trials were conducted prior to program implementation to give a good idea of average deemed demand reductions from each PeakSmart-enabled air-conditioner.

There have only been between 2 and 6 dispatch events by Energex over the last 5 years. Each event was 1–3 hours in duration and occurred somewhere between 3pm and 7:30pm. To date, the Ergon Network has run demand response events for PeakSmart air-conditioners for testing purposes only.

During the recent (May 2021) Callide C Power Station failure, the PeakSmart Program was not used to provide emergency load shedding capability because it occurred in late autumn when air-conditioners are predominantly not in operation. Instead, hot water load control was utilised during this event.

In future it would be advantageous to activate air-conditioners through two-way HEMs/IoT communication. New business models and tariff arrangements for managing air-conditioning FD could also be explored and another potential future research topic could be to investigate the role of air-conditioning demand to address minimum demand issues.

3.2.3 Queensland University—Battery FD

The University of Queensland reported on the performance of a 1100 kW/2150 kWh Tesla Powerpack battery system over the first three months following its installation. At a cost of $2.05m installed, the system reported a net return of almost $74,000 in the first quarter of 2020, which was 20% over the business case forecast.

The system is operated automatically by an in-house developed software control system that is hosted in the cloud. The software integrates measurement and actuation devices in the field with information such as weather and electricity market forecasts from third-party sources, a model-based decision engine, and data storage enables analysis and reporting. The full case study report is available from the University of Queensland.

Financial performance

The battery installation was intended to derive financial value from four benefit streams: i) wholesale market arbitrage, ii) wholesale price exposure risk management, iii) network peak demand charges, and iv) frequency control ancillary services (FCAS). During the reporting period the battery system delivered close to or more than the expected value for three of the four benefit streams. However, the control strategy for network peak demand reduction was not implemented in time to operate effectively within the reporting period. Consequently, the operating strategy deployed for the other benefit streams resulted in a minor increase ($2357) in network demand charges.

This is the first battery system installed by the University of Queensland for primarily commercial purposes following on from experience gained from research systems such as zinc bromide batteries since 2011, a 600 kW/750 kWh lithium-ion system in 2016, and a 150 kW/ 600 kWh vanadium redox system more recently.

The cost of the 1100 kW battery itself was $1.7m, with the remaining funds covering the balance of plant, installation, and commissioning. The majority of the financial return was from FCAS—$46,000 from 12 FCAS events over three months. The average duration of participation in each event was less than four minutes and the average power supplied 250 kW. The financial return for FCAS was more than the budgeted amount of $30,000 as there were several high price events during January due to a combination of natural disasters affecting the National Electricity Market. Of the rated 2150 kWh of energy storage (8.6%), 185 kWh had to be reserved for maintenance of FCAS capability rather than exploited for arbitrage.

Financial returns attributed to arbitrage in the wholesale market were $8500, which was slightly less than forecast. Volumetric underperformance was almost compensated by an arbitrage spread of $107/MWh, which was better than expected average and achieved by average prices of $43/MWh for purchase and $150/MWh for sales. This compares to an average wholesale price over the reporting period of $54/MWh. Variable costs due to round-trip storage losses (15.5%), battery degradation, and other considerations such as ancillary charges were estimated at only $4.30/MWh. Arbitrage operated on an approximately daily cycle, resulting in the battery operating on a capacity factor (combined charging and discharging) of 8.3%. The volumetric underperformance was partly due to a fault with the supplied battery—resulting in only 90% capacity being available—as well as the impacts of communications failures, both of which have since been addressed.

The battery system also partially substituted for an energy futures financial hedging mechanism that the University of Queensland would otherwise have purchased to manage the risks of its pre-existing exposure to the wholesale market. Without the battery system, the University would have purchased a financial instrument at a fixed cost in advance at approximately $30,000 to insure against high prices (greater than $300/MWh). The battery storage system provides a physical hedge rather than a financial contract to mitigate the risk of high electricity wholesale prices and at a lower cost. This aspect of the battery system function was attributed with $19,400 net financial value compared to a forecast of $15,500. This value is primarily due to savings in upfront costs of the financial instrument, with the difference made up in a combination of foregone payout by the financial contract for high price periods and periods of time where the battery system stored energy was insufficient to provide the intended physical hedge. In total the battery system provided only 58% of the volume of energy that would have been required for the physical hedge to completely replace the financial instrument.

Operational performance

The project team encountered and resolved several setbacks during the initial implementation phase. For example, one of the ten battery packs that comprised the full system was identified as faulty during commissioning, resulting in only 90% of the design capacity of the battery being available until a replacement component was acquired.

Temporary loss of communications occurred more frequently than anticipated. Due to network connection technical requirements the originally designed protocol in the case of this contingency was to open the circuit breakers until they could be reset manually, resulting in several outages of duration greater than one day over weekend periods. This was resolved by re-engineering a less risk-averse response to an interruption of communications, namely going on standby and suspending exports until communications were restored. Nevertheless, subsequently at least one instance of temporary loss of communication resulted in missing a significant arbitrage opportunity.

The decision algorithm used for operational decisions is model predictive control, which is reliant on price forecasts and sensitive to price forecasting errors. This has been addressed by developing a modified (hybrid) decision rule that is less adversely affected by forecasting uncertainties.

Future plans include developing site consumption forecasts to further improve management of peak demand by the battery system decision engine. There are also plans to both improve forecasts of market prices and to develop decision rules that better account for the uncertainties in imperfect price forecasts. Finally, the recent addition of 3.5m litres of thermal energy storage to the University of Queensland's portfolio of FD assets will provide additional opportunities for customer-side energy management and will require integration of the battery system within the broader operational context.

4 Flexible demand resource assessment

4.1 Data on existing flexible demand availability

Section 3.2 of D10 collates known quantitative data on demand response (a narrower category than flexible demand) by program or market (Table 12). There is limited information about the size of the existing shift demand response deployed either in the wholesale market (either through wholesale exposed customers or through retailers and intermediaries) or in network demand response programs. However, the NSW peak reduction scheme is projected to reduce peak demand in 2030 by 7.5% on the 2019 peak and to lower average wholesale prices by $4.30/MWh between 2022 and 2030. Reserve capacity is a little more transparent, with 1422 MW of (shed) demand response contracted in the RERT and 5223 MWh delivered over two years. In the WEM capacity market only 1.4% is supplied by demand response at about 13.4% of the cost per MW. The quantity of (shimmy) FD participating in the FCAS market is about 12% of the total market scale.

Section 4.3 of D10 considers existing demand response capacity by sector but finds that there is limited quantitative information, as shown in Table 13 and Table 17.

Table 13 presents a qualitative indication of the *amount* of future flexible demand potential whereas Table 17 indicates *readiness* for a slightly different sectoral disaggregation. Of the sectors assessed in the two tables, the Water, Pulp and Paper, and Chemicals Production sectors are the most directly comparable sectors across the tables.

Table 12. Existing flexible demand availability.

Value stream	Scheme	Demand response scale	Notes
Wholesale and retail	Retailer demand response	Lack of transparency makes it difficult to establish FD capacity	
	Wholesale exposed customers	Little available information on FD currently deployed	
	Wholesale demand response mechanism	AEMC has not modelled the size and impact	
Network	NSW peak demand reduction scheme (2030 projected)	61 MW average (0.76% of 2019 avg.) 1029 MW peak (7.5% on 2019 peak)	Also projected to lower average wholesale prices by $4.30/MWh over 2022–2030, in addition to network investment benefits
	Network FD programs.	No data has been identified regarding the total FD potential	
Reserve	NEM Reliability & Emergency Reserve Trader (CY2019 and CY2020)	5223 MWh delivered over two years at $13,930/MWh	1422 MW FD total contracted
	WEM capacity market (FY2019/2020)	66 MW at $16,990/MW	4822 MW of generation capacity at $126,684 MW
FCAS	FCAS market (CY2020)	180 MW	Total market scale 1500 MW each raise and lower

Table 13. Identified deployed demand response quantity by industry sector.

Sector	Known existing DR	FD potential
Mining	68 MW	Reasonable
Food and beverage	Unknown	Medium
Pulp and paper	60 MW	Good
Basic ferrous metals	69 MW	Good
Non-ferrous metals	800 MW	Medium
Building materials	Unknown	Medium
Water	Unknown	Medium
Chemicals production		Poor
Plastics packaging		Medium
Commercial cold storage		Medium

4.2 Flexible demand valuation methodologies

Document D11 is an international (United States, United Kingdom, and Australia) literature review on forward looking (i.e. ex-ante) flexible demand evaluation methodologies. Taking a long-run perspective, these methodologies are intended to shed light on the economic value of flexible demand and to understand its quantity and role in an efficient, optimised electricity system.

Five challenges of ex-ante FD valuation encountered by system planners, market analysts, researchers, and policy makers include:

1. methods for quantification of value of individual FD elements
2. the perspectives of multiple participants along the supply chain (candidate flexible demand providers; intermediaries; whole-of-system planners)
3. the diverse set of potential revenue streams for flexible demand
4. treatment of uncertainty as flexible demand impacts the inherent volatility of electricity markets, and
5. assessment of FD reliability benefits more relevant in an energy-only market with increasing generation from low marginal cost variable renewables.

The value created by FD is notoriously challenging to quantify. Intricacies like market design (i.e. energy only versus capacity market), price elasticity and volatility, spatial and temporal variation (grid connection location, timing of dispatchability, duration, frequency, notification period) all highlight the diverse and complex nature of value quantification. Any successful method must further make assumptions or derive proxies to appropriately account for this complexity when assessing participation likelihood and impact.

One evaluation approach that addresses the perspective of multiple participants is the Californian Standard Practice Manual (SPM), which quantifies the value of energy efficiency programs as cost reductions. This methodology is composed primarily of four cost-effectiveness tests each characterising one perspective.

The Participant Cost Test (PCT) (1) addresses the question of whether flexible demand providers will benefit from a specific program over the investment economic lifetime. The Ratepayer Impact Measure Test (RIM) (2) assesses the impact on electricity prices or rates and other indirect consequences for non-participants (i.e. reduced wholesale market volatility beneficially impacting non-participating end users although negatively affecting peaking generators). Demand response opportunities are often realised by an aggregator or, more broadly, a program administrator (retailer; network service provider; government agency) and participation depends on the viability of the adopted business model. This is assessed through the Program Administrator Cost Test (PAC) (3). Demand response can also have considerable impacts on the total costs and benefits along the whole electricity supply chain. The SPM measures this through its Total Resource Cost Test (TRC) (4), defined as "the net costs of a demand-side management program as a resource option based on the total costs of the program, including both the participants' and utility's costs." It is one of the more comprehensive standards for cost benefit analysis that does not consider externalities. A more detailed overview of the four tests is found in Appendix A of D11.

A fifth perspective—not addressed by the SPM—is Market Performance Impact (5). This is the ability of demand response to mitigate the potential for generators to exert power in wholesale electricity markets, for example, through strategic capacity withholding. The Total Resource Cost Test notably does not take into consideration any increase in competition due to FD although it does consider the impact of lower electricity prices along the supply chain (i.e. beneficial to end-users but detrimental to some generators that would otherwise benefit from high market clearing prices).

FD resources provide both portfolio revenue and risk management value in situations involving low probability/high consequence events. This increases the importance of properly treating uncertainty and considering the reliability impacts of flexible demand and suggests considering a range of scenarios in any FD valuation method.

Four valuation methodologies used by researchers and modellers are capable of answering some of the main challenges: (i) the Avoided Costs (AC) Method, (ii) Integrated Resource Planning (IRP), (iii) Market Simulation Models (MSMs), and (iv) Real Options Valuation (ROV) methodology. No single methodology currently meets all five challenges, suggesting the use of a mix of methods and tools rather than a single approach. While the estimation of flexible demand quantitative potential in other assessment processes can be of technical potential or economic potential, the four valuation methodologies, which all evaluate likely participation, consider only market potential.

The Avoided Cost approach is the dominant methodology used to date in FD program performance studies. It measures the expected delivered value to independent grid operators, network service providers or load serving entities of demand response programs designed and implemented by them. The approach is typically limited in the scope of benefits considered and reflects market conditions over a short time period. It consequently tends to report the lowest valuations of flexible demand.

Integrated Resource Planning considers the benefits of flexible demand within a broader resource portfolio context using whole-of-system simulation models which consider weather patterns, fuel prices, and other forecasting variables. It has its infancy in the cost-benefit analyses carried out by vertically integrated electric utilities and independent market operators.

Additional complexity results from consideration of real time pricing (e.g. critical peak pricing; interruptible rates) and wholesale FD market participation, which are heavily determined by price elasticity. The Market Simulation Model approach estimates price benefits of FD implementation by simulating an organised wholesale market and quantifying the dynamic feedback loop between market price and FD participation that depends on demand price elasticity.

The methods mentioned above evaluate investment opportunities by applying Discounted Cash Flow valuation, which unfortunately does not fully quantify the impact of risks and uncertainties. Real options analysis offers a more nuanced approach by quantitatively accounting for investment risks and the value of ‘having the option to participate.’ It attempts to captures the value of the FD investment option that would be created for future demand flexibility (e.g. technology enablement and capacity building) rather than solely current cash flows.

These four valuation methods and their advantages and limitations are described in more detail in D11, along with a summary of the limitations. Table 14 summarises the purpose of each method and how it deals with the identified challenges.

Table 15 assesses how well each method addresses the challenges. D11 concludes that future research on flexible demand valuation should focus on the methodological gap between long term integration resource planning methods which assist capacity planning and shorter-term economic market dispatch simulations that assess FD at a trading interval resolution and the impact of price elasticity and operational flexibility.

There is a significant gap in knowledge about the characteristics of FD technical potential, especially in Australian electricity markets. A bottom-up assessment of technical potential should be undertaken before the economic and market potential assessments can be verified via a long-term expansion planning and market dispatch models. Collecting the necessary data to value the technical, economic, and market potentials would be time-intensive and involve significant resources.

Table 14. Summary of characteristics of four demand response evaluation methodologies.

	Avoided cost	Integrated resource planning	Market simulation model	Real options valuation
Purpose	Perspective of an individual participant	Least cost whole-of-system planning	Wholesale market impacts	Recognise benefits of choice flexibility to mitigate impacts of uncertainty
FD value	Costs had the FD program not occurred	Compare least cost plan with and without FD	Impact on market prices	Evaluation of right, but not obligation, to exercise FD
Value stack	Limited consideration of FD competition or mutual exclusivity in practice	Supply curves can be incorporated but are analysed separately	Models FD and generation competition	Complicated
Uncertainty	Typically not included; extension potential	Scenario analysis, probabilistic assessment	Monte Carlo probabilistic	Geometric Brownian Motion
Reliability valuation method	Value of Customer Reliability (VCR)	Value of Lost Load (VOLL); Expected UnServed Energy (USE); Loss of Load Probability (LOLP)	Stress test scenarios	Black Scholes equation
Limitations	Uncertainty missing; Reliability missing; Demand Elasticity missing; Whole-of-system assessment missing	Data intensive; Top-down approach to representing FD—FD analysed separately; Fast Time scales missing; Individual participant perspectives missing	Requires integration with capacity investment planning models	Complex mathematical formulation; Data, assumptions requirements; Communication challenges

Table 15. Valuation challenges addressed by methods (Figure 2 of D11).

	Avoided cost	Integrated resource planning	Market simulation model	Real options valuation
Multiple perspectives	✓	~	~	~
Value quantification	✓	~	~	✓
Multiple revenue streams	×	✓	✓	×
Uncertainty	×	✓	✓	✓
Reliability benefits	×	✓	✓	×

4.3 Industrial resource assessment

Section 3.1 of D10 provides a top-down estimate of the total realistic FD potential in the NEM across all sectors as a percentage of system demand. It estimates it as around 10% or 3 GW. Of this, ~0.9 GW would come from industrial energy use.

4.3.1 Potential resource by industrial sector

Table 6 of D12 (and here Table 17) provides quantitative estimates of the economic potential of industrial demand response by sector. This was achieved by determining the amount of flexible demand provided by over 200 known market-exposed companies and extrapolating across the industrial sector they represent.

Document D6 applies a systematic semi-qualitative HUFF method to assess the potential of various sector and technology combinations for providing flexible demand, evaluating each of four aspects: Homogeneity (which facilitates replication of solution within the sector), Ubiquity (which addresses the quantitative scale of the potential resource), and Feasibility, both techno-economic and practical. Assessment of Australian industry sectors results are shown in Table 16 where the higher numbered scores represent more prospective opportunities (note that the in-principle range of the score is 9 to 144, see D6 for further details).

Table 16. The HUFF Matrix for the industrial sector.

	Refrigeration	Heat pumps	Irrigation	Thermal storage	Processes	Material storage	Embedded generation	Electrical storage
Iron & steel		56		56	70		70	63
Pulp & paper		64		64	80	64	80	72
Cold stores	72	72		72			90	81
Water utilities		72		72	90	72	90	81
Agriculture	80	80	90	80	100		100	90
Mining		64		64	80		80	72
Chemicals	56	56		56	70		70	63
Cement		64		64	80	64	80	72
Manufacturing	80	80		80	100		100	90
Aluminium		56		56	70	56	70	63

Table 17. Summary of potential estimates by industrial subsector.

Sector	Consumption (% industry total)	ClimateWorks load-shed potential estimates (MW)		Market response analysis load-shed potential estimates (MW)				End-user load-flexing readiness
		Bill savings		Market price				
		5–15%	20–30%	$2,000/MWh		$10,000/MWh		
				2019	2020	2019	2020	
Basic non-ferrous metals	28.2	1028	1059	–	–	–	–	Medium
Other (non-coal) mining	18.7	80	610	761	652	1047	1040	Low
Oil and gas extraction	13.0	–	–	–	–	–	–	Medium
Coal mining	5.8	–	436	–	–	–	–	–
Food, beverages, and tobacco	5.5	140	212	288	18	433	14	Medium
Basic chemical and chemical, polymer, & rubber product manufacturing	3.5	–	33	–	–	–	–	Low
Pulp, paper, and printing	3.4	8	273	–	–	–	–	Medium
Iron and steel	3.4	–	–	–	–	–	–	–
Water supply, sewerage, & drainage services	3.3	155	155	56	41	98	67	High
Other transport, services, and storage	2.7	–	–	(15)	2	21	22	–
Agriculture, forestry, and fishing	1.97	–	–	116	68	172	107	High
Non-metallic mineral products—cement, lime, plaster, and concrete	1.36	14	19	–	–	–	–	–
Machinery and equipment	1.22	–	–	–	–	–	–	–
Fabricated metal products	1.05	63	63	–	–	–	–	–
Subtotal (% industry consumption)	93.0	1,488 (83.8%)	2,860 (83.8%)	1,206 (32.1%)	781 (32.1%)	1,771 (32.1%)	1,250 (32.1%)	(77.0%)

An investigation in the UK into industrial process demand-side participation estimated the demand turn-up potential for various sectors (Figure 3). Quantity data in MW in the original source was converted to percentage of 2019 peak demand here to enable comparison with flexible demand potential in Australia.

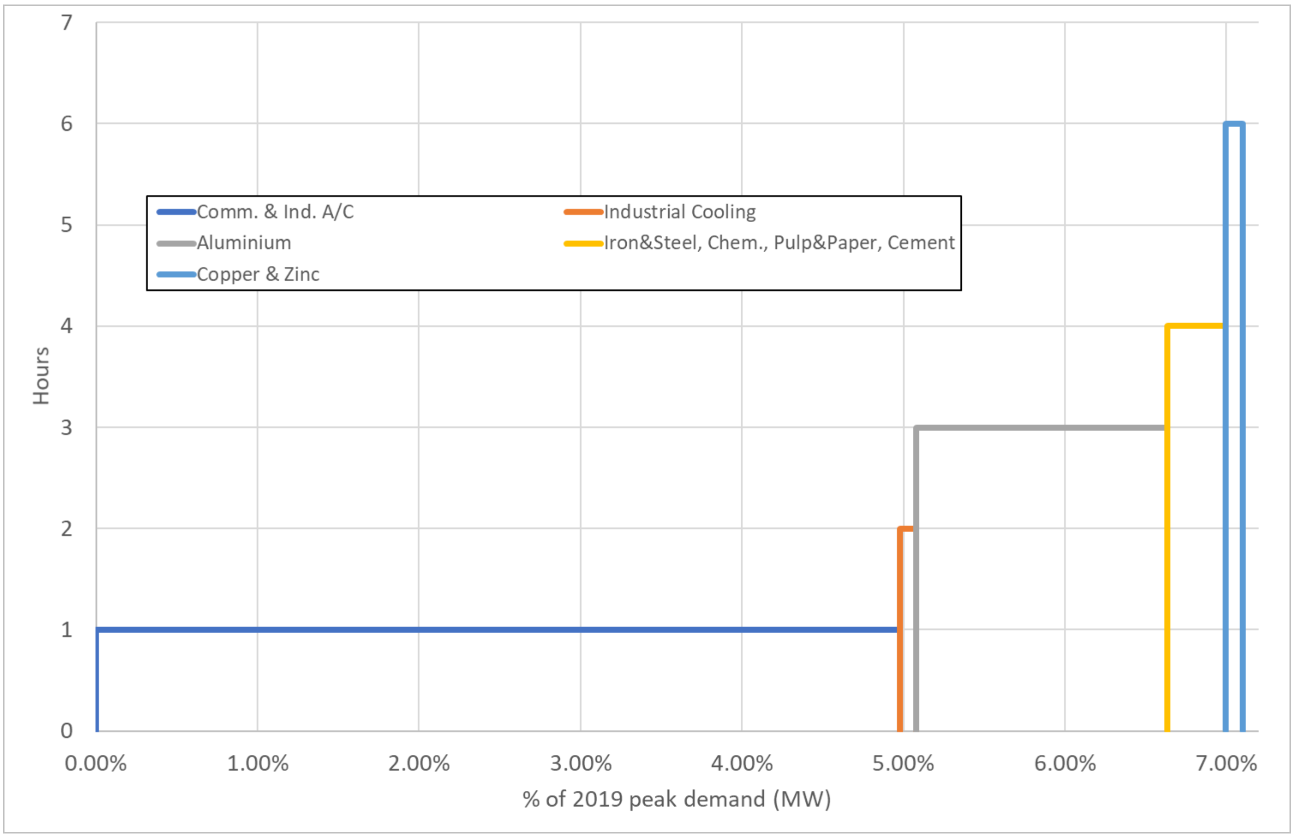

Figure 3. Estimate of industrial and commercial turn-up demand technical potential in the UK from Figure 20 of Charles Rivers Associates, 2017.[10]

4.4 Built environment resource assessment

D12a estimates the FD potential in the built environment (i.e. the approximate resource potential coincident with peak and minimum demand by sector and technology) as presented in Table 18 below. Air-conditioning FD potential was estimated by measured top-down disaggregation of the temperature dependent component of substation demand. Hot water and swimming pool pump FD potential was determined by bottom-up stock modelling of appliances in homes. Distinction is made between (i) completely switching off air-conditioning (shed) as an emergency measure, and (ii) reducing air-conditioning by shifting thermostat settings (shift), the latter being more suitable for regular flexing in response to price signals.

Table 18. Built environment quantitative flexible demand resource potential.

	Coincident with peak demand		Coincident with minimum demand
Sector / technology	**Emergency FD resource**	**Market participation FD resource**	**Indicative estimate only**
	(MW Shed)	(MW Shift)	(MW)
Residential hot water	450	450	4900
Residential swimming pool pumps	170	170	450
Residential air conditioning	6900	970	970
Commercial HVAC	1500	190	190

[10] See reference in footnote 5.

Compared with other literature estimates, the top-down estimate of total realistic FD potential in the NEM from Section 3.1 of D10 indicates that the commercial sector potential might be much higher (~1.8 GW). This is based on a 2017 estimate of FD potential in California's commercial sector being double that of industrial FD potential. This quantity is close to the emergency shed potential modelled here. However, the modelled non-intrusive, market-tradeable shift flexible demand is considerably less. The quantities here consider only the shift potential coincident with peak demand events in the network. A more accurate assessment in the Australian context will require more experimental data on the flex potential in real commercial building trials.

The prevalence of commercial building HVAC and residential air-conditioning loads on network substations and the potential to extract FD from these loads (by nudging thermostats) are illustrated in Figure 4 (Figure 7 of D12a). It shows the variability of air-conditioning potential for both substations and distribution network service providers. This is the single biggest contributor to peak demand on network substations. Hot water and swimming pool pumps also provide important opportunities for FD participation in energy markets, with negligible impact on end-use service outcomes. Coordination of hot water systems during daytime minimum demand events appears to be a very low-cost feasible approach to managing minimum demand.

4.4.1 Commercial buildings opportunity assessment

Document D6 also applies the systematic semi-qualitative HUFF method to assess the potential of various sector and technology combinations to provide flexible demand in the commercial sector (recall Section 4.3.1 above for description of the HUFF assessment method). Results of this assessment appear in Table 19.

Table 19. The HUFF Matrix for the commercial sector.

	HVAC	Heat pumps	Hot water	Thermal storage	Electric vehicles	Pool pumps	Embedded generation	Electrical storage	Refrigeration
Retail	70	56	63	63	35		63	70	
Offices	80	64	72	72	40		72	80	
Warehouses	80	64		72	40		72	80	72
Apartments	90	72	81	81	45	72	81	90	81
Public buildings	90	72	81	81	45		81	90	81
Data centres				63			63	70	
Supermarkets	90	72	81	81	45		81	90	81
Aquatic centres		72	81	81	45	72	81	90	

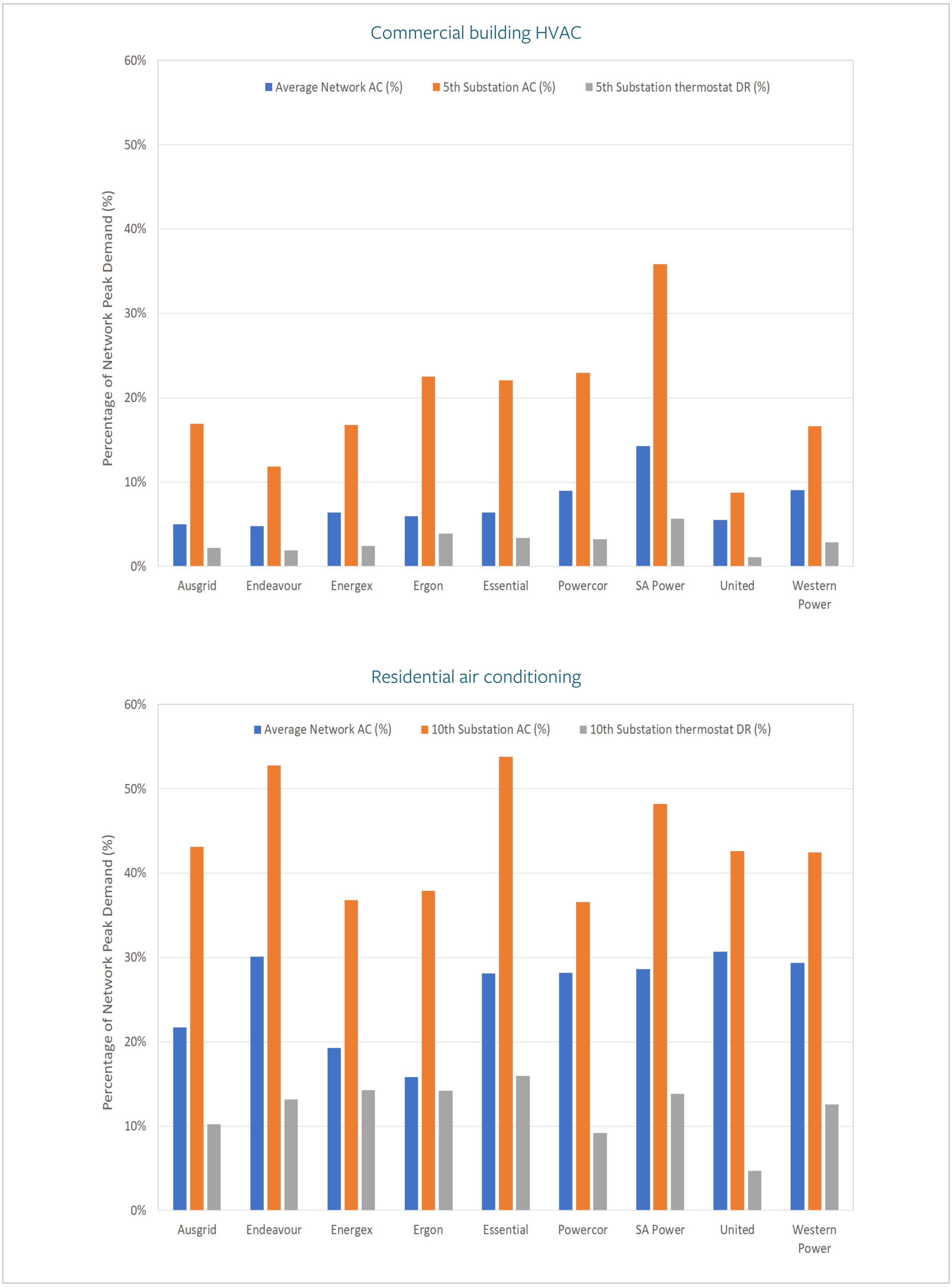

Figure 4. Fraction of demand attributable to air-conditioning in commercial and residential buildings during peak network demand events; (1) average across each network, (2) for substations where air-conditioning loads are high, and (3) contribution that thermostat-nudging flexible demand could make in substations with high air conditioning loads.

4.4.2 Residential buildings resource

For the residential sector three candidate sources of flexible load were investigated: air-conditioning, hot water, and swimming pool pumps. The breakdown of each of the candidate flexible residential loads during 99.5th percentile *peak demand* events in summer in each of the various network areas is illustrated in Figure 5 from D12a (Figure 5 below). Air-conditioning is the dominant residential load during peak demand events and responsible for 16 to 32% of all demand in each of the mainland network areas. Hot water systems and pool pumps are relatively minor loads in all network areas except TasNetworks, where hot water is significant.

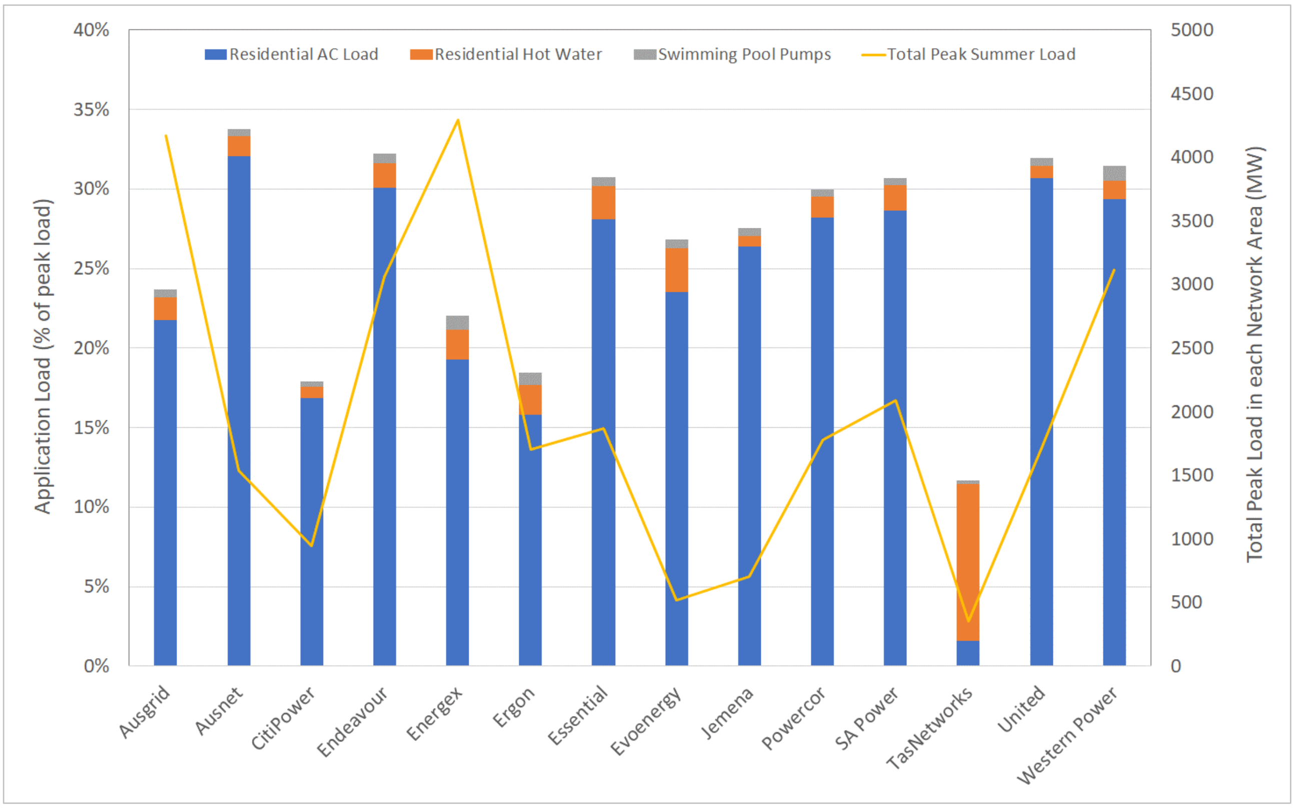

Figure 5. Magnitude of potentially flexible residential loads during summer peak demand events.

The breakdown of each of the candidate flexible residential loads during *minimum demand* events in spring in each of the various network areas is illustrated in Figure 6 from D12a (Figure 6 below). In contrast to summer peak demand events, the most significant flexible residential load on the networks during minimum demand events is hot water. In southern states, where gas is used extensively for hot water heating, hot water represents 6 to 15% of minimum demand. In NSW and Queensland hot water represents 21 to 36% of minimum demand.

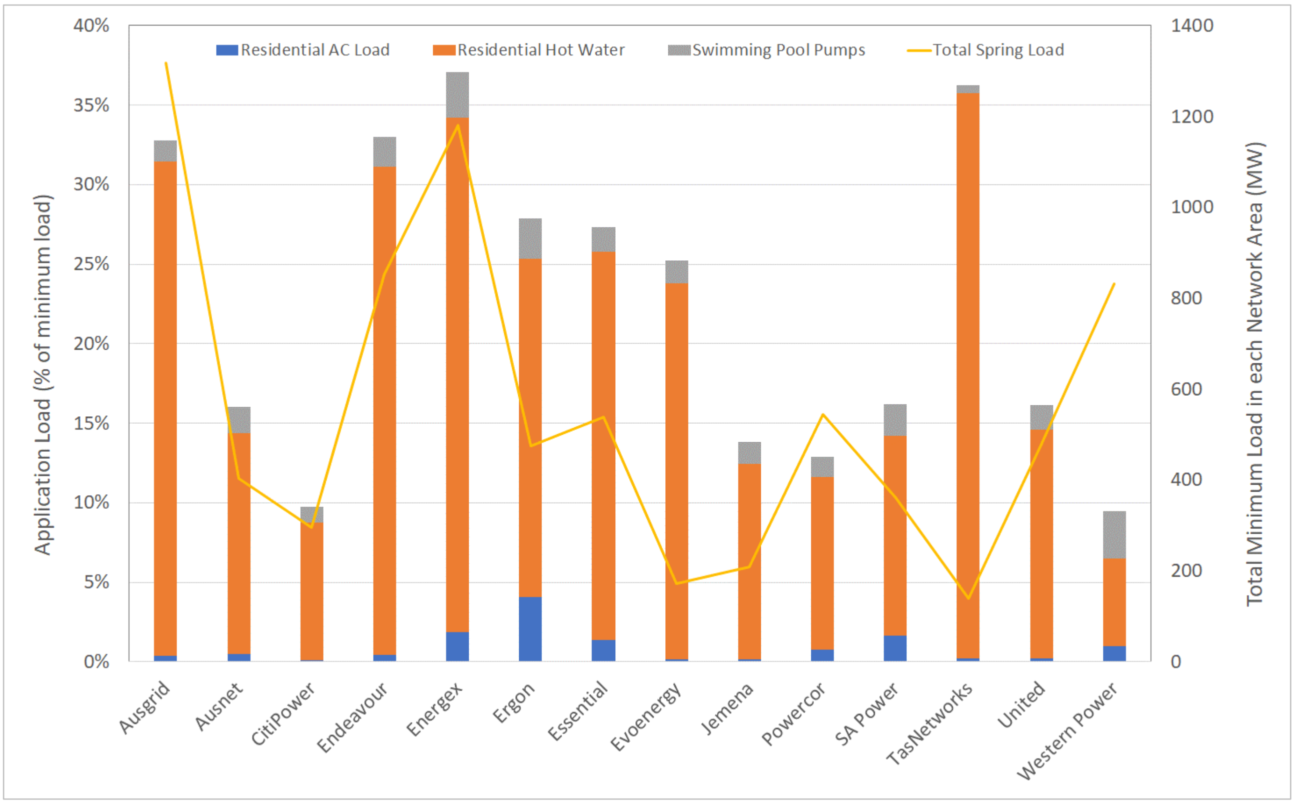

Figure 6. Magnitude of potentially flexible residential loads during spring minimum demand events.

4.5 Estimates of economic value of flexible demand

Based on findings reported here and additional data, a conservative estimate of the potential additional economic benefit of flexible demand in the commercial and industrial sectors (see Appendix A for calculation details) is $290m/year in the wholesale market. Assuming that peak demand on network infrastructure will continue to increase, there is further potential of more than $100m/year in network savings.[11]

Flexible demand presently attracts approximately $35m/year revenue in emergency reserve payments. The value of the FCAS market proportional to the contribution of flexible demand capacity is $30m/year. In future the requirement for FCAS may increase due to an increase in variable renewable generation. However, FD may face competition for the provision of FCAS from large scale batteries. Addressing minimum demand may be worth $5m/year from wholesale market benefits.

11 This compares to a total business benefit estimate from the initial impact assessment of $378M/year by 2030 ($272m/year wholesale and $100m/year network savings). RACE for 2030 (July 2020, unpublished), *RACE for 2030: Initial Impact estimates and assumptions*

5 Research opportunities

A wide range of research gaps and research opportunities were identified in each of the topic reports. These are extracted and aggregated in the following sub-sections.

5.1 Research opportunities in the industrial sector

Resulting from the research conducted in the resource assessments, the following list from Section 6 of D12 details suggestions for further work to facilitate greater uptake of flexible demand participation in the Australian industrial sector.

- Identifying and exploiting capacity:
  - Investigate the saturation point for flexible demand participation
    - Understand how increased participation affect revenue streams and frequency of price events to provide certainty for new proposals
    - Identify the relationship between market volatility and increased penetration of variable renewable generation
  - Drive participation uptake in sectors with greatest resource to offer
    - Target end users with high load-flexing readiness and strong price response
    - Exhaust simplest options before engaging less suitable end users
- Operational optimisation:
  - Identify strategies and technologies to facilitate operation and provision of flexible loads:
    - Automation of load-control; integration of response signalling and forecasting of price events
  - Extend analysis of the demand price-response behaviour of spot-exposed industrial end user:
    - Increase diversity and sample size of subsectors
    - Cover more years of data to identify trends and isolate COVID19 impacts
    - Relate performance to site-specific assets, operational cultures, and financials
  - Investigate opportunities for industrial end users to exploit negative market prices
    - Develop and test tariffs and price signalling to encourage load-shifting
    - Identify key technologies and assets that facilitate load-shifting
    - Identify temporal probability distribution for negative intervals
- Expanding capacity:
  - Investigate various behind-the-meter generation options to provide flexible demand
    - Quantify existing dispatchable behind-the-meter generation in industry (and in the commercial sector)
    - Investigate capabilities to flex cogeneration plants
  - Determine potential flexibility and impact of electrification of industrial processes
    - Identify resultant flexibility (and increase options) of electrified loads
  - Quantify the potential for large providers to provide flexible demand to the additional grid applications (e.g. wholesale and network services) beyond RERT:
    - Determine adequate compensation for end user production interruptions and risk to equipment and processes
- Knowledge sharing:
  - Develop case studies for flexible demand provision to demonstrate opportunities:
    - Provide success stories to inform new participants of potential capabilities
    - Link flexible demand to site-specific loads, practices, and economics

5.2 Research opportunities for facilitating flexible demand participation in electricity markets

From the literature review on pricing and incentives in D5, the following key research areas emerge:

- Shift and shape FD capability and wholesale markets
  - Investigate the potential for increasing FD provider participation by targeted knowledge sharing
  - Investigate the extent to which critical peak pricing, other dynamic tariffs, or other incentives could encourage FD deployment to reduce wholesale risk for retailers and wholesale exposed energy users
  - Investigate the potential impact of improving market predictability by encouraging visibility of FD capacity through mechanisms such as registration in the Wholesale Demand Response Mechanism rather than as direct response to the wholesale market
  - Investigate the potential to improve competition by ensuring a more level playing field between retailers and aggregators
- Network savings
  - Investigate the potential increase in FD provider participation by allowing their access to network tariff charges based on dynamic peak network infrastructure usage (e.g. critical peak pricing) and cost-reflective, long-term marginal cost principles
  - Investigate potential to improve network investment efficiency by ensuring retailers and aggregators have competitive access for the provision of FD services in place of traditional network investments. This could potentially be achieved by introducing an independent purchaser of FD tasked with reducing network capacity investment.
- Emergency reserves
  - Investigate incentive stacking by permitting contingent participation in RERT
  - Investigate potential increase in RERT participation by offering availability payments
  - Investigate the potential for improving the transparency of RERT contracts and/or moving to standardised RERT services and pricing paid for by the purchaser (currently the market operator)
  - Investigate the potential for emergency demand turn-up ('reverse RERT') to address periods of minimum net demand
- Frequency Control Ancillary Services (FCAS)
  - Estimate the projected future scale of the market for FCAS considering both generation variability (due to increased renewables contribution) and demand variability
  - Estimate potential impact on the FCAS market of large scale or VPP batteries potentially soaking up the services that could otherwise be provided by FD
  - Investigate the potential for provision of FCAS services by aggregated broadscale FD deployment, considering technology status and costs
- Other ancillary services
  - As a lower priority, until benefits can be quantified as material, maintain a watching brief on the potential of behind the meter flexible demand to contribute to other ancillary services such as voltage/reactive power support, harmonic compensation, and power loss mitigation

Document D6 identified two key research areas that could help overcome major barriers to FD. These are research areas relating to (1) Industry 4.0 (see Section 5.3), and (2) innovative pricing and incentives.

Research topics for improving pricing and incentives included:

- helping customers to respond to pricing and incentives, including better communication and co-developing or facilitating responses strategies (acknowledging response fatigue);
- developing hardware and/or software solutions that can facilitate FD (e.g. advanced metering/monitoring and ADR);
- optimising the alignment of pricing and/or incentives with network needs; and
- avoiding options that have the potential to cannibalise more valuable FD markets since 'flexibility can only be used once.'

Further research could develop business tools such as the Demand Response Quick Assessment Tool that could be made widely available to unveil hidden FD potential in commercial and industrial processes and/or assets.

D2 suggests that possible opportunities for further research might include the development of products or platforms that enable the currently most critical services to maintaining grid stability and maximising consumer benefit, such as by mitigating minimum demand through load-shifting and enabling a wider variety of FD sources to participate in shimmy services.

5.3 Research opportunities in Industry 4.0

D6 research topics for Industry 4.0 include:

- New IoT options such as Low Power Wide Area Networks for improved data capture
- Improved data analysis (including developing better incentives) using artificial intelligence to improve the reliability of reinforcement learning approaches
- Hybrid approaches for multi-agent systems and extending artificial neural network approaches
- Digital twins for FD scheduling and scenario testing, extending Automated Demand Response and transactive control technology particularly to better understand the responsiveness of FD for different customers; creating efficient standard and transparent markets and interfaces for customers; better characterising baselines for accurate transactions; and modelling lead and rebound effects
- Novel business models within the current rules and reform options to improve energy market regulation under a 'Virtual NMI' to maximise their benefits from FD

5.4 Research opportunities in flexible demand valuation

Document D11 highlights the immaturity of flexible demand valuation even now. Section 5 of D11 recommends that to adequately value FD through an ex-ante methodology it is important to comprehend the intricacies of the resource. Further research should focus on bridging the gap between long-term integration resource planning methods that focus on capacity planning optimisation, and shorter-term economic market dispatch simulations that assess FD at a trading interval resolution, price elasticity, and operational flexibility. Further research about FD integration within these two time horizons is warranted. As each methodology has limitations, future researchers should use a mix of tools.

D11 concludes that there is evidently a significant gap in knowledge of FD technical potential, especially in Australian electricity markets. A bottom-up assessment of technical potential should be undertaken before the economic and market potential assessments can be verified via long-term models of expansion planning and market dispatch models. Collecting the necessary data would be time intensive and involve significant resources. However, this appears to be necessary to adequately value the economic, technical, and market potentials. Issues related to FD's technical potential characterisation, dynamic pricing and price elasticity, impact of non-financial barriers, and the valuation of FD flexibility and reliability are other important areas to assess.

5.5 Research opportunities to address data gaps

Document D2 explored the techno-economic aspects of FD in Australia. Of the FD sources found in Australia, Section 6 of D2 concludes that although many physical assets and technologies are currently employed to provide FD services, most of these sources are currently used only for load shedding. While there is a significant number of pilot projects aiming to extend these capabilities, particularly for load shifting, it is unclear how these pilots will impact the energy system as there is little information regarding the technical potential of these new applications. Furthermore, economic potential is difficult to determine given the scarcity of cost information for these sources.

Most costs reported in D2 are not directly related to FD activation costs but rather are capital or energy delivery costs. These quantitative data may provide an indication of the economic potential of each source, but more detailed information specific to FD activation could facilitate new programs and more FD services. A comprehensive asset-level, techno-economic assessment that identifies technical potential and activation costs for each category of FD service such as those performed in the UK (Figure 2 and Figure 3) or in California[12] would also be beneficial in Australia. Document D5 suggests that a regular annual review of the state of the flexible demand market similar to those in the US[13] or Europe would also enhance the competitiveness of the market.

The review of Australian sector potential for FD found that disaggregation of potential by subsector is only performed for shed FD services in the literature. Additionally, this disaggregation represents only broad estimates of shed potential rather than detailed analysis at the subsector level. While there are examples of assessment of shape and shift FD in the Australian context, these assessments do not disaggregate by subsector and their coverage is not exhaustive. Shimmy FD for commercial and industrial applications has not been investigated in the Australian literature. In the case of load shedding, further investigation should be made into the subsectors that were identified as having the greatest shed resource to refine the estimates of potential. Other research efforts in this space should focus on determining disaggregated potential to provide a variety of FD services, not just load shedding. In this way new programs or projects can be targeted at subsectors that represent the greatest resource for a given FD service as well as the subsectors that present the best economics for providing flexible loads. This will not only streamline the development of new policies and business models but also maximise the potential benefit for the energy system and participating consumers.

The analysis reported in D12a (see the last section of p. 18) is an initial scoping study of the magnitude of the possible flexible demand resources that could be accessed from the built environment, which accounts for the majority of electricity consumption in the commercial and residential sectors. Air-conditioning and hot water provide important opportunities including the coordination of hot water systems during daytime minimum demand events.

This resource assessment could be further developed by:

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12 See reference in footnote 25.

13 See reference in footnote 8.

- examining key assumptions (e.g. diurnal and seasonal operating profiles of hot water and swimming pool pumps) and conducting more detailed assignment of building/appliance stock to substations,
- refining calculations of the magnitude, duration and post-event readjustment from thermostat-based flexible demand through additional experimental research, and to
- explicitly evaluate flexible demand potential during minimum demand events, and
- develop modelling capability that enables scenario analysis of adoption rates of technologies based on policies and incentive programs.

5.5.1 Research opportunities emerging from energy end-user interviews

Research questions suggested in interviews with industry (identified in Document D8) include:

- What are existing flexible demand successes and how can they be scaled up further both within existing organisations and across sectors?
- To what extent can aggregation achieve economies of scale to enable flexible demand?
- To what extent can flexible demand exploit synergies with ongoing trends such as 100% renewables and circular economy principles, the uptake of distributed energy resources, and gas pipeline energy storage?
- To what extent can improving data for forecasting the production cost and benefit of flexible demand improve the business case?
- How can flexible demand technology be aligned to organisational purpose, strategy and business model, business planning, capital expenditure assessment processes, and project planning?

5.6 Research opportunities workshop findings

A flexible demand Barriers and Opportunities workshop was held on 16 March 2021. The aim of the workshop was to validate the barriers identified in the literature and to prioritise those that are considered the greatest obstacles to the adoption of flexible demand. The Barriers and Opportunities workshop was further used to begin identifying actions that could be taken nationally to overcome these barriers. The findings of the workshop are documented in D7, D9, and D14. High priority solutions identified in D14 were themed around the following:

- **Clearer, simpler, trustworthy communication of flexible demand opportunities to end users:** This would include access to tariff data, case studies, and other ready reckoner information in a 'one stop shop' education and engagement source. Information needs to be layered/targeted for specific audiences. The availability of incentives should be broadcast to customers.
- **A demand-side buyer:** A centralised procurer of various forms of demand flexibility. For example, the demand-side buyer could procure demand flexibility that reduces the need for network investment in specific locations in the grid. A demand-side buyer could also provide incentives (analogous to feed-in-tariffs for solar PV) for installing DR devices or similar.
- **Provide incentives for networks to facilitate FD:** including regulation for greater transparency and targets for flexible demand capacity and value.
- **Political visibility:** Proper governance for energy management needs to be put in place in Australia to avoid energy management falling between the cracks. A Demand Management Advocate (similar to the Renewable Energy Advocate position) could bring focus to this opportunity. More scenario analysis should be undertaken to better understand the benefits.
- **Training and skills development:** More training is required at various levels including energy industry knowledge and training in plant monitoring and control.

- **Demonstrations:** Use demonstrations to reduce perceived risks.

A further Research Opportunities workshop was held with industry participants on 13 April 2021 to further progress the conversation on solutions for increasing adoption of flexible demand. The workshop shifted the focus to addressing what RACE for 2030 could do to facilitate transformation in ways that support the interests of the RACE participants.

Prior to the Research Opportunities workshop, the solutions from the Barriers and Opportunities workshop and generalised solutions from literature were synthesised into the following research topic propositions. The propositions were categorised under the headings used to categorise the barriers (Table 20).

- Economics and incentives
- Technology
- Cultural and behavioural, and
- Other.

In the Research Opportunities workshop these research project areas were prioritised as follows and further analysed to develop the research roadmap presented in Section 6.

Table 20. Research areas identified as high priority in the final workshop.

Votes for priority research areas	Priority	Tally
Economics and incentives		
1. Investigate alternative tariff structure models, price signalling mechanisms and impacts on customers	1	23
2. Investigate options to drive FD to address network issues (including minimum demand) either by encouraging NSPs to procure FD or creating open markets for FD	1	16
3. Investigate options to facilitate value stacking	1	13
4.Investigate aggregator models and concept of FD 'buyer'	2	9
5.Review the early operation of WDR mechanism		
Technology		
6. Develop data management tools and interoperability/data standards for streamlining information exchange	2	5
7. Examine options for improving real-time metering of supply and demand in distribution networks	2	8
8. Feasibility studies and demonstration of technologies and loads that provide FD (EVs, batteries, HVAC, standby gensets etc.)	1	11
9. Develop M&V baselining tools, guides and settlement procedures	2	4
10. Review options for uniform technical standards	3	4
Cultural and behavioural		
11. Study customer decision-making and participation triggers	1	17
12. Develop strategies to improve energy user awareness and understanding of flexible demand (e.g. advocate)	1	19
13. Investigate flexible demand contracting Ts and Cs	3	4
14. Research cultural barriers within energy industry	3	1
Other		
15. Investigate costs and benefits of governance reform to encourage demand-side activity	3	2
16. Investigate processes, standards and requirements for FD registration and compliance	3	2
17. Investigate methodologies and benchmarks for demonstrating FD supply firmness & cost-effectiveness	2	7
18. Identify opportunities for creating more transparency and certainty for FD providers	2	7
19. Identify DR potential in specific end-use segments	2	8

6 Research roadmap

Document D16 sets out a roadmap for categorising and prioritising research under the B4 research theme and provides an impact framework to evaluate research proposals. D16 first introduces the 'FD buyer and FD seller journey' (Figure 7). These comprise of several steps required to realise the deployment of valuable FD, any of which could be a point of intervention that could be facilitated by the outcomes of B4 Research proposals.

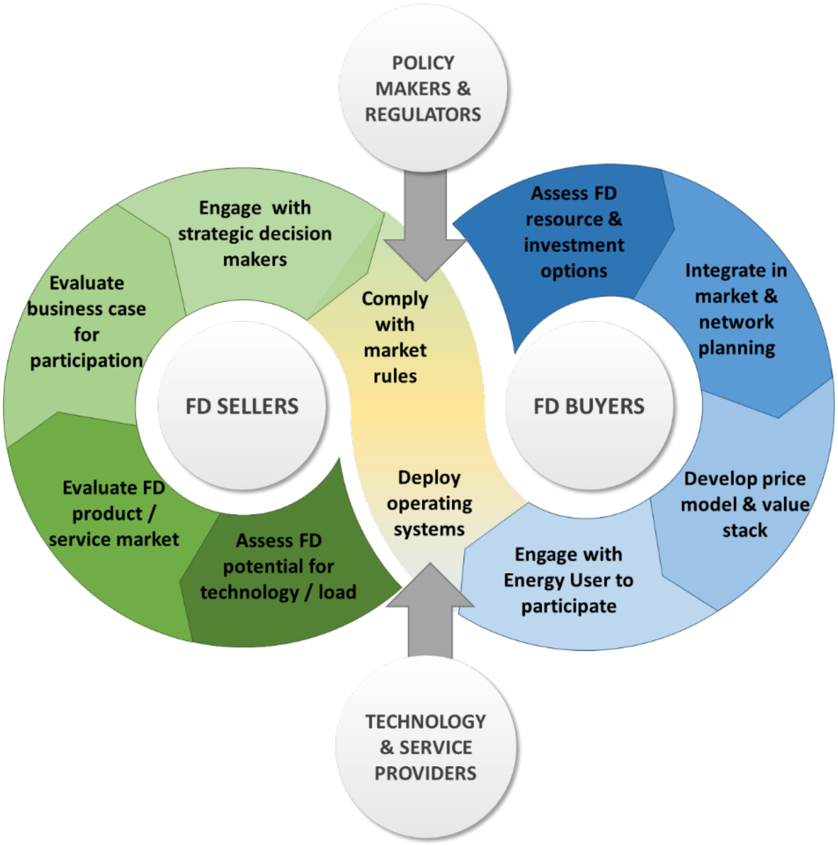

Figure 7. Flexible demand buyer and seller journey.

6.1 Opportunity categorisation and prioritisation

Figure 7 identifies four broad actor categories (buyers, sellers, technology providers, policy makers and regulators). With the addition of 'knowledge sharing and outcomes assessment', these actor categories represent the columns of the B4 research project classification matrix that appears in Table 21. The rows correspond to the policy palette solutions specified in Dunstan et al. (2009)[14] and discussed in Section 4 of Document D5. Each box at the intersection of the actors and the intervention type represents a priority area that should be addressed by research proposals.

[14] Dunstan, C., Langham, E. and Ison, N. (2009) *20 Policy Options for Developing Distributed Energy*. 4.2. Available at: igrid.net.au/sites/igrid.net.au/files/images/IGrid Policy Tools for Distributed Energy Working Paper 4 2 Version 1 0_1.pdf

Table 21. B4 Research project matrix.

Opportunity		Strategic integration	Enabling FD buyers	Supporting FD sellers	FD products, services & implementation	Knowledge sharing and outcomes assessment
Target audience / actors		Policy makers and regulators	Energy market (networks, retailers etc.)	Energy users (C&I)	Technology and service providers	All of industry
Intervention/ Policy Palette	Regulation, policy, standards & targets	**Market design & rules for FD** • Governance • Rules (e.g. control, value stack distribution)	**Network FD methodologies** • Network FD methodologies • Network investment assessment methods & tools for RIT-D/ RIT-T • Methodologies for assessing firmness and value of FD	**Rules & systems for consumer participation** • Rules & systems for consumer participation • Assessment of network value, targets and bid acceptance criteria	**Technical standards** • Technical standards • Review & establishment of common technical standards	**Policy evaluation & monitoring** • Policy evaluation & monitoring • Evaluation & monitoring of policies, rule-changes, programs (e.g. DMIS, WDR)
	Information	**Strategic engagement with C&I decision-makers** • FD advocate • Strategic education/awareness campaigns, e.g. communicating role & link between FD, RE & Net Zero targets.	**FD resource assessment tools** • Planning tools for networks, retailers	**FD potential** • FD potential of sectors, technologies and loads • End-user tools for assessing FD and business cases	**FD technology trials** • Trials of FD technologies	**Industry use cases** • Promoting energy user awareness and understanding of FD
	Pricing & incentives	**FD market models (roles and rules)** • FD Buyer model design • Aggregator model design	**Pricing models & value-stacking** • Alternative tariff structures • Methodologies to calculate 'value stack' for FD products (revenue streams, double accounting)	**FD pricing trials** • Pricing mechanisms and signalling processes for energy users/FD sellers	**Metering, M&V & settlement** • Simplified metering baselining, monitoring and verification • Standardised settlement procedures/platforms • Automation/communication protocols	**Pricing trial knowledge sharing** • Knowledge sharing on outcomes of pricing model trials and impacts for different types of end users
	Facilitation			**Consumer participation** • Consumer FD participation triggers (economic and non-economic) • Strategies for engaging energy users	**Information, data & contracting standards** • Shared protocols for information exchange/interoperability Data access • De-risked contracting procedures • Standardised processes for registration and compliance	**Change management processes and cultural acceptance**

Further details expanding on each of the boxes in the above matrix are in Annex 2 of Document D16.

Document D16 recommends that research projects be supported under three priority streams (Figure 8).

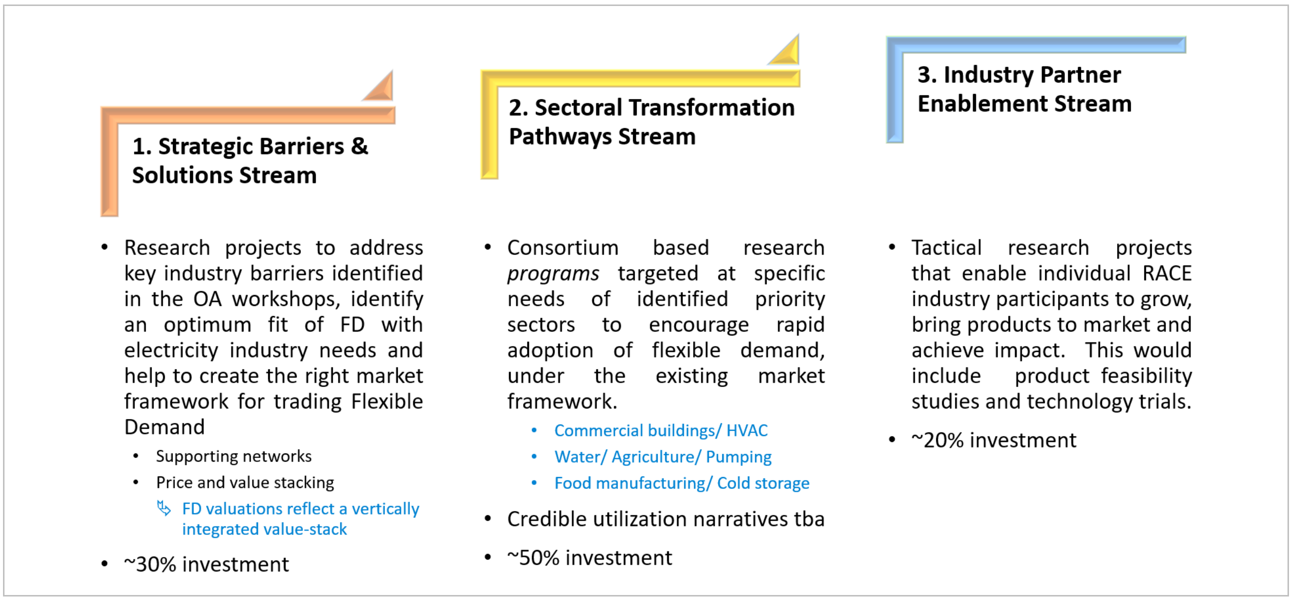

Figure 8. Recommended priority research streams.

1. **Strategic barriers and solutions stream:** These projects take a strategic perspective helping to identify an improved fit between (i) electricity industry structures and markets, and (ii) flexible demand characteristics and opportunities helping to create the right market framework for trading flexible demand. Four research opportunities are prioritised for the first tranche of call for proposals:

   i. **Network flexible demand methodologies**: Evaluating the cost, viability and firmness of FD for network requirements.

   ii. **Pricing trials**: Including identifying how flexible demand resources can be valued and shared across relevant electricity system services (wholesale, network, RERT, FCAS etc). A key aim of the pricing trial research would be to enable flexible demand providers (end-users and/or intermediaries) to be rewarded from multiple sources of value (combined, vertically-integrated value stack).

   iii. **Technical, communications, information and data standards**: Establish common technical standards and protocols for FD technologies, communications platforms, information sharing, and settlement systems by working with technical standards bodies and technology manufacturers.

   iv. **Consumer participation in flexible demand**. Research on common issues relating to the participation in flexible demand by consumers (separate to consumer research in specific sectors covered in Stream 2 below).

2. **Sectoral transformation pathways stream:** A stream that is open for RACE for 2030 partner consortia to submit proposals that identify a credible national pathway for increased adoption of flexible demand in priority sectors. Proposals would address specific barriers (or opportunities) relating to the sector with focus on new flexible demand resources becoming realisable under *existing* market conditions. Proposals would ideally create a strong community of practice where energy end users (flexible demand providers) can learn from each other and share knowledge. Based on identified sector opportunities,

industry interviews and resource assessment work (documented in D2, D6, D8, D12, and D12a), the recommended priority sectors and technologies for initial CRC investment are:

i. Commercial buildings (with a focus on Heating Ventilating and Air Conditioning)
ii. Water/ Agriculture (with a focus on water pumping)
iii. Food and beverage manufacturing (with a focus on refrigeration and cold storage)

Initial research-to-impact hypotheses are provided for the three priority sectors in D16.

3. **Industry partner enablement stream:** A stream that is open for RACE for 2030 industry partners to nominate projects that have targeted benefit and strong utilisation pathways; e.g. energy users assigned a high priority to research involving technology trials and technology feasibility studies. This could also include other project ideas that may not otherwise have been fully captured in the project matrix.

Together these three streams would cover the key priorities identified and prioritised by stakeholders in the Research Opportunities Workshop. Some overlap may occur, for example, feasibility studies and technology trials would likely occur in all streams. The overlay of stream focus to identified research priorities is illustrated in Table 22.

6.2 Impact targets and KPI metrics

The impact framework outlined in D16 describes the pathways to impact (Figure 9), including outputs, that would be expected from RACE for 2030 research and the logical high-level flow to outcomes and impact. Bringing together the identified priority research (Section 6.1) with the B4 Impact Framework, Figure 10 illustrates the pathway from selected priority research areas to an integrated transformation process that reduces barriers to entry, improves cultural acceptance, and paves a pathway to adoption.

The resulting RACE for 2030 impact of lower energy bills and lower network costs are estimated in Section 4.5 (and in more detail in the Appendix 0). The long-run economic value of 1 GW of flexible demand is estimated at $455M/year ($290M/year from the wholesale energy market, $100M/year from network peak demand management, $35M/year from RERT, and $30M/year from FCAS).

At an indicative cost (paid to flexible demand providers) of $155M/year,[15] 1 GW of flexible demand could reduce energy bills for consumers by around $300M/year.

6.3 Implementation and RACE investment prioritisation

The proposed process and timeline for activating research in each of the three streams is illustrated in Figure 11.

Stream 1 (Strategic barriers and solutions) will need to interact with reform processes in the electricity sector to transition the electricity system towards a so-called two-sided market. This strategic work is expected to have important long-term transformational potential beyond that of *ad hoc* projects. However, it will likely be a slow measured process. Work is required immediately to ensure that a strong evidence base is available for engaging in such processes. It is recommended that a call for proposals be issued immediately, focusing on initiating projects in the identified priority areas.

[15] See P Graham, J Hayward, J Foster and L Havas, 2020, GenCost 2020–21 Consultation draft, CSIRO, Appendix Table B.7 for cost of batteries with 2 h storage at $1083/kW. Assuming a 10-year lifespan and return on investment of 7% pa, the equivalent annualised cost is $154/kW/year.

Table 22. Research stream fit to priority project areas.

Stream 1: Strategic Barriers & Solutions
Stream 2: Sectoral Transformation Pathways
Stream 3: Industry Partner Enablement

Theme		Strategic Integration	Enabling FD Buyers	Supporting FD Sellers	FD Products, Services & Implementation	Knowledge Sharing and Outcomes Assessment
Target Audience / Actors		Policy makers, AEMO, AER Energy User Associations Company Boards	Networks, Retailers, Aggregators, AEMO	Energy Users (C&I)	Technology Providers Energy Users (C&I) – Procurement , Engineers	All of industry
Intervention/ Policy Palette	Regulation (Policy, Standards, Targets)	Market Design & Rules for FD	Network FD Methodologies	Rules & Systems for Consumer Participation	Technical Standards	Policy Evaluation & Monitoring
	Information	Engagement with C&I decision-makers	FD Resource Assessment Tools	FD Potential (sectors, loads, technologies)	FD Technology Trials	Industry Use Cases
	Pricing & Incentives	FD Buyer/ Market Models (roles and rules)	Pricing Models & Value-Stacking	FD Pricing Trials	Metering, M&V & Settlement	Pricing Trial Knowledge Sharing
	Facilitation			Consumer Participation Determinants	Information & Data Models, Systems & Standards Contracting Standards	Change Management Processes and Cultural Acceptance
	Coordination	Important to be addressed, but probably not a direct *research* topic for the RACE for 2030 CRC				

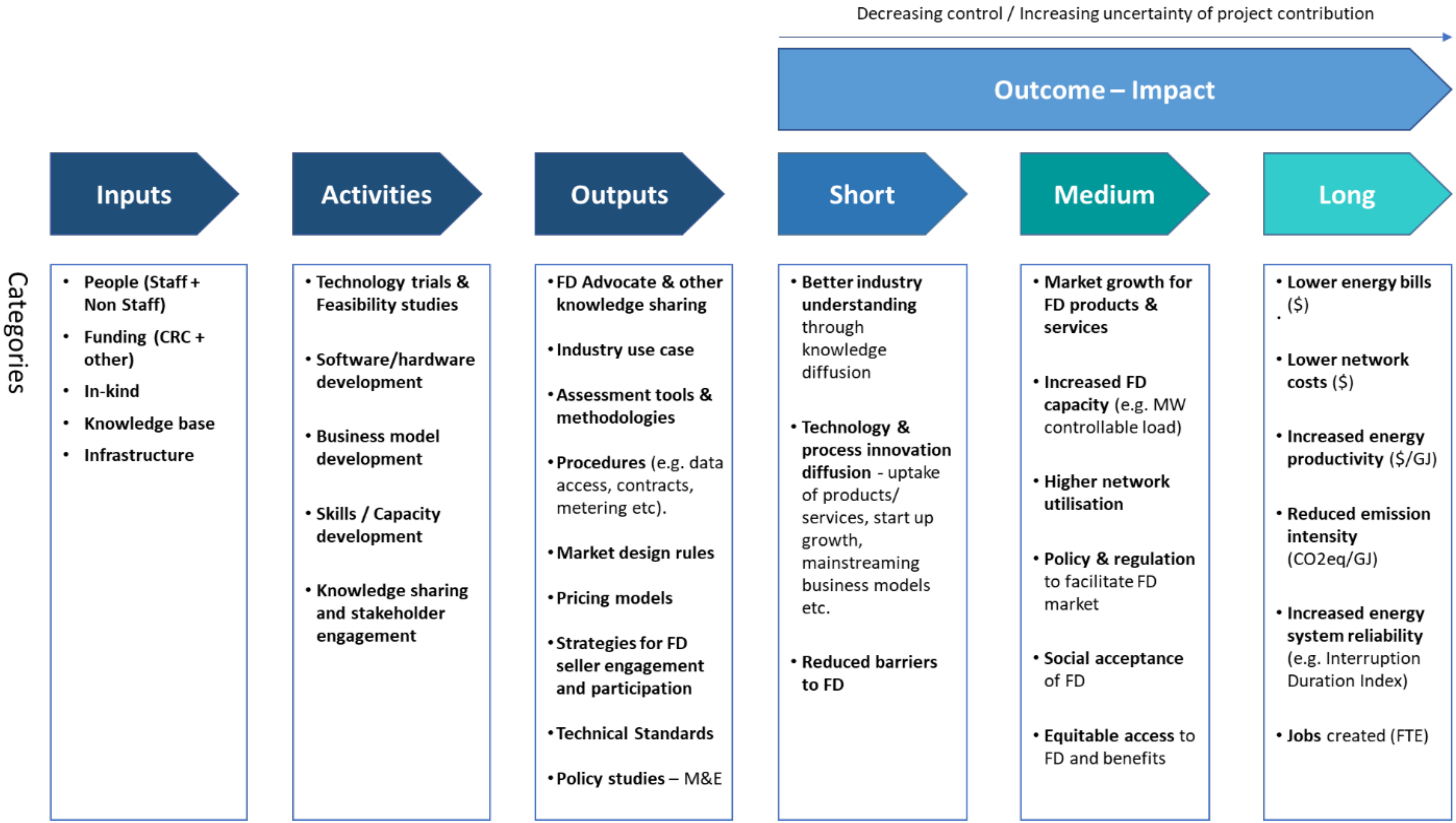

Figure 9. Detailed impact framework for B4.

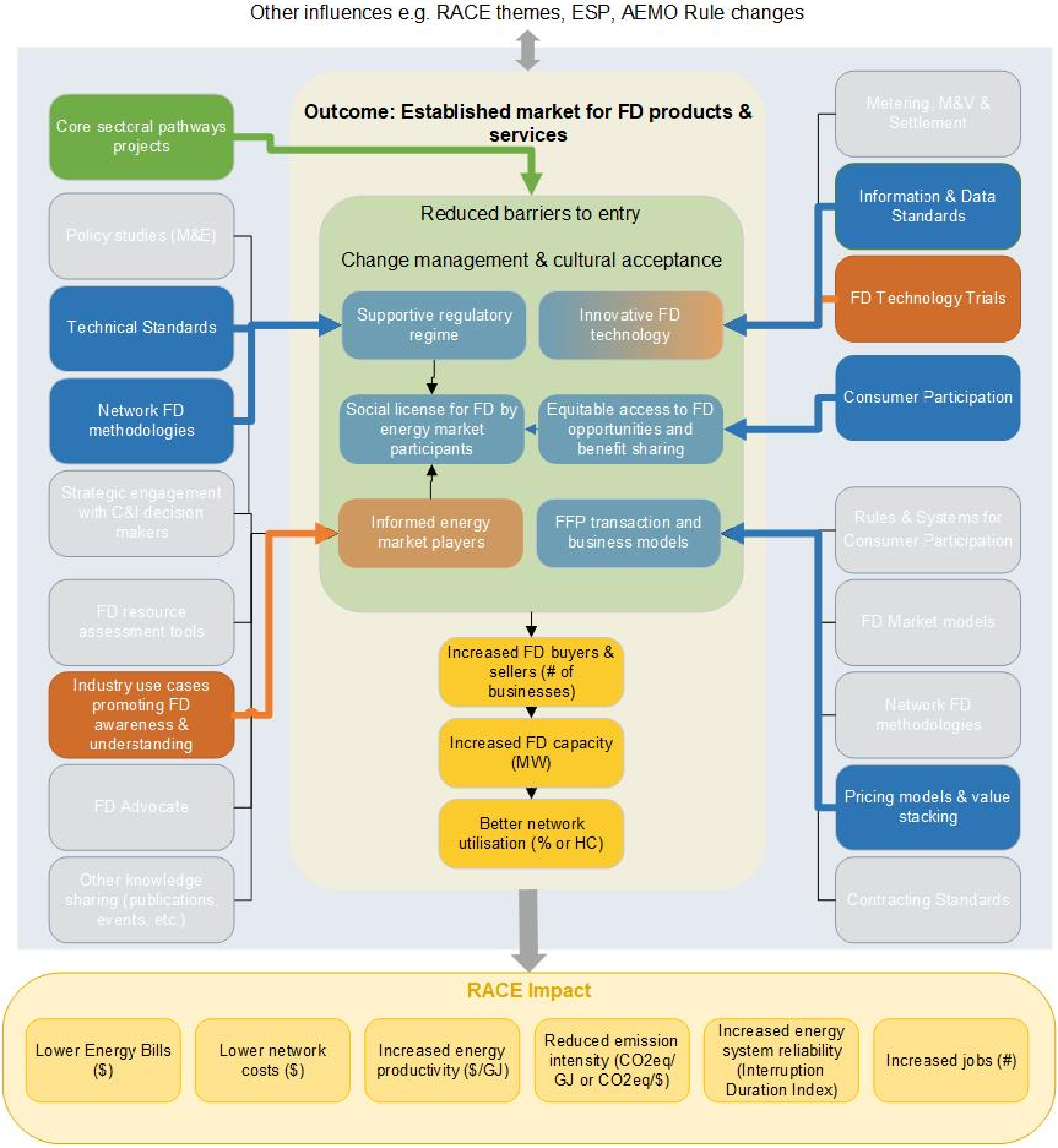

Figure 10. RACE B4 flexible demand research streams and links to impact.

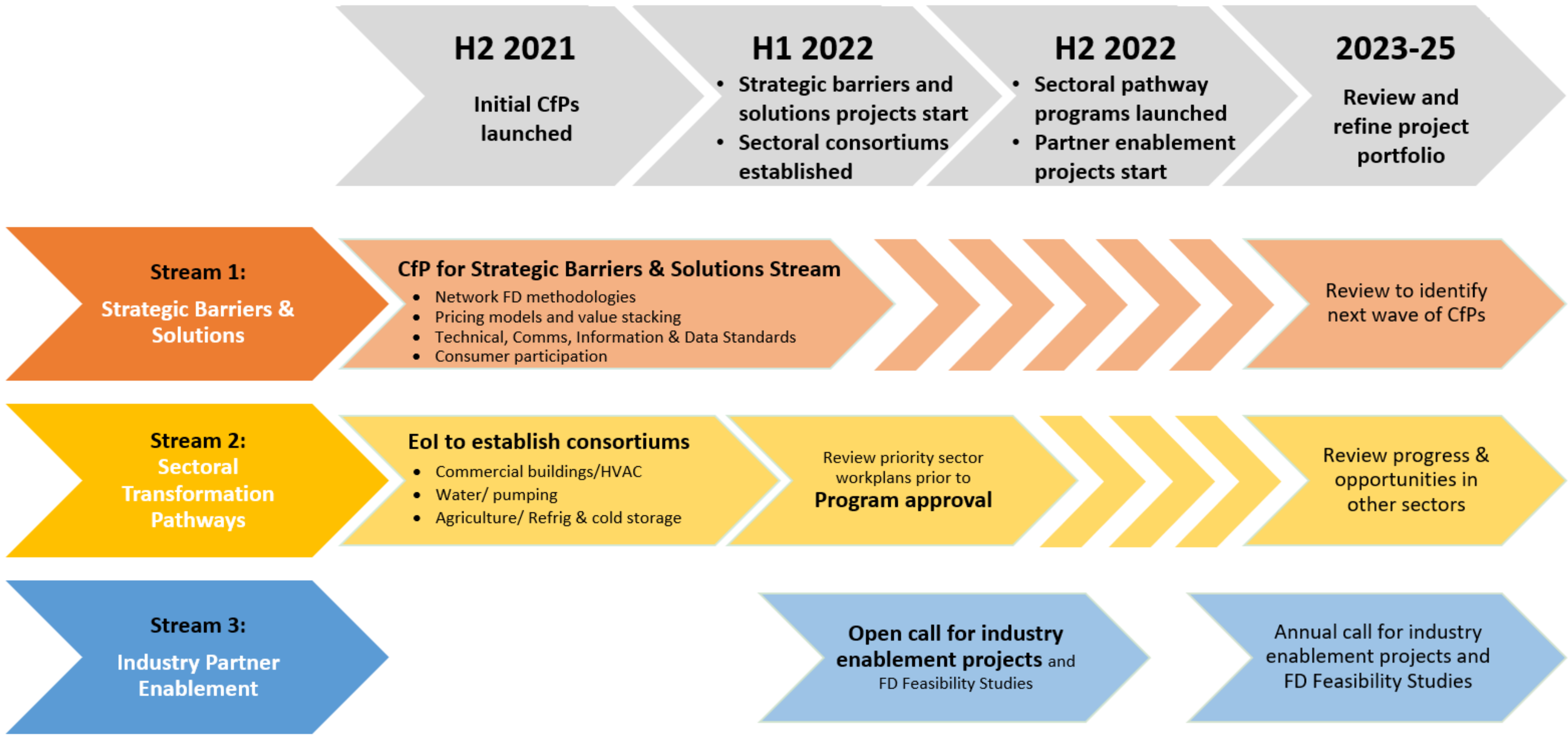

Figure 11. Proposed process and timeline for B4 research.

Work in Stream 1 will have significant overlap with research in other programs and research themes across RACE for 2030. As such, investment of resources in this stream would be shared with other research themes.

Stream 2 (Sectoral transformation pathways) requires that consortia of RACE for 2030 partners form to (i) create a vibrant sectoral community of practice, and (ii) identify and commit to a coherent research-to-impact pathway. It is beyond the scope of this opportunity assessment to coordinate these consortia for each of the priority sectors. It is therefore recommended that a Call for Expressions of Interest be issued immediately to identify leads for each priority sector. Once consortia have been established, sectoral consortium proposals would be approved for funding when they can demonstrate a compelling proposition for RACE for 2030 consistent with the CRC's funding processes and principles. This two-step process would enable high quality, focused programmatic research for the identified priority sectors.

Stream 2 is considered to be the core of the RACE for 2030 B4 Research Theme (Flexible demand and demand control), which aims to engage directly with energy users (flexible demand providers) and to provide immediate measurable flexible demand adoption. Indicative RACE cash investment for a vibrant sectoral consortium would be expected to be at least $300,000/year.

Stream 3 (Industry partner enablement) provides a more tactical opportunity for individual FD service providers to innovate and collaborate. With reduced requirements for coordination and alignment of partners, these projects can be identified through simple partner-initiated project proposals using the RACE for 2030's Fast and/or Standard Track processes.

This stream provides an important process for quick win projects and to provide clear return on investment for individual RACE for 2030 partners. However, it does not take full advantage of the collaborative ecosystem of the CRC mechanism and, compared to Stream 2 Pathway projects, may not add as much additionality over other funding mechanisms in Australia's innovation ecosystem. Consequently, recommended investment in this stream has a lower weighting. The roadmap recommends accepting and considering such project proposals once the other two streams are established.

Appendices

A Background

A.1 Context

The questions to be addressed specifically by theme B4 (see Document D0) are the following:

1. What are the key barriers to load flexibility for Australian businesses?
2. What are the prospective load flexing opportunities that RACE for 2030 should prioritise for research?
3. Which Australian business sectors are best placed to capitalise on load flexibility benefits?
4. What commercial and industrial loads are best suited to flexing, and which load control technologies could unlock this flexibility?
5. How can better pricing signals and/or incentives for businesses unlock demand side resource?

Issues to be addressed in opportunity assessment projects for all themes appear in Table 23, which includes cross referencing to documents and sections of this report where they are addressed.

Table 23. Common Issues to be addressed by all RACE for 2030 Opportunity Assessment projects (see also Call for Proposals, section 5).

			Related documents	Final report sections
1.	Work Plan and Reference Group		D1	A.3, B
2.	Current Technology and Market Status			
	a.	Current scale of market and cost	D10, (D2)	4.1
	b.	International and Australian practice	D6	2.2.2, 4.1
	c.	Global and Australian leaders	D6, D10	2.2.2, 4.1
3.	Technology and Market Potential			
	a.	Business as Usual	D10, D2	4.1
	b.	Accelerated Scenarios	D12, D12a	4.3.1
	c.	Benefits and Costs	D11	4.1, 4.2, 4.5, A
	d.	Barrier Analysis	D3, D8, D9, D14	2.1, 5.6
	e.	Solution Analysis	D5, D8, D9, D14	5.5.1
4.	State of the Art Research		D6	2.2.6, 2.2.2, 4.3.1, 4.4.1
5.	Research Project Opportunities and Priorities		D16	5
6.	Industry Development Opportunities		D8	3, 4.3
7.	Stakeholder Analysis and Engagement			
	a.	Establish Industry Reference Group		
	b.	Identify Key stakeholders		
	c.	Engagement plan	D1	B
	d.	Stakeholder inception and findings workshops	D1a	
8.	Key Metrics for Research Impact		D16	
9.	Project Assessment and Delivery			
	a.	Draft Report	D17	
	b.	End of Project evaluation survey		
	c.	Final Report	D18	1, A.1

A.2 Scope and intentions of the project

This project sits under the **RACE for Business** research program, which aims to boost business energy productivity via digitalisation, electrification and value chain optimisation. This is one of the four research programs of RACE for 2030, the others being **RACE for Homes**, **RACE for Networks**, and **RACE for Everyone**.

This project addresses Theme B4, one of five RACE for Business program themes:

- Theme B1: Transforming energy productivity through value chains
- Theme B2: Industry 4.0 for energy productivity
- Theme B3: Decarbonising industrial process heating
- **Theme B4: Flexible demand and demand control**
- Theme B5: Anaerobic digestion for electricity, transport and gas.

Research Theme B4 is looking to develop business models, hardware and software solutions to optimise electricity demand in response to supply conditions and more cost-reflective pricing of electricity. It includes optimisation of on-site generation, on-site storage (thermal, battery, material, pumped and other) and efficiency at times of peak load.

The industry problem addressed by Theme B4 is the need for packaged and low-cost technology for load flexibility to optimise costs based on time varying energy market signals. Research, analysis and reform are needed to develop and implement electricity prices, which reflect the dynamic cost of supply.

A.3 Partners

This Opportunities Assessment has been completed under contract with RACE for 2030. The project delivery partners are: CSIRO, Energy Efficiency Council (EEC), University of Technology Sydney (UTS), Royal Melbourne Institute of Technology (RMIT), and Australian Alliance for Energy Productivity (A2EP).

Industry partners include: AGL, Ausgrid, DELWP (Vic), Enzen, Flow Power, Fohat, Monash University, NSW Department of Planning, Industry & Environment, Powerlink, QUT, and Sydney Water. An Industry Reference Group was established to liaise with the delivery partners and represent the industry partners.

B Project delivery, structure, and approach

Document D1 describes the opportunity assessment approach and delivery structure. The project is divided into five main phases:

1. Understanding barriers to the provision of flexible demand
2. Assessing the amount of flexible demand available from industrial customers
3. Assessing the amount of flexible demand available from the built environment
4. Gap analysis and research opportunities
5. Research Roadmap and final report

To facilitate coordination, the delivery partners were divided into five working groups:

1. Literature Review Team (CSIRO, RMIT, RACE for 2030)
2. End-user engagement Team (RMIT, A2EP, EEC)
3. Resource Assessment Team (RMIT, CSIRO, EEC)
4. Market Driven and System-wide Response Evaluation (Energetics)
5. Research Roadmap Team (UTS, CSIRO, EEC, RACE for 2030)

Figure 12 (from Document D1a) provides an overview of the project task timing and dependence relationships. A more detailed work breakdown structure, described in D1, assigns tasks within each phase to particular working groups. Section 3 of D1 provides a Gantt chart with the planned timing, with tasks arranged by the responsible working group. Section 2 of D1 describes the dependency relationships between tasks and milestone deliverables in greater detail (Figure 13 shows a typical example). The remainder of this report summarises the findings of each working group.

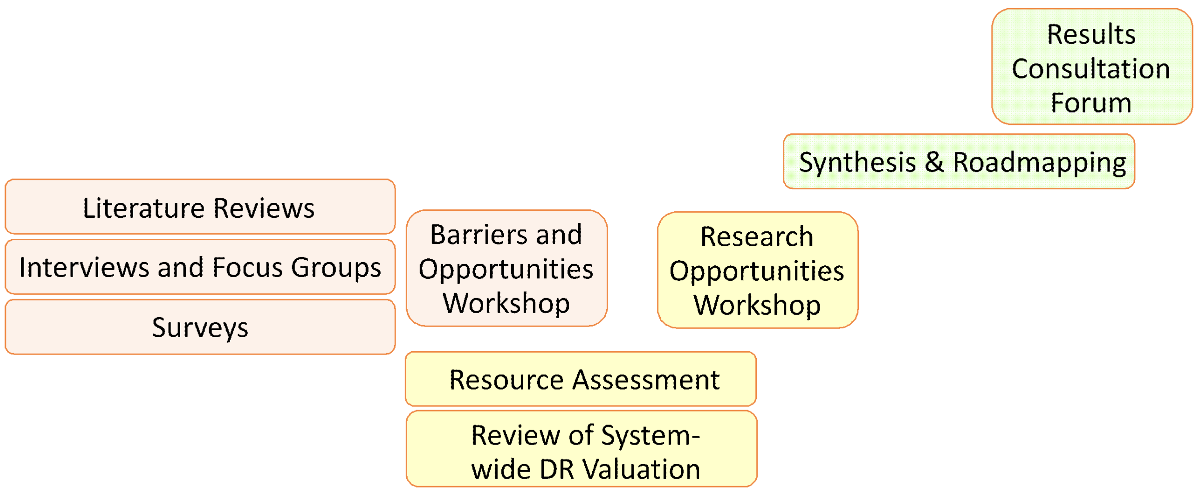

Figure 12. Overview of Opportunities Assessment tasks.

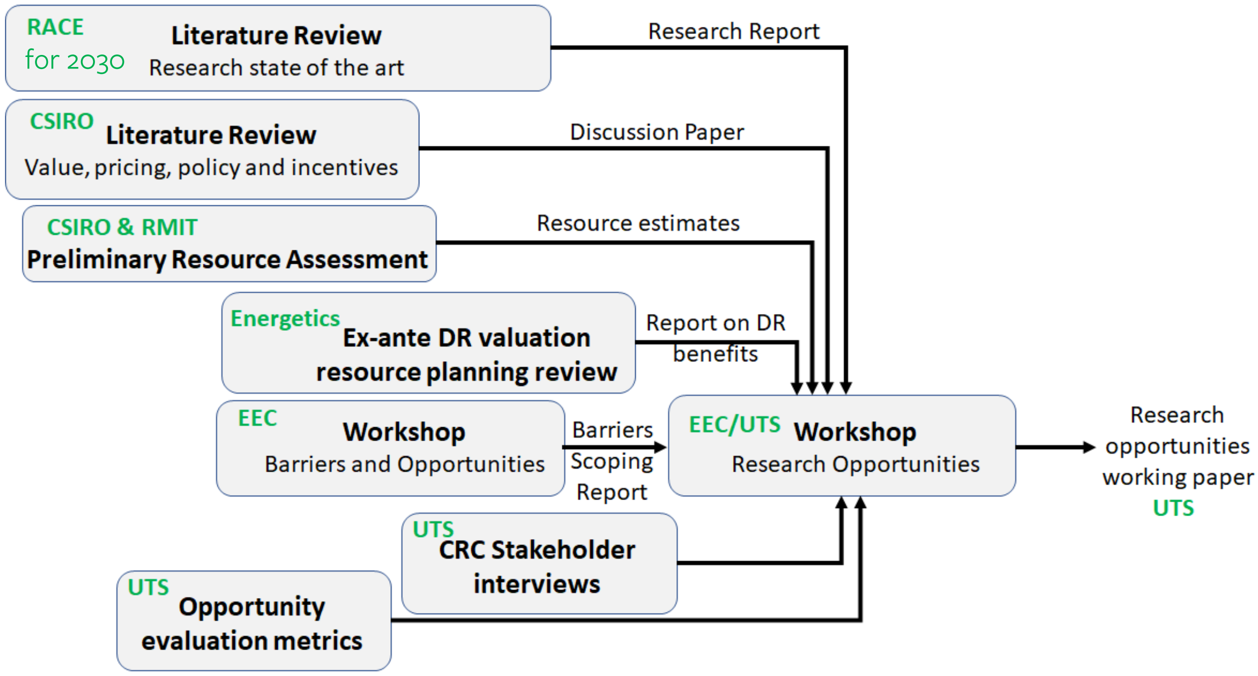

Figure 13. Typical detailed task and report dependency plan (Document D1).

C Economic value estimates

C.1 Wholesale value

First consider the wholesale market. A simplified analysis using 2018 NEM half hourly spot price/volume data (see below) was undertaken to provide a rough estimate of the benefit to the wholesale market of an additional 1000 MW of flexible demand. This is a reasonable assumption based on estimates of market-based flexible demand potential in industry of 781 to 1206 MW (Document D12) and commercial AC potential of 190 MW (Document D12a).

Compare this assumption of potential FD capacity with other data sources and methods, confirming that it is conservative. Maximum demand projections by NEM state are NSW 13.3, Qld 9.3, SA 2.9, Tas 1.4, and Vic 8.8 GW[16] for a total of 35.7 GW, so that 1 GW is 2.80%. Document D10 says that there is industrial demand market potential of 3% of maximum demand and commercial potential of 6%. Document D4 has industrial demand reduction technical potential of 4.7–10.5% and commercial potential of 1.1–4.0%. The NSW peak reduction scheme is projected to reduce network demand in NSW by 1029 MW by 2030.[17] This is 7.74% = 1029 / 13,300 of projected maximum demand. The Future Grid Forum[18] suggests that by 2030 the difference in network capacity factor between the set-and-forget scenario of 53% and demand-response counterfactual scenario of 65% is 18.4% = (65 – 53) / 65.

Now continue calculations of the value of 1000 MW flexible demand capacity. The average price of electricity in 2018 was determined for discrete ranges of NEM demand (e.g. 15–17 GW, 17–19 GW) and used to estimate a demand cost curve.[19] For each interval where price exceeds $120/MWh, which occurred for 678 hours of the year, the change in settlement price for a 1 GW demand reduction was estimated from the demand cost curve to be $103.07/MWh. The change in pool value for each half hour is calculated as the wholesale price reduction multiplied by the new (lower) demand quantity. This reduces wholesale market cost by **$290M/year** ($290/kW/year).

Note that if the demand reduction during high wholesale prices is shifted to other times, provided it is averaged over the remaining trading intervals the resulting increase is only 83.9 MW. This is expected to make only a negligible difference to the wholesale price. The value to FD providers can be estimated as $69.9M = 1000 MW × 678h × $103.07/MWh, which comes to $69.9/kW/year.

To compare this with an alternative method, note that the NSW peak reduction scheme is projected to achieve $4.30/MWh average savings in the wholesale market by 2030 (see reference in footnote 17). Scaling this to NEM demand in 2018 of 196TWh, this comes to $843M/year, which is well in excess of the conservative value estimated above.

16 AEMO, Electricity Statement of Opportunities 2019.

17 NSW Department of Planning, Industry and Environment, 2020, Energy Security Target and Safeguard consultation paper and Acil Allen, 2020, Energy Security Safeguard Scenario Projections Modelling Report.

18 CSIRO and ROAM Consulting, 2018, Modelling the Future Grid Forum scenarios, Figure 11.

19 AEMO: Aggregated price and demand data, half-hourly settlement prices. aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/aggregated-data

C.2 Network value

We use an approximate long-run marginal cost of network capacity of $100/kW/year.[20] The conservative annual value is therefore **$100M/year** = (1000) × $0.1. This relies on the assumption that peak demands on network infrastructure would otherwise continue to increase, requiring ongoing network augmentation.

For comparison of the estimates of the value of network savings per unit FD capacity, note that total annual costs of distribution networks are about $11B/year and $2.8B/year for transmission networks[21] for a total of $13.8B/year. The average cost per kW is given by $387/kW = $13.8B / 35.7 GW.[22] The long run marginal cost of network capacity of $100/kW is of a similar order of magnitude but more conservative.

From the above, the conservative estimated value of wholesale and network savings together from FD is **$390M/year** = 290 + 100. The average value of the wholesale electricity market over the last four years is $16.5B/year,[23] so the value of savings is 2.36%. For comparison of this total with an alternative estimated market value of shed capability, consider that a potential US$200–500M/year savings is expected by 2030 in the Californian market.[24] This savings estimate is consistent with the earlier estimate of $678M/year savings (reference in footnote 2) based on a 20% shift of the wholesale market of which 10% is expected to be cost effective, yielding cost effective savings of $339M/year. As the 2018 value of the relevant wholesale market value was $10.8B,[25] the percentage savings is 1.85–4.63% = (200–500) / 10,800. The conservative 2.36% savings calculated here is within this range.

C.3 Emergency reserve value

For emergency reserve we note that the value of the RERT market between Jan 2019 and December 2020 was $73M, that is approximately **$35M/year**, for existing FD capacity of 1422 MW (Document D10).

For comparison of this emergency reserve valuation estimate with another method, consider the value of shed in the California market of US$31M/year (reference in footnote 25) which comes to 31 / 10,800 = 0.29% (reference in footnote 25) of the value of the wholesale market. Transferred to the Australian context, the value attributed to the commercial and industrial sectors (see footnote reference number 21) is $47.9M/year = 16,500 × 0.29%, which is of a similar order of magnitude.

For an estimate of the savings value note that the economic value of FD for emergency reserve should be at least equivalent to a backstop technology of gas turbines at $950/kW (see the reference in footnote 15, Appendix Table B.1), so that the potential savings is equivalent to (a one-time payment of) $1351M = 1422 × $0.95.

For further context consider the potential for additional FD in the RERT. Reserve requirements are the size of the two largest units in each state which is 4435 MW (Qld: 744, 443; NSW: 2 × 720; Vic: 2 × 560; SA: 2 × 200;

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20 See tariff structure statements from each DNSP at aer.gov.au/networks-pipelines/determinations-access-arrangements/pricing-proposals-tariffs

21 AER State of the Energy Market 2020

22 See reference in footnote 16

23 See reference in footnote 21

24 B. F. Gerke, G. Gallo, S. J. Smith, Jingjing Liu, Peter Alstone, Shuba Raghavan, Peter Schwartz, Mary Ann Piette, Rongxin Yin, and S. Stensson, 'The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030,' Lawrence Berkeley National Laboratory, 2020.

25 California ISO, 2018, Annual Report on Market Issues and Performance

Tas: 2 × 144). Assume that demand response will be able to supply emergency reserve for the smaller of the two largest units in each state, which sums to 2067 MW. This is an additional potential of 2067 – 1422 = 645 MW. Now confirm that there exists sufficient potential demand response capacity. The potential industrial demand response capacity is 1071 MW = 35,700 MW × 3% and 2142 MW = 35,700 MW × 6% (see footnote reference number 16 and Section 4.3). Note that Document D12 finds 1250–1771 MW of industrial capacity and Document D12a finds 1500 MW of emergency response from the commercial sector (and 7520 MW residential).

C.4 Frequency control and minimum demand

Finally, for an estimate of the value of FCAS, note that over the last four years the regulation FCAS market has been worth $70–120M/year, and the contingency FCAS market $50–270M/year (refer to the citation in footnote 21), for a total of $120–390M/year. Document D10 observes that 200 MW of demand response is in the Australian FCAS market, which has a total magnitude of about 1500 MW. The value is **$25.3–52.0M/year** = (120 to 390) × 200/1500.

For comparison of this estimate of FCAS value the shimmy value of demand response in the California market is estimated to be US$22.5M/year by 2030 (reference in footnote 25). This is for 600 MW of capacity of which 300 MW is identified as being cost effective. Thus, cost effective value is 0.104% = 22.5/10,800 × 300/600 of the value of the wholesale market. Transferred to the Australia context (see footnote reference number 21) the value is approximately $17.2M/year = 0.104% × 16,500, which is similar to the range estimated.

For an estimated value of minimum demand, note that there is estimated to be about 4900 MW of flexible demand turn-up capacity in hot water systems (Document D12a). Assume value of savings of $50/MWh, which is less than the average wholesale price of electricity in 2018 ($86.8/MWh), less than the magnitude of common negative prices (see Document D12), and less than a feed-in tariff of 10 c/kWh for PV that otherwise might be curtailed at the time of minimum demand. Assume also that there are 20 hours per year when demand can be shifted to a time of minimum demand. An estimated annual value based on existing available capacity is therefore **$4.9 M/year** = 4900 MW × $50/MWh × 20h.

For a less-conservative estimate of value based on the potential market scale note that minimum demand projections by state are NSW 5.4, Qld 4.1, SA 0.57, Tas 0.88, Vic 3.0 GW (reference in footnote 16) for a total of 13.95 GW. Assume that the market can absorb an increase in minimum demand by a capacity quantity of 10% of the scale of minimum demand and can do so for 365 h/year. The estimated value of this is thus $25.5M/year = 13,950 × 10% × $50 × 365.

C.5 Other top-down comparisons

As a final comparison of these estimated economic values with other sources observe that there is estimated to be US$100–200B in savings from flexible demand in buildings over the next 20 years.[26] This comes to $5–10B/year = (100–200)/20. This is comparable to similar magnitude estimates of US$13.3B/year grid savings from residential flexible demand in the US.[27] To transfer these US figures to an Australian context, observe that NEM demand in 2018 was 196TWh compared to US energy demand of 4178TWh. If available savings in Australia are

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[26] US Department of Energy, 2020, A National Roadmap for Grid-Interactive Efficient Buildings

[27] M. Dyson, J. Mandel, P. Bronski, M. Lehrman, J. Morris, T. Palazzi, S. Ramirez, and H. Touati, 'The Economics of Demand Flexibility: How 'flexiwatts' create quantifiable value for customers and the grid,' Rocky Mountain Institute, August 2015.

proportional to energy demand (footnote reference number 21), this would come to US$235 to 469M/year for buildings and $624M/year for grid savings from residential flexible demand. Again, these are of a similar order of magnitude to, or larger than, the conservative headline numbers presented here.

D Key findings slides

Key work completed and reports produced

1. Overview of Demand Response Market in Australia

2. Key Barriers to Flexible Demand
    - Barriers Literature Review
    - Energy User Engagement Report
    - Barriers and Opportunities Workshop

3. Flexible Demand Resource Assessment
    - Techno-Economic Analysis Literature Review
    - Built-Environment Resource Assessment
    - Industrial Resource Assessment

4. Other Literature Reviews
    - Pricing, Policies and Incentives Literature Review
    - Ex-Ante Flexible Demand Valuation Methodologies
    - Research State of the Art Report and ECEEE paper

5. Research Roadmap
    - Research Opportunities Workshop
    - Case Studies
    - Research Roadmap

6. Final Report

Overview of demand response market in Australia

The total realistic flexible demand potential in the Australian market is around 3GW of which ~60% could come from commercial energy use, 30% from industrial and 10% from residential energy use. (This doesn't include well established residential off-peak programs)

Identified markets for flexible demand in the electricity industry include

- Reliability and Emergency Reserve Trader (RERT) – 1.4GW
- Wholesale Electricity Market (WEM) Reserve Capacity Mechanism in Western Australia
- Wholesale market-exposed end user DR
- Retailer DR
- Wholesale Demand Response Mechanism (WDRM)
- Frequency Control Ancillary Services (FCAS) market that supports grid stability.
- Network DR programs
- NSW Peak Demand Reduction Scheme

Different types of Flexible Demand for Different Applications

	Wholesale Market & Grid scale Renewable Support	Network Investment Savings	Contingency & Emergency Reserve	Distribution Network Support	Frequency Control Ancillary Services
Shift	H	MH	L	ML	NA
Shape	MH	MH	L	ML	NA
Shed	ML	H	H	L	ML (Lower only)
Shimmy	NA	NA	NA	H	H

shift, *shed*, *shimmy*, and *shape*, distinguished by their time scales. *Shift* moves demand on hourly timescales (suitable for arbitrage and renewables exploitation). *Shed* is foregoing electricity consumption altogether, typically infrequently and at short notice (suitable for system peaks, contingencies and reserve). *Shimmy* is changing demand on frequency control ancillary services time scales. *Shape* is moving demand on a consistent or permanent basis. It is always implemented as either 'shape as shift' (regularly moving load across periods), or 'shape as shed' (a regular reduction of load).

D.1 Barriers

Energy-user engagement

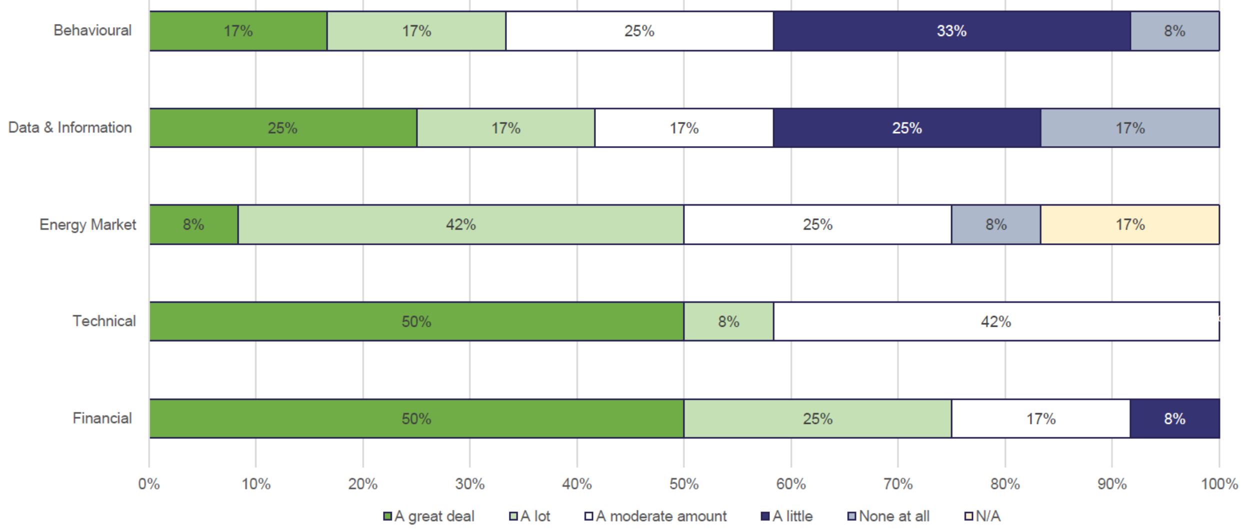
Nine interviews and three industry roundtables were held (18 interviewees in total), to better understand the barriers and opportunities for flexible demand from large commercial and industrial energy users.

Outside of Reliability and Emergency Reserve Trader (emergency services), the most prospective and ready-to-engage energy users were those with 'energy storage inherent to their facilities/operations (e.g. water storage (pumping), cold storage). Opportunities also exist to increase the use of onsite power generation in a more integrated way to support the grid.

Companies that are already doing demand response activities tend to be most keen to do more and tend to see more opportunities. Those not doing it typically consider the risk of load flexing to far exceed any possible reward. Consistent with a risk first mindset, Participation in RERT is justified based on reducing the risk of production being halted by emergency power outages.

It is possible that many of the barriers for energy users are, at least partly, barriers of perception rather than fundamental barriers.

Barriers do not all appear to energy users at the same time, but act as sequential 'hurdles' or 'gates' that need to be addressed along a journey. At each stage, *value* (cost v benefit) and *risk* are constant lenses through which the viability of load shifting is considered.



Barriers literature review and barriers workshop

This report found that a majority of barriers to FD can be summarised as

Lack of reward for participation. Price signals for energy users (providers of FD) are both muted (not fully cost reflective) and uncertain. This makes it difficult to build a business case. Of particular note is the difficulty for providers of demand flexibility to access value from network applications and in bundling incentives to obtain full value from demand flexibility; and

End user engagement issues; including (i) lack of awareness of the opportunity, (ii) perceptions of risk/risk aversion, (iii) disinterest, confusion and competing priorities for time and resources, and (iv) a lack of trust amongst energy users (providers of FD) in both the electricity industry (buyers of FD) and rules of markets where FD can participate.

Summary of Identified Barriers

Economics and Incentives

- Muted price signals
  - Fixed price retail tariffs
  - No market for network services
- Uncertain business case
  - Split incentives
  - Uncertain price, uncertain baseline
  - Duration of contract and/or incentive
- Upfront cost
  - transaction/ customer acquisition costs
  - equipment/technology costs
- Lack of access to capital

Cultural & Behavioural

- Electricity industry inertia
- End-user disinterest and lack of trust
  - awareness
  - perceived risk
  - complexity and competing priorities
- Lack of capability and capacity
- Purchasing processes and incentives
  - Contracting
  - Individual site vs portfolio perspective

Technology

- Lack, or poor quality of metering data
- Difficulty with information management
- IT, cyber-security and interoperability issues
- The industrial process isn't able to flex

Other

- Arduous regulatory requirements to participate
- Achieving scale and firmness at specific locations
- Operational control of assets when value stacking
- Market transparency/ lack of competition

These findings were confirmed by a Barriers Workshop attended by 38 industry stakeholders (evenly covering networks, retailers, aggregators, government, energy users, consultants and solution providers)

Importantly, the 'business-case' (which needs to stack-up) is intimately connected to the market framework, both in terms of value and certainty. If FD can only access one value stream (wholesale, network, FCAS or RERT) it will be hard to build the business case. In this way, financial considerations and market framework considerations are intertwined. Market frameworks need to be developed that enable FD to access a vertically integrated value stack and FD should not be considered as a drop in alternative to traditional supply side solutions.

What would really make a difference … ?

“For many, greater uptake of electricity load shifting doesn’t require a stronger business case, it requires integration into the business model and strategy”

Make it easy and trustworthy

Make it relevant

Make it financially visible and viable

- ? Does FD need to mirror complex ‘cost-reflective’ supply industry pricing
- ? Does FD need to plug in as a drop-in replacement to existing supply industry structures, procedures and constraints
- ? Does FD need complex registration, metering and settlement procedures
- ? What attributes/narrative would make FD ‘a thing’ (worthy of attention) to the board/minister

D.2 Priority sectors

- By scale of opportunity
- By cost to provide

Built environment FD resource assessment

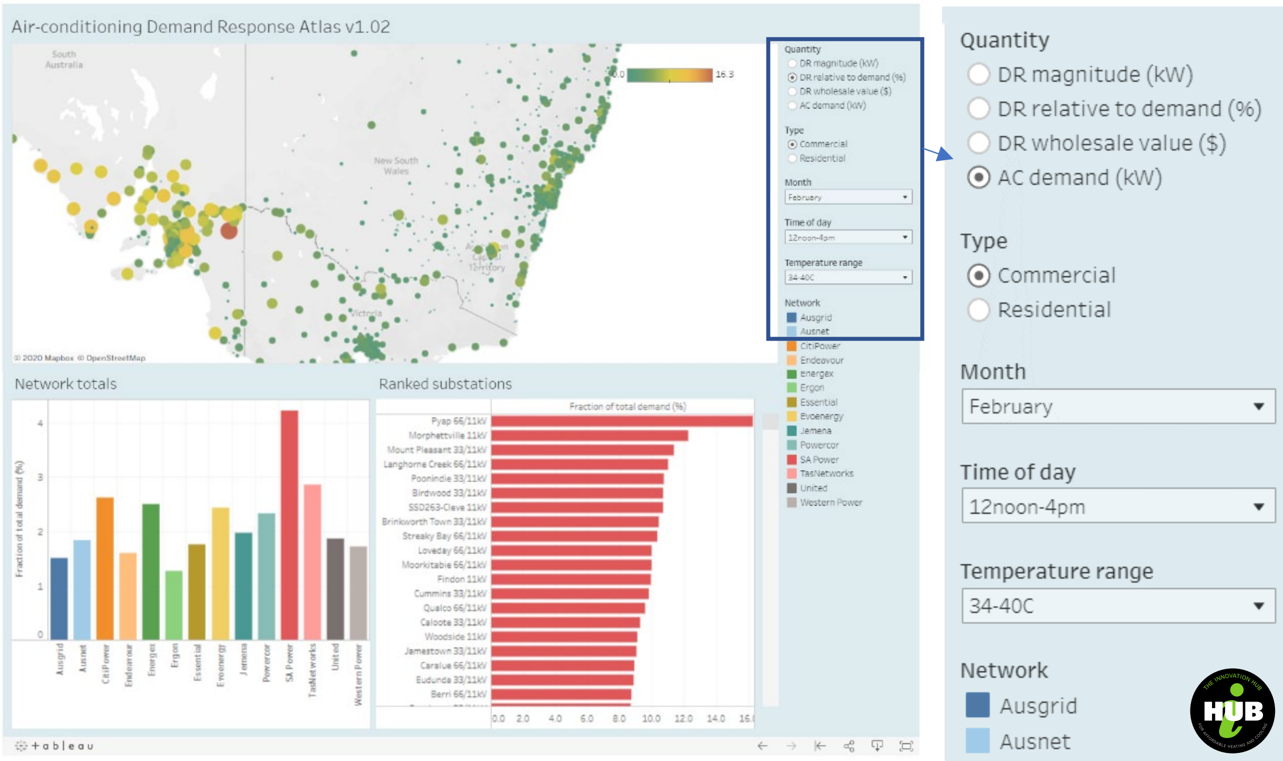
public.tableau.com/profile/mark.goldsworthy#!/

Estimates of (i) total air conditioning load and (ii) flexible demand potential were calculated by top-down disaggregation of zone substation data. The temperature dependent component was apportioned to commercial and residential buildings in the substation. The fraction of total load that could be reduced by implementing a 2°C thermostat set-point adjustment was modelled.

More research is required to better understand room temperature changes and load reduction resulting from thermostat management.

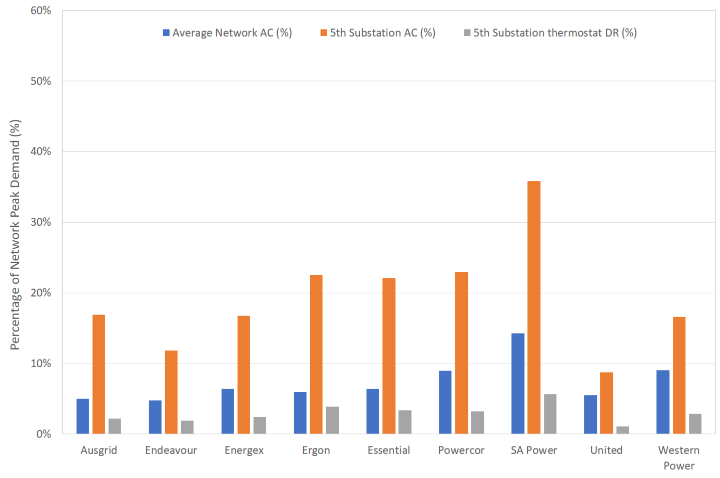
Estimates can be viewed online in an interactive Tableau database, allowing the impact of air conditioning to be investigated at (i) different times of the day and year, (ii) temperature and (iii) under different network conditions (average or peak)

Residential hot water and swimming pool pumps were also considered with a bottom-up appliance stock model.

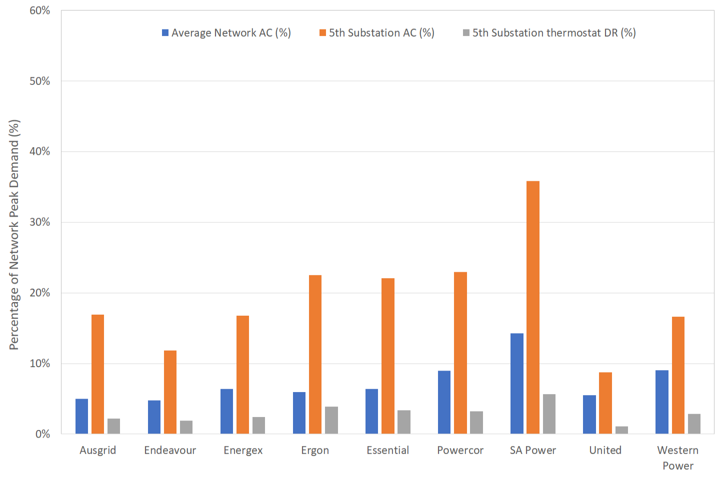


Built environment FD resource assessment findings

Commercial building HVAC



Residential air conditioning



Energy Queensland (EQ) case study

EQ has ~136,000 airconditioners under control, providing ~150MW of diversified load from a 'Broad-Based' program.

AFLC activated DRED controllers are installed by industry providers with $50 incentive/device. A one-off cash incentive of either $200 or $400 is provided to owners, after which the airconditioner is managed by EQ. The 2021/22 cost is less than $244/kVA.

DREDs are randomly grouped into 1 of 5 channels that can be staggered at the start and end of the flexible demand event to prevent sudden large loss or gain of load.

A 'Targeted' program with larger users achieves FD at less than $80/kVA.

Nationwide

- Residential air conditioning load is larger than commercial air conditioning during peak demand events.
- Switching off air conditioning during an emergency weather related peak demand event has the technical potential to unlock *load-shed* of
  - 6.9GW of residential air conditioning demand
  - 1.5 GW of commercial HVAC demand
- Nudging thermostat settings by 2°C during a high price event has the technical potential to unlock *load-shift* of
  - 970 MW of residential air conditioning demand
  - 190 MW of commercial HVAC demand

Individual substations

- In different network substations across the NEM, implementing air-conditioning DR in commercial and, residential buildings, achieves a median DR potential of between i) 1.1% and 4.0% and, ii) 5.0% and 15.3%, respectively, of peak total substation demand.

US DoE roadmap for grid-enabled buildings

The U.S. Department of Energy (DOE) Buildings Technologies Office (BTO) recently developed a Roadmap for implementation of Grid-interactive Efficient Buildings (GEBs).

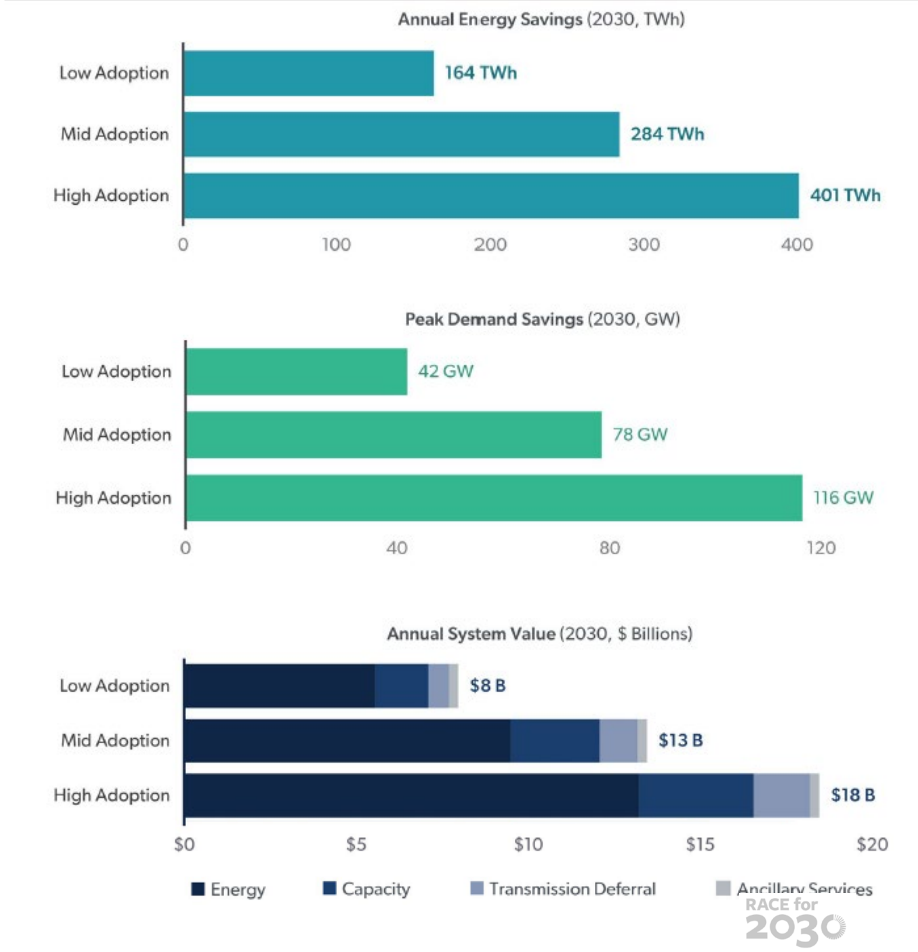
GEBs are energy efficient buildings with smart technologies characterised by the active use of Distributed Energy Resources (DERs) to optimise energy use for grid services, occupant needs and preferences, climate mitigation, and cost reductions *in a continuous and integrated way*. In doing so, GEBs can play a role in promoting greater affordability and reliability across the U.S. power system (through increased demand flexibility) and reduce greenhouse gas emissions (through lower overall energy use).

The roadmap found that over the next two decades, adoption of GEBs could be worth between $100–200 billion in U.S. electric power system cost savings. By reducing and shifting the timing of electricity consumption, GEBs could decrease CO_2 emissions by 80 million tons per year by 2030, or 6% of total power sector CO_2 emissions.

Assuming linear scaling to Australian market size, the ‘Mid Adoption’ scenario would (by 2030) give savings of

- Energy AUD $560million/year
- Capacity AUD $151million/year
- Transmission deferral AUD $65million/year
- Ancillary services AUD $16million/year

Reduced energy costs are driven largely by energy efficiency (not just FD)



Industrial FD resource assessment

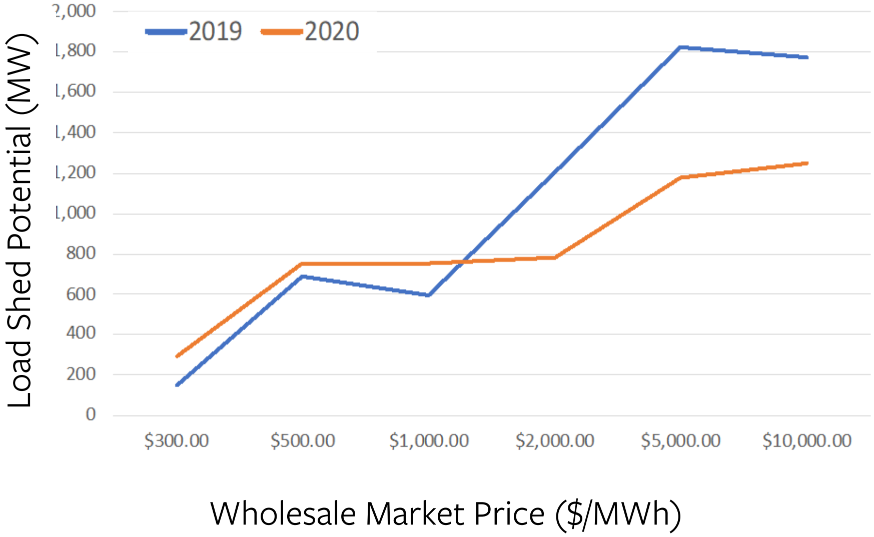
The opportunity for obtaining flexible demand from industrial energy users was assessed based on the findings of qualitative interviews and focus groups with industrial end-users and stakeholders covering 8 of the 14 subsectors considered. The questions asked during these sessions were aimed at determining the ability or readiness of different subsectors to provide load shifting and load shedding flexible demand. Readiness is attributed as either low, medium or high according to a subsector's: **technical capabilities** (such as physical load assets and control technologies); **cultural or behavioural practices** (including production schedules and awareness/understanding of flexible demand); and **commercial readiness** in terms of potential revenue streams and business cases.

Sector	Share of Industry Electricity Consumption	Flexible Demand Readiness
Basic non-ferrous metals	28.17%	Medium
Other (non-coal) mining	18.71%	Low
Oil & gas extraction	13.00%	Medium
Food, beverage & tobacco manufacturing	5.45%	Medium
Chemical & chemical product manufacturing	3.54%	Low
Pulp, paper & printing	3.44%	Medium
Water supply, sewerage & drainage services	3.29%	High
Agriculture, forestry & fishing	1.97%	High

Industrial FD resource assessment

The quantity of flexible demand available from various industry sectors, across Australia, was estimated by analysing the load-shed response of 175–225 known wholesale market price exposed industrial energy consumers, over two years, and extrapolating their response to the rest of their respective sector (assuming that others in the sector could technically contribute in similar proportion). The known consumers represented five different industrial subsectors. Their response was analysed at various market price bands.

While it is noted that the industry subsector sample sizes were small (as few as 4 sites), and there is potential selection bias toward energy consumers that may have unique opportunities to respond, the analysis is based on actual actions taken rather than aspirational survey responses.



Sector	Response Potential $10,000/MWh (MW, 2019)	Response Potential $10,000/MWh (MW, 2020)
Other (non-coal) mining	1,047	1,040
Food, beverage & tobacco manufacturing	433	14
Other transport, services & storage	21	22
Water, sewerage & drainage services	98	67
Agriculture, forestry & fishing	172	107
Total (32% industry consumption)	1,771	1,250

For comparison, ClimateWorks (2014) estimated flexible demand potential of 1,488MW to 2,860MW depending on the extent of the bill savings that could be achieved. Differences are noted regarding the distribution of flexible demand potential across sectors between this study and that of ClimateWorks.

Other markets and technologies

Reliability and Emergency Reserve Trader (RERT)

AEMO identifies and contracts emergency, out-of-market electricity generation, or interruptible load resources that can be triggered during generation shortage events. AEMO forms a panel of suppliers and contracts for (i) medium-notice situations where there is between ten weeks and seven days of notice and (ii) short-notice situations where there is less than seven days of notice of a projected shortfall in reserves.

1,422MW of FD was contracted over the last two years delivering 5223 MWh of flexible demand at $1296.86/MWh. This cost $72.74 million and avoided $138.99million.

Frequency Control Ancillary Services

Flexible Demand provides ~180MW (12% of market capacity)

Other technologies

A number of other approaches to providing flexible demand, not directly covered in this study, are considered out of scope;

Voltage tapping (United Energy reduced voltage by ~3% to achieve 30MW of flexible demand). Nationally, this would equate to around 450MW

Batteries (AEMO forecasts that grid-scale battery storage will reach 5GW by 2025 and 19GW by 2040 with potential to swamp the market for FD)

Electric vehicles. Indicative 40–100 kWh per vehicle

Solar PV curtailment (for managing minimum demand)

Flexible demand from standby gensets (2GW) is common, and may be a significant fraction of aggregated commercial and industrial FD capacity, that is cost effective at prices above $300/MWh

Table 1: Contracted companies under the RERT - January 2019 to December 2020

Company	Industry sector	Max capacity contracted (MW)
AGL Energy Services	Electricity retailing	12
Alcoa Portland Aluminium	Aluminium smelting	440
Australian Steel Company	Iron Smelting and Steel Manufacturing	51
Cadia Holdings	Gold ore mining	68
Enel X	Electricity retailing	50
Energy Australia	Electricity retailing	22
Infrabuild	Iron Smelting and Steel Manufacturing	38
Intercast and Forge	Iron Smelting and Steel Manufacturing	10
Paper Australia (trading as Australian Paper)	Pulp, Paper and Paperboard Manufacturing	30
Powershop	Electricity retailing	4
Progressive Green (Flow Power)	Electricity retailing	74
Reposit Power	Electricity retailing	4
South Australia Power Networks	DNSP	217
Tomago Aluminium Company	Aluminium smelting	300
United Energy	Distribution Network Service Provider (DSNP)	30
Victoria Power Networks Pty Ltd	Distribution Network Service Provider (DSNP)	**40**
Visy Industries	Pulp, Paper and Paperboard Manufacturing	32
Total	-	**1422**

Priority sectors

Research state-of-the-art review

Looking to the next viable tranche of FD in Australia, it is estimated that approximately half the industrial subsectors have a moderate capacity for FD. Industries with more limited potential are metals: both non-ferrous and iron & steel; food processing; and chemicals. This is primarily due to the limited flexibility of, and importance of energy in, their production processes. Emerging FD opportunities appear to be in the commercial sector, at least partly resulting from the potential of "Industry 4.0" digital technologies to aggregate (through advanced monitoring and control technologies) loads across organisations.

Sectors and loads were ranked for suitability based on a HUFF matrix scoring framework

- **H**omogeneity: solution is replicable.
- **U**biquitous: solution is scalable
- **F**easible (techno-economic): solution is cost effective
- **F**easible (realistic): solution fits with industry

The heat map identifies targets in (i) commercial building HVAC, (ii) agriculture and water sector pumping and (iii) agriculture and food manufacturing refrigeration and cold storage.

Industrial Sub Sectors

	Refrig-eration	Heat pumps	Irri-gation	Thermal storage	Processes	Material storage	Embedded generation	Electrical storage
Iron & Steel		56		56	70		70	63
Pulp & Paper		64		64	80	64	80	72
Cold stores	72	72		72			90	81
Water utilities		72		72	90	72	90	81
Agriculture	80	80	90	80	100		100	90
Mining		64		64	80		80	72
Chemicals	56	56		56	70		70	63
Cement		64		64	80	64	80	72
Manufacturing	80	80		80	100		100	90
Aluminium		56		56	70	56	70	63

Commercial Sub Sectors

	HVAC	Heat pumps	Hot water	Thermal storage	EVs	Pool pumps	Embedded generation	Electrical storage	Refrig-eration
Retail	70	56	63	63	35		63	70	
Offices	80	64	72	72	40		72	80	
Warehouses	80	64		72	40		72	80	72
Apartments	90	72	81	81	45	72	81	90	81
Public buildings	90	72	81	81	45		81	90	81
Data centres				63			63	70	
Supermarkets	90	72	81	81	45		81	90	81
Aquatic centres		72	81	81	45	72	81	90	

Digital enablement

The first two waves of digital innovation were built on technical breakthroughs around personal computing and the internet. The next “Industry 4.0” wave of digital innovation involves a convergence of information and communication technology with physical processes applicable across a broad cross-section of industries. It is inherently about enabling informed yet autonomous decisions, for flexibility and agility.

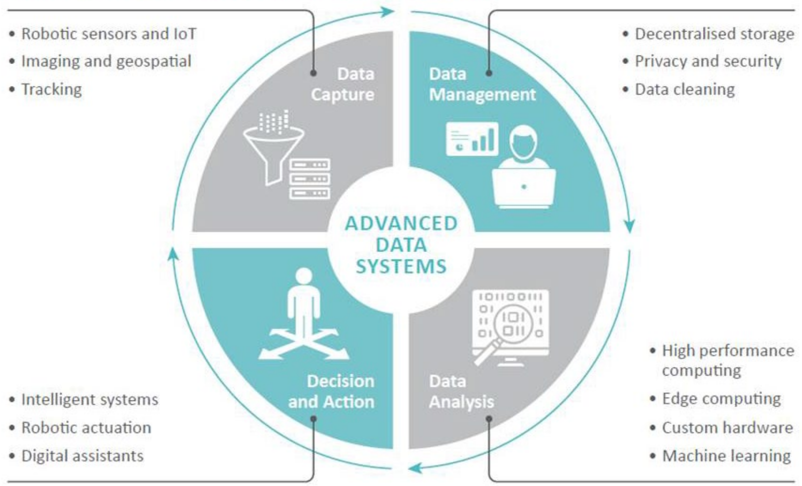
Relevant innovations can be grouped as follows

- **Data capture:** The “Internet of Things” IoT enables ubiquitous sensing and situational awareness, bringing information back from ‘the field’ to the cloud where it can be used to inform decision making. IoT could enable low-cost alternative settlement approaches (than billing meters)
- **Data Management:** Data platforms that link disparate data sources (eg weather forecasts, NEM price forecasts, equipment operational status, IoT sensors) and provides contextual structure, so that information can be understood and exchanged by machines. Managing privacy and security (potentially utilising blockchain)

AlphaBeta, 2018, “Digital Innovation: Australia’s $315B Opportunity”

EXHIBIT 6

DATA INNOVATION RELIES ON SPECIALISED SYSTEMS FOR DATA CAPTURE, MANAGEMENT, ANALYSIS, AND ACTION



- **Data Analysis:** Applications of AI and machine learning that can identify patterns in the data, determine robust energy baselines for M&V and provide predictive capability to optimise plant scheduling.
- **Decision and action:** Machine to machine automation of equipment operation with embedded business rules that manage stakeholder needs and give visual interfaces for supporting positive human interaction.

Digital platforms have the potential for scaling large numbers of smaller FD transactions in a way that (i) improves the business case, through reduced transaction costs and (ii) could overcome cultural/behavioural barriers through streamlined energy-user engagement and building trust.

D.3 Valuing FD. Pricing and policy incentives

Ex-ante flexible demand valuation methodologies

Taking a long-run whole-of-system perspective, "how much flexible demand is the right amount in an ideal efficient and reliable electricity system?". This perspective could be used to set targets for FD, through some forward-looking plan such as the ISP. Literature was reviewed on how this question might be answered.

- AEMO (2019) found that 8.5% of forecast peak demand is a reasonable contribution from DR resources
- Energetics modelling found that 300MW FD in NSW (2.2%) could reduce average spot price by more than 7% and reduce unserved energy by about 400MWh each year

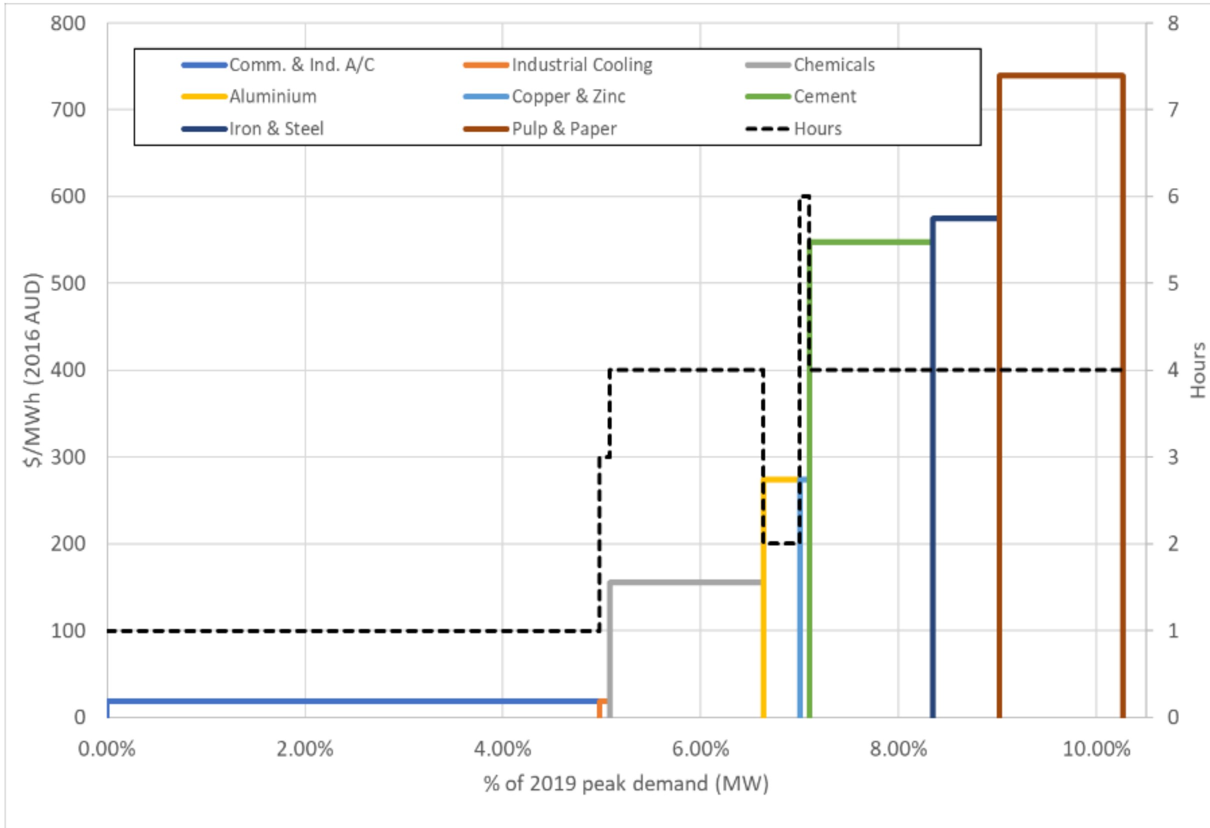
Five key sub-questions were identified that a system level benefits evaluation should address. Four system level benefits evaluation methodologies were identified and evaluated for their explanatory capability.

There is a significant gap in the analysis of the ex-ante characteristics of FD potential in Australia. The review highlighted that capacity, flexibility and responsiveness (not just markets) must be valued to meet physical and operation requirements of the power system. Additional bottom-up resource assessment will also be required to firm up models.

Ability of Four Valuation Methods to Address Key Questions	Avoided Cost	Integrated Resource Planning	Market Simulation Model	Real Options Valuation
Multiple Perspectives	✓	~	~	~
Value quantification	✓	~	~	✓
Multiple Revenue streams	×	✓	✓	×
Uncertainty	×	✓	✓	✓
Reliability benefits	×	✓	✓	×

	Avoided Cost	Integrated Resource Planning	Market Simulation Model	Real Options Valuation
Purpose	Cost vs benefit from the perspective of an individual participant	Least cost whole of system planning	Wholesale market impacts	Recognise benefits of choice flexibility to mitigate impacts of uncertainty
FD Value	Costs had the FD program not occurred	Compare least cost plan with and without FD	Impact on market prices	Evaluation of right, but not obligation to exercise FD
Value Stack	Limited consideration of FD competition or mutual exclusivity in practice	Supply curves can be incorporated but are analysed separately	Models FD and generation competition	Complicated
Uncer-tainty	Typically not included, extension potential	Scenario analysis, probabilistic assessment	Monte Carlo probabilistic,	Geometric Brownian Motion
Reliability Valuation method	Value of Customer Reliability (VCR)	Value of Lost Load (VOLL), UnServed Energy (USE), Loss of Load (LOLP)	Stress test scenarios	Black Scholes equation
Limit-ations	Missing - Uncertainty - Reliability - Demand Elasticity - Whole of system assessment	- Data intensive - Top down approach/ FD analysed separately - Fast Time scales missing - Individual participant perspectives missing	Requires integration with capacity investment planning models	- Complex maths/ communication challenges - data, assumptions requirements

FD doesn't squeeze well into existing market frameworks



Estimate of industrial and commercial turn-down demand technical potential in the UK

Charles River Associates. An assessment of the economic value of demand-side participation in the Balancing Mechanism and an evaluation of options to improve access. (2017).

Peak demand in the NEM is ~35 GW. AEMO's suggestion that ~8.5% might be a suitable amount of flexible demand in an efficient market suggests a target of ~3 GW.

Between air conditioning load shifting (~1.2 GW), industrial load shedding (~1.5 GW), standby gensets (~2 GW) and batteries (~5 GW in 2025), there is no shortage of technical capacity competing to be the flexible demand source of choice.

So, in an economically rationale world, the uptake would presumably be where the bid stack for flexible demand meets the bid stack for electricity supply (some combination of wholesale energy and other possible value streams)

Unfortunately, on the FD provider side units of cost in the literature are jumbled ($/kVA, $/kVA/year, $/MWh), transaction costs are difficult to assess, and the potential to include other value streams (UPS reliability, energy efficiency) all combine to make it very difficult to create a bottom-up bid stack. Similarly, on the FD buyer side it is difficult to obtain a single vertically-integrated (value stack) price for comparison.

Size of the wholesale market prize

What does the last 1GW cost consumers?

In the absence of an easy bottom up analysis, it is interesting to look at how much it costs the electricity system to provide the last (rarely used) 1 GW of capacity. This could be viewed as a proxy for the long-run value that would be unlocked if there was a target of ~3% of peak NEM demand sourced from dispatchable shift/shed Flexible Demand resources. Such analysis is closer to an 'integrated resource planning' assessment (than 'avoided cost').

A simplified analysis, using 2018 NEM half hourly spot price/volume data, was undertaken to provide a rough estimate of the benefit to consumers of setting a 1 GW/3% target. Average NEM price over 2018 was $86.8/MWh

Value to the FD provider

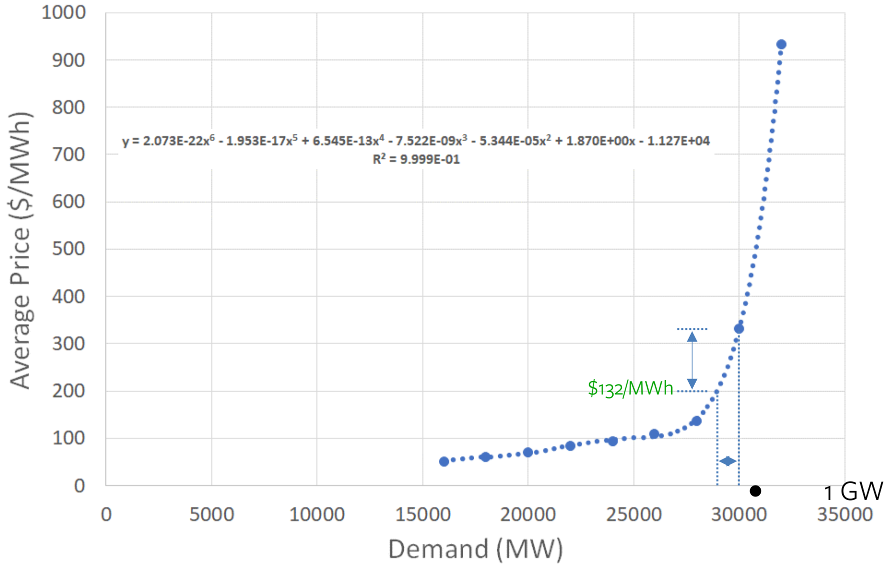
- for each half hour interval where price > $120MWh, 1 GW of flexible demand was dispatched at a cost of $86.8/MWh – giving value to the FD provider of ~$70m/year ($70/kW/yr)

Value saved in the pool

- the average price of electricity was determined for bins of NEM demand (15 to 17GW bin, 17 to 19 GW bin etc) and used to correlate price with demand
- For each interval where price >$120/MWh, 1 GW of flexible demand was dispatched. The change in settlement price Δ_{price} was calculated and the change in pool value estimated for each half hour

$$\Delta_{Value} = (\Delta_{price} * (\text{Demand} - 1\text{GW}))/2$$

- This reduces wholesale market cost by $290m/year ($290/kW/year)



Benchmarking against other top-down numbers

The NSW Peak Demand Scheme estimates $4.30/MWh reduction in average wholesale price from an FD contribution of 7.5% (2.7 GW) in NSW. This would scale to ~$842m/year in savings across the NEM

Ignoring fuel cost the average annual cost of the NEM wholesale market spread across NEM peak demand is ~$460/kW/year

↳ The numbers estimated here are conservative

Size of the prize (full vertically integrated value stack)

Source	Value	Basis	Additionality
Wholesale (Shift and shed)	$290m/yr	1GW demand reduction triggered whenever wholesale price rises above $120/MWh, leading to lower pool prices	Yes
Network (Shed, shift and shape)	$100m/yr	1GW can be provided at average long run *marginal* cost of $100/kVA/yr (note: customers are charged average ~$387/kVA/yr)	Yes
RERT (Shed)	$30m/yr	Existing market	No
FCAS (Shimmy)	$24m/yr	20% of a $120million/yr market (~300MW)	Partly
	$444m/yr	Value from ~1GW of Flexible demand (~$444/kW.yr)	

Minimum demand ~$10m/year

(5 GW of avoided PV curtailment for 20 h at FIT of 10c/kWh)

Benchmarking against other comparable studies

Having identified over 5GW of flexible demand potential, a target of 1GW seems eminently achievable. With $444/kW per year of value on the table, the identified flexible demand sources should be highly cost effective. For example, the Energy Queensland broad-based air conditioning program could provide flexible demand at around $30/kW per year utilising existing AFLC infrastructure for free (but is limited to use during hot weather conditions).

Even an expensive flexible demand option such as batteries could provide last GW capacity at ~$143/kW per year – suggesting a potential to provide consumers with at least $300m/year in bill savings [1 GW at ($444–$143)/kW per year]

Customers would benefit substantially if more FD providers were attracted into the market, by paying them a higher fraction of the long-run whole-of-system value. Unfortunately, this does not appear to be possible under the current market framework

Pricing and incentives literature review

Price and incentive-based FD programs were reviewed including over 200 demand side management programs analysed in 2004 for the IEA. Rebates and cash inducements cover the majority of programs (rather than tariff incentives). Other incentives include subsidised improvements to customer energy efficiency, and gifts or merchandise. The financial risk and energy availability risk are variously shared between the FD service provider and purchasing counterparty. In programs involving subsidies and non-financial inducements, the risk of non-delivery is typically borne by the purchaser of the FD service.

Breakdown of Incentive Types Used in 200 DSM programs

Category	Incentive	Program Proportion
Tariffs and Pricing	Tariff reduction	9%
Financial Rewards	Rebates and cash awards	52%
Other subsidies, discounts, or free of charge improvements	Financing, loans and leasing	13%
	Bulk purchasing	9%
	Direct installation	7%
Non-financial	Gifts and merchandise	4%
	Other	14%

A review of US energy efficiency programs (in 1992) found that larger scale, older (mature) programs were more cost-effective. Another review of 122 programs found that 51 programs achieved 0.1 (cost to benefit) or better, 73 achieved 0.3 or better, and only 16 programs were worse than break even.

Pricing/ incentive scheme suitability by FD capability

Time-varying Energy Price Based Programs	Incentive-Based Programs
• Time-of-Use Pricing • Peak Time Rebate • Critical Peak Pricing with Control • Critical Peak Pricing • System Peak Response Transmission Tariff • Real-Time Pricing	• Demand Bidding and Buyback • Direct Load Control • Interruptible Load • Load as Capacity Resource • Regulation Service • Non-Spinning Reserves • Spinning Reserves • Emergency Demand Response

Offer to Customer	• Peak Load Pricing	• System Peak Response Transmission Tariff • Real-Time Pricing	• Interruptible/ Curtailable Load • Load as Capacity Resource	• Demand Bidding and Buyback • Time-of-Use Pricing	• Peak Time Rebate • Critical Peak Pricing with Direct Control • Critical Peak Pricing • Peak Day Rebate	• Direct Load Control • Non-Spinning Reserves • Spinning Reserves • Emergency Demand Response	• Regulation Service
	Price	Price	Incentive	Price	Price	Incentive	Incentive
Shape	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓		
Shift	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓		
Shed		✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓
Shimmy							✓✓✓

Government intervention options

The structure and market design of the Australian electricity industry constrains the type of energy tariffs and other incentives that energy suppliers can offer to FD providers. This, at least partly, prevents FD services from accessing fair return from the full stack of potential value streams (wholesale, network, reliability etc). It also creates complexity which is difficult for energy users (FD providers) to navigate.

A range of government policy instruments could be deployed to overcome these barriers and create a more level playing field for FD.

Many recommendations in the literature are for network regulation and pricing reform with the aim of enhancing transparency and competition in networks and energy markets. Recommendations also emphasise the need for better co-ordination and provision of information (both mandatory and voluntary). Some studies point to the need to encourage the role of intermediaries, mostly through regulatory reform.

Demand Side Management Policy Support Mechanisms

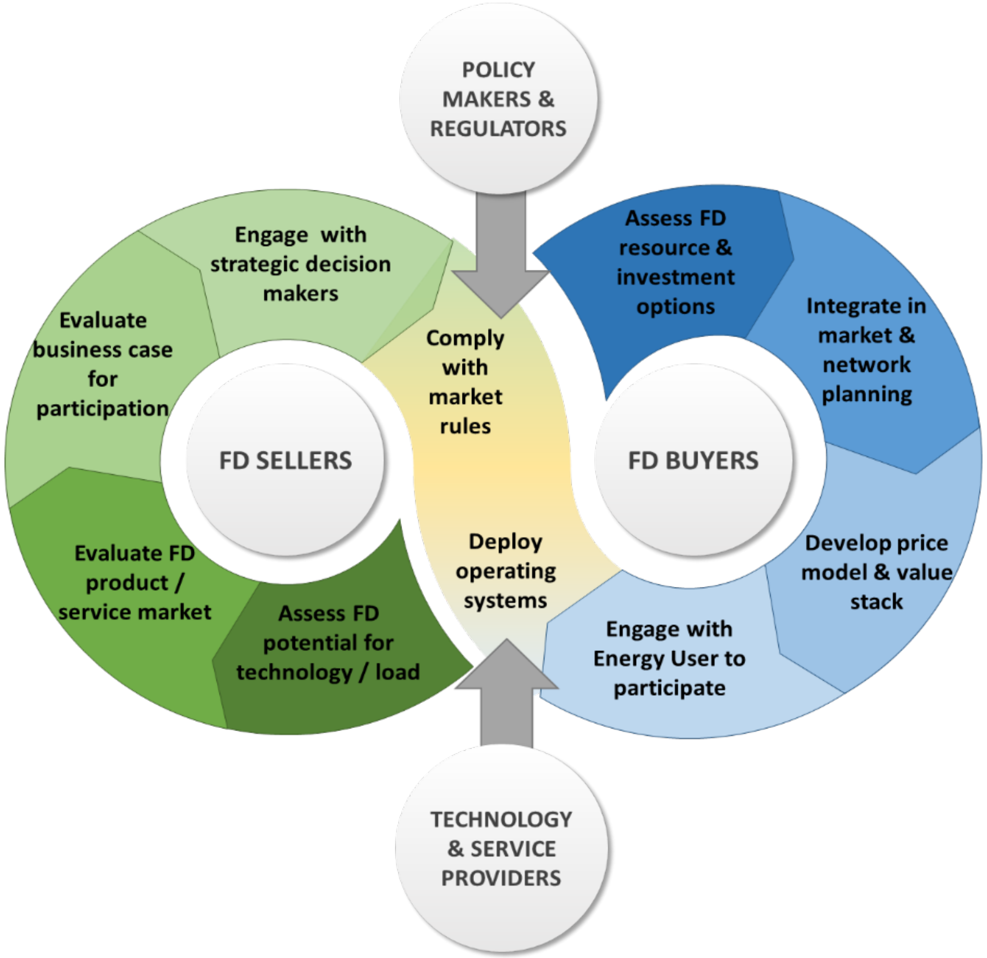
Control Mechanisms	
C1	Mandatory sourcing of energy efficiency
C2	Energy efficiency licence conditions for electricity businesses
C3	Integrated resource planning
C4	DSM and energy efficiency as alternatives to network expansion
C5	Revenue regulation
Market Mechanisms	
M1	Taxes on energy
M2	Tax exemptions and incentives for energy efficiency
M3	Providing consumption information on customers' electricity bills
M4	Communicating pricing and other information for energy efficiency
M5	Energy performance labelling
M6	Developing an energy efficiency brand
M7	Cooperative procurement of energy efficient appliances and equipment
M8	Energy performance contracting
M9	Competitive sourcing of energy services
M10	Competitive sourcing of demand-side resources
M11	Demand-side bidding in competitive markets
Funding Mechanisms	
F1	Public benefits charge for energy efficiency
F2	Financing of energy efficiency by electricity businesses
Support Mechanisms	
S1	Sustainable energy training schemes for practitioners
S2	Energy centres
S3	Creating entrepreneurial energy organisations
S4	Developing the ESCO industry
S5	Promotion of energy efficiency by industry associations
S6	Aggregating electricity purchasers to achieve energy efficiency
S7	Voluntary agreements for energy efficiency

D.4 Research priority areas

Votes for Priority Research Areas	Priority	Tally
Economics and incentives		
1.Investigate alternative tariff structure models, price signalling mechanisms and impacts on customers	1	23
2.Investigate options to drive FD to address network issues (including minimum demand) either by encouraging NSPs to procure FD or creating open markets for FD.	1	16
3.Investigate options to facilitate value stacking	1	13
4.Investigate aggregator models and concept of FD 'buyer'	2	9
5.Review the early operation of WDR mechanism		
Technology		
6. Develop data management tools and interoperability/data standards for streamlining information exchange	2	5
7. Examine options for improving real-time metering of supply and demand in distribution networks	2	8
8. Feasibility studies and demonstration of technologies and loads that provide FD (EV's, batteries, HVAC, standby gensets etc)	1	11
9. Develop M&V baselining tools, guides and settlement procedures	2	4
10. Review options for uniform technical standards	3	4
Cultural and Behavioural		
11. Study customer decision-making and participation triggers	1	17
12. Develop strategies to improve energy user awareness and understanding of flexible demand (e.g. FD advocate)	1	19
13. Investigate flexible demand contracting Ts and Cs	3	4
14. Research cultural barriers within energy industry	3	1
Other		
15. Investigate costs and benefits of governance reform to encourage demand-side activity	3	2
16. Investigate processes, standards and requirements for FD registration and compliance	3	2
17. Investigate methodologies and benchmarks for demonstrating FD supply firmness & cost-effectiveness	2	7
18. Identify opportunities for creating more transparency and certainty for FD providers	2	7
19. Identify DR potential in specific end-use sectors	2	8

D.5 Research roadmap

Four roles and the dance of intimacy



Role related research priorities areas

	Theme	Strategic Integration	Enabling FD Buyers	Supporting FD Sellers	FD Products, Services & Implementation	Knowledge Sharing and Outcomes Assessment
	Target Audience / Actors	Policy makers, AEMO, AER Energy User Associations Company Boards	Networks, Retailers, Aggregators, AEMO	Energy Users (C&I)	Technology Providers Energy Users (C&I) – Procurement , Engineers	All of industry
Intervention/ Policy Palette	Regulation (Policy, Standards, Targets)	Market Design & Rules for FD	Network FD Methodologies	Rules & Systems for Consumer Participation	Technical Standards	Policy Evaluation & Monitoring
	Information	Engagement with C&I decision-makers	FD Resource Assessment Tools	FD Potential (sectors, loads, technologies)	FD Technology Trials	Industry Use Cases
	Pricing & Incentives	FD Buyer/ Market Models (roles and rules)	Pricing Models & Value-Stacking	FD Pricing Trials	Metering, M&V & Settlement	Pricing Trial Knowledge Sharing
	Facilitation			Consumer Participation Determinants	Information & Data Models, Systems & Standards Contracting Standards	Change Management Processes and Cultural Acceptance
	Coordination	Important to be addressed, but probably not a direct *research* topic for the RACE for 2030 CRC				

Other relevant research themes in RACE

Stream	Content
N2	Low voltage network visibility and optimising DER hosting capacity
N3	Local DER network solutions
N4	Distributed system operator and beyond: optimising planning and regulation for DM & DER
H1	Residential solar precooling
H3	Using home energy technologies for grid support
H4	Rewarding flexible demand: customer-friendly cost reflective tariffs and incentives
H5	Smart Algorithms for optimising home energy supply and use
B1	Value chain optimisation to transform energy productivity
B2	Industry 4.0 for Energy Productivity (including IoT, advanced metering/reporting)
E1	Trust building for collaborative win-win customer solutions

D.6 Recommendations

Recommended CRC investment in three streams

1. Strategic barriers & solutions stream

- Research projects to address key industry barriers identified in the OA workshops, identify an optimum fit of FD with electricity industry needs and help to create the right market framework for trading Flexible Demand
  - Supporting networks
  - Price and value stacking
  - FD valuations reflect a vertically integrated value-stack
- ~30% investment

2. Sectoral transformation pathways stream

- Consortium based research *programs* targeted at specific needs of identified priority sectors to encourage rapid adoption of flexible demand, under the existing market framework.
  - Commercial buildings/ HVAC
  - Water/agriculture/pumping
  - Food manufacturing/cold storage
- Credible utilisation narratives tba
- ~50% investment

3. Industry partner enablement stream

- Tactical research projects that enable individual RACE industry participants to grow, bring products to market and achieve impact. This would include product feasibility studies and technology trials.
- ~20% investment

Covering identified priorities

Stream 1: Strategic Barriers & Solutions
Stream 2: Sectoral Transformation Pathways
Stream 3: Industry Partner Enablement

	Theme	Strategic Integration	Enabling FD Buyers	Supporting FD Sellers	FD Products, Services & Implementation	Knowledge Sharing and Outcomes Assessment
	Target Audience / Actors	Policy makers, AEMO, AER Energy User Associations Company Boards	Networks, Retailers, Aggregators, AEMO	Energy Users (C&I)	Technology Providers Energy Users (C&I) – Procurement , Engineers	All of industry
Intervention/ Policy Palette	Regulation (Policy, Standards, Targets)	Market Design & Rules for FD	Network FD Methodologies	Rules & Systems for Consumer Participation	Technical Standards	Policy Evaluation & Monitoring
	Information	Engagement with C&I decision-makers	FD Resource Assessment Tools	FD Potential (sectors, loads, technologies)	FD Technology Trials	Industry Use Cases
	Pricing & Incentives	FD Buyer/ Market Models (roles and rules)	Pricing Models & Value-Stacking	FD Pricing Trials	Metering, M&V & Settlement	Pricing Trial Knowledge Sharing
	Facilitation			Consumer Participation Determinants	Information & Data Models, Systems & Standards Contracting Standards	Change Management Processes and Cultural Acceptance
	Coordination	Important to be addressed, but probably not a direct *research* topic for the RACE for 2030 CRC				

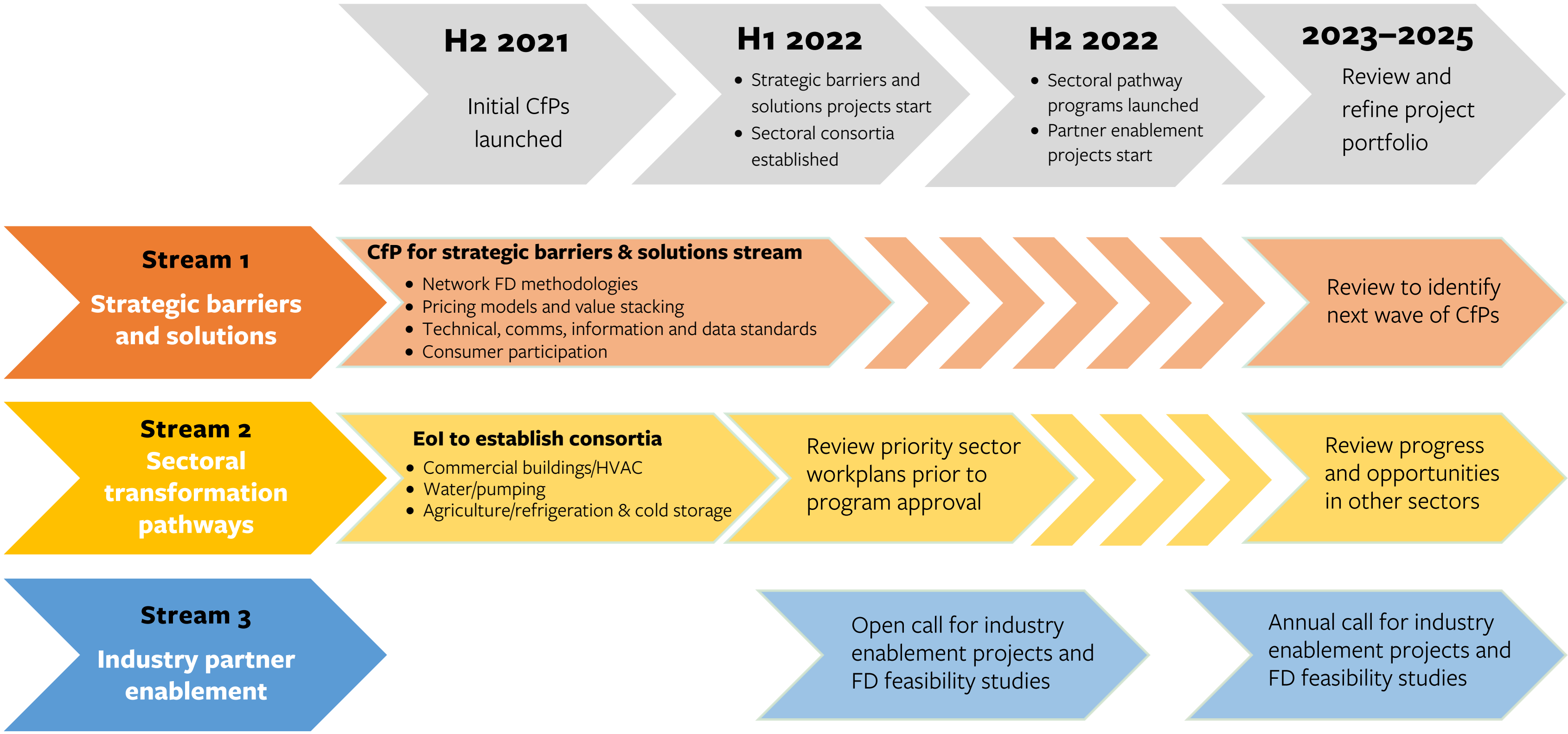
Commercial buildings/ HVAC sectoral transformation pathway

(example for illustrative purposes)

Desired Impact	• Assist commercial and institutional building owners to increase building energy ratings and building asset value, reduce emissions and energy bills • Provide **200MW of flexible demand** to support increased grid reliability, 15% reduction in energy bills and **5Mt/yr CO_2-e/yr savings** • **>10,000 jobs** in the building automation + facilities management industry
Pathways to Impact	The hypothesised transformation pathway is for the CRC to conduct research to support state and federal government intentions to lead by example with their own building portfolios (NEPP Measure #12). This could be achieved by developing additional terms for green-leases, that **require compliant buildings to be 'flexible demand ready' (by registering their *measured flexible demand capacity*)**. This is a proven pathway where government uses its purchasing power to unlock market transformation through the adoption of green-leases. Key identified barriers would be overcome as follows. • ***Low and split incentives***: Market forces would drive incentive for action from landlords. Green-leases have implications on building occupancy rates which is a core business issue and far more financially motivating than energy costs. Linking flexible demand to green-leases also links FD to net zero commitments. • ***Capability barriers***: A standardised clause in green-leases would create a standardised service offering (ie registering measured flexible demand capacity). Suppliers would be able to build up capability and capacity to service this market demand. • ***Transaction costs:*** A standardised clause in green-leases would create a standardised 'known' tradeable commodity. This would substantially reduce financial and technical uncertainty. In order to register *measured* flexible demand capacity, all the required technology would need to be installed. This would eliminate subsequent technology investment costs. The volume of buildings being upgraded would also help to drive scale and cost reduction

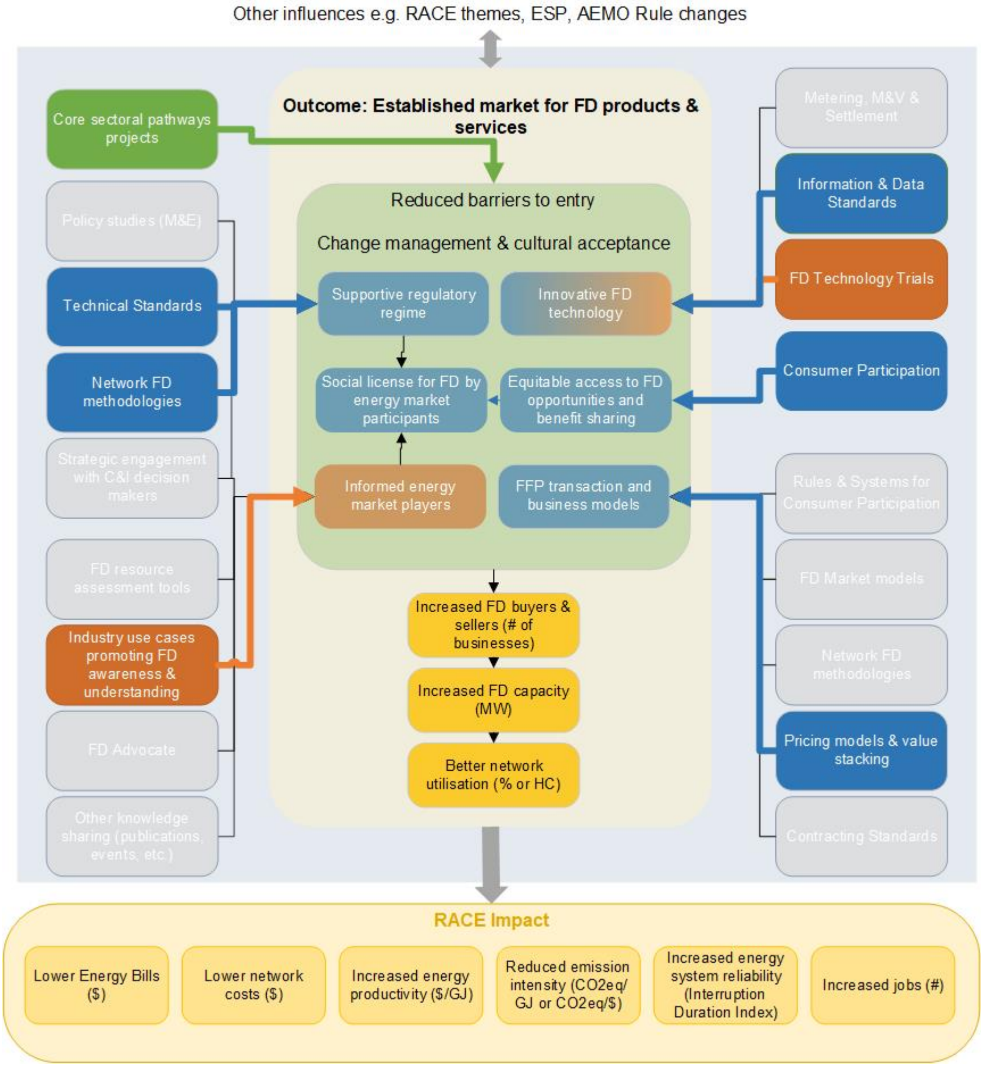
Scalability	Commonwealth and State Governments own or lease over 5 million m² of floor area. This represents a significant portfolio of buildings in Australia that could shift the market toward adoption of Flexible Demand; building critical mass and capability for broader adoption across the nation. The technology required to adopt Flexible Demand in commercial buildings is cost effective, such that there is no fundamental economic barrier to scaling the market.
Capability Inputs	• Host site buildings: **CRC's State and Federal Government participants** are large building portfolio owners and tenants. In the National Energy Productivity Plan they have committed to 'lead by example' (measure #12). • Technology capability: A number of CRC industry and research participants have developed **smart buildings technology** (IoT, smart metering, HVAC data streaming, trading platforms…) that could be used to support automation of FD. • Flexible demand buyers: CRC participant **networks, retailers, aggregators** can provide voice of customer input for developing new business models.
Key research Opportunity / Activities	• ***FD Trials and Resource Assessment Tools/ FD Potential***: • ***Metering M&V and Settlement***: Test the rigour and cost of alternative commercial building baselining and metering/monitoring approaches • ***Information Data and Contracting Standards/ Rules & Systems for Consumer Participation***: Identify technical requirements for automating and integrating Flexible Demand services from commercial buildings. Develop standards and definitions that could be incorporated in green-lease schedules. • ***FD Pricing Trials/Contracting Standards***: Develop one-stop-shop (easy to understand) flexible demand product valuation and price signalling interfaces that simplify flexible demand contracting for the property industry. • ***Change Management Processes** and Cultural Acceptance/ Strategic Engagement with C&I Decision Makers*: Identify and communicate the role of flexible demand in the net zero industry narrative. Work with industry bodies to obtain endorsement for standardised procedures. Provide user friendly online interfaces for facilities management staff, that integrate well with existing work-flows.

Proposed process



Impact pathway

From activities to outcomes to impact



Stream 1: Strategic barriers & solutions
Stream 2: Sectoral transformation pathways
Stream 3: Industry partner enablement

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