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V2X.au Summary Report – Opportunities and Challenges for Bidirectional Charging in Australia

30 June 2023

Prepared for the Australian Renewable Energy Agency

ARENA disclaimer

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Executive Summary

About this report

This report provides a high-level snapshot of the current state of V2X technologies, and associated opportunities and challenges for the Australian market. It has a particular focus on residential and light commercial vehicle-to-grid (V2G) applications. Findings in the report are based on interviews with national and international supply chain stakeholders and cash flow modelling for 24 residential customers across the National Electricity Market (NEM).

The opportunity for Australia

While future consumer uptake of bidirectional charging is uncertain, it is clear that the scope of the economic opportunity for Australia is enormous.

Bidirectional EV charging represents one of the largest potential enablers of Australia's energy transition. To put it in context, AEMO's 2022 ISP reported that the NEM will require 640 GWh of all forms of storage by 2050. As shown in Figure 1, the usable storage in Australia's EV fleet at that time will be nearly four times total NEM storage requirements. Flexible bidirectional charging from only 10% of this capacity could provide 37% of total NEM storage needs, offsetting around $94 billion of large-scale battery storage investment (at current prices)[2]. By the early 2030's, EV fleet battery capacity is likely to surpass all other forms of storage in the NEM, including Snowy 2.0 (see page 12).

The near-term capital cost premium for enabling V2G (DC V2G) is estimated at around $25,000/MWh, or 6% of current large-scale battery costs on a simple per MWh basis. The basis of this cost advantage is that the cost of enabling V2G is only a marginal increase in the cost of installing a V2G-capable charger. The battery comes with the car.

Compared to other jurisdictions (such as Germany, the Netherlands, South Korea and California), Australia lacks a policy framework to accelerate the supply of bidirectional charging-capable equipment. In some ways, our complex and opaque framework for technical standards and regulation makes Australia one of the hardest developed economies for international OEMs to enter. There are a range of ways that policy can make Australia a more attractive target market, and these are explored through this report.

[1] 2022 Integrated System Plan (p.10) [2] CSIRO GenCost 2022-23 consultation, $400,000/MWh (p.18) [3] Based on an $1500 price premium for an installed EVSE [4] Commercial-Readiness-Index [5] Integrating Energy Storage Systems, Unlocking CER benefits through flexible trading, Scheduled Lite Mechanism

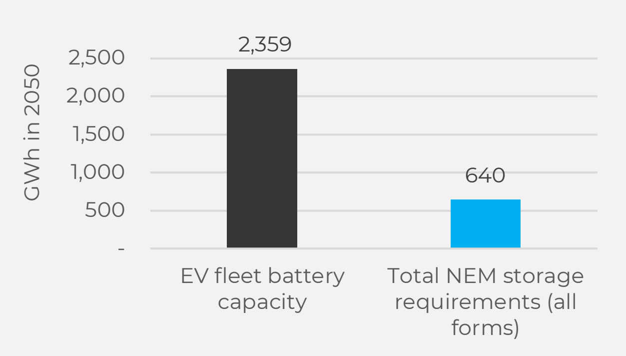

Figure 1: Estimated gross energy storage capacities in the NEM in 2050 (GWh)

Total NEM Storage requirements from AEMO 2022 ISP[1] See Appendix C for details about EV fleet battery assumptions. Figures do not represent estimated or likely resource availability.

Key findings

1. Australia's EV vehicle fleet will be largest and lowest cost *potential* storage resource in our energy transition. Wide ranging measures are needed to make the most of this opportunity. National EV policy should signal that we value V2G and V2H/B as a near term priority for industry development and we should set out a V2G vision in our National EV Strategy.
2. Australia will be left behind in the early stages of global growth in V2G due to our limited engagement in international standards development and product certification processes for Electric Vehicle Supply Equipment (EVSE). Government and network businesses can play more active role in supporting new product homologation, as is done in other jurisdictions.
3. The current AS 4777.2:2020 listing issues can be addressed immediately by the Clean Energy Council agreeing to a more permissive interpretation of the standard, reflecting its original intention, while it is being revised.
4. Formal V2G functionality in OCPP (the dominant framework to manage EVSEs) remains under active development. Established local communications protocols should be supported by EVSE OEMs (e.g. as Modbus TCP/IP), to enable advanced V2G applications (e.g., flexible export limit conformance, frequency response).
5. Network tariffs can make or break V2G. Networks should collaborate to develop more V2G-supportive tariffs to signal national coherence to international supply chain stakeholders. The most preferable current pricing arrangements are bidirectional network support tariffs.
6. V2G is most valuable when exposed to wholesale spot-passthrough arrangements.
7. ARENA should consider funding V2G supply chain facilitation initiatives while also investing in early commercial trials (CRL 2-3[4]) demonstrating CSS-based V2G incorporating the ISO 15118-20 communications standard and other open communication protocols (e.g., Modbus, OCPP).

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** Long-form URLs are provided for all hyperlinked text to fulfil report accessibility requirements*

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About enX

enX works at the cutting edge of distributed energy resource integration, bridging contemporary local and international technology and commercial innovation with high-profile national policy reform and grid strategy initiatives. Distributed energy resources are a heavy lifter in Australia's decarbonisation journey, and we want to unlock their full potential.

V2X typologies and use cases

Vehicle-to-X (V2X) is a set of capabilities that allows electric vehicles to export power to a home or building (V2H/B), to the grid (V2G) or directly to an electrical appliance (V2L). While V2L is easily identified by a general-purpose outlet being located inside or outside the vehicle, there is no internationally agreed way of differentiating between other V2X types.

In this report we differentiate V2H/B and V2G by the configuration of infrastructure external to the vehicle, meaning the underlying capabilities of the EV is essentially the same. We refer to V2H/B where the whole electrical system is **islanded from the grid**. Conversely, V2G is **grid connected** and coupled with the prevailing AC grid frequency (e.g., 50Hz). Whether or not a generating system is coupled to the grid has important implications for system electrical design, the capabilities of the power conversion equipment and requirements for grid code compliance (e.g. AS/NZ 4777.2:2020, AS/NZS3000:2018 and local network Service and Installation Rules).

Like photovoltaic solar panels, EV batteries produce direct current (DC) which generally needs to be converted to AC prior to use. This conversion can occur within the vehicle itself using an **onboard power converter** or via an **external power converter**.

Figure 2 provides the taxonomy of V2X types as used in this report, while **Figure 3** provides a high-level summary of V2X technical characteristics and example consumer use cases.

Compared to V2G, V2H/B has much more limited application and economic value for mass-market grid connected customers. However, it is important not to understate the value of having a back-up power supply in areas of poor electricity network reliability or in remote locations where the cost of establishing a grid connection is prohibitive. Australian consumers may also like the idea that they can be more 'independent' from the grid.

Figure 2 – Technology-based taxonomy of V2X types

	Grid islanded	Grid connected
Power converter external to EV	DC V2H/B	DC V2G
On-board power converter	AC V2H/B V2L	AC V2G

Figure 3 – V2X Types, technical characteristics and example consumer uses cases

V2X Category	Technical characteristics	Example consumer use cases
V2L	Provides grid forming AC power through general purpose power points inside or outside the vehicle. The power converter is on-board.	• Charging electronic devices while driving (where the outlet is inside the cabin) • Mobile generator for selected appliances (e.g., power tools or camping fridge) • Back-up generation to selected appliances (e.g., refrigeration during a blackout)
AC V2H/B	Provides grid forming AC power through to a building electrical circuit that is islanded from the grid. The power converter is on-board.	• Backup power supply to an islanded electrical circuit (e.g., a backup supply circuit of a home or building) • Power supply to an off-grid premises (e.g., a farm shed) where only temporary power supplies are needed • Islanding of a building to reduce grid imports • Customers who want greater perceived independence from the grid
DC V2H/B	Provides DC power to an off-board inverter that then provides grid forming AC power to a load. The electrical system is islanded from the grid.	
AC V2G	Provides grid following AC power through an electrical circuit that is coupled to the grid. The power converter is on-board.	• Electricity spot market participation (including solar shifting) • Electricity retail and network tariff mitigation (including solar shifting) • Providing network support services (e.g., peak demand mitigation, power quality services)
DC V2G	Provides DC power to an off-board inverter that provides grid following AC power to load. The circuit is grid-connected.	

The standards environment for V2G

V2X requires a working confluence of several relatively independent standards families, i.e.:

- **EVSE to EV communications** (e.g., ISO/IEC 15118, IEC 61851-1, CHAdeMO)
- **EVSE to controlling infrastructure** (e.g., OCPP, IEC 63110, Matter, MQTT, Modbus)
- **Smart grid interoperability standards** (e.g., IEEE 2030.5, OpenADR)
- **Inverter standards** (e.g., AS/NZS 4777.2, IEEE 1547, SAE J3072, VDE-AR-N 4100)
- **Wiring and power quality standards** (e.g., AS/NZS 3000, AS/NZS 3112, AS/NZS 61000.3.12)

The timing of V2G proliferation depends significantly on the above standards families being sufficiently mature, permissive and aligned in any given market. Achieving this is a current global priority – few markets have their market, regulatory and policy settings fully resolved.

The US and EU markets are currently converging in some areas to accelerate V2G adoption as part of their broader energy transitions. While there are differences in standards between these markets (such as IEEE 2030.5 for US smart grids and OpenADR in Europe and many Asian nations), there are similarities and some convergence in relation to small-scale inverter standards across regions (including Australia). Interest in AC V2G in the US has renewed efforts to finalise relevant standards, driven by EV OEMs aiming to offer or support more integrated energy services including retail electricity and demand management services.

OCPP is the de facto means of controlling EVSEs by remote agents. OCPP may be incorporated into future versions of IEC 63110 and it is already mandated in Korea[1] California[2] and under the US National Electric Vehicle Infrastructure (NEVI) funding program (see Table 2)[3]. The upcoming OCPP version 2.1 will formalise V2G control and is only backward-compatible with 2.0.1.

While the OCPP 2.x family is being developed with *some* consideration of Australian requirements, this functionality is not yet finalised. OCPP does not specifically provide for Australian use case such dynamic tariffs, dynamic export limits or AEMO specifications for frequency control ancillary services (FCAS) enablement. Some key V2G value cases (e.g., FCAS), require faster local control with IoT standards (e.g., Matter, MQTT, Modbus). This is likely to result in Australia relying on more readily adaptable local protocols such as Modbus, or other local protocols, until such time as they are provided for in global standards frameworks.

Table 1 – **Key standards and protocols and their current status in Australia**

Standard	Current status in Australia
IEC 62196	IEC 62196 and the Combined Charging System (CCS Type 2) is the apparent market direction in Australia, though is not formalised in requirements, while CHAdeMO represents a shrinking market share.
ISO 15118	ISO 15118-20 is required for CCS-based V2G. Whilst production-ready for DC V2G, significant revisions are underway to finalise before Q1 2024 for AC V2G. ISO 15118 (or CCS, of which it is part of) is not a requirement in Australia.
OCPP*	Version 2.1 of the Open Charge Point Protocol (OCPP) framework is required for *standardised* V2G interoperability. The specification and certification tool is yet to be finalised. Version 2.1 will be backwards-compatible with 2.0.1 (collectively '2.x'), but not with 1.6 which is used widely today. OCPP is not currently a requirement in Australia although SA will require OCPP 1.6 V2 or higher by 1 July 2024.
IEEE 2030.5	Australia is adopting CSIP-Aus[4] based on IEEE 2030.5 as the national profile for communicating dynamic operating envelopes from distribution network businesses to customer premises. These will typically be received by a site gateway device/inverter with local communication to the EVSE via OCPP or Modbus.
OpenADR	The OpenADR 2.0b Profile Specification was approved as IEC 62746-10-1 in 2019 as a systems interface between customer energy management system and the power management system. OpenADR is not currently used or required in Australia.
AS/NZS 4777.2	AS/NZS 4777.2 applies to all grid connected inverters including AC V2G vehicles and DC V2G EVSE (not V2H/B). AS/NZS 4777.2:2020 was designed to facilitate V2G, however it is currently being interpreted by the CEC as requiring IEC 62109-1 and IEC 62109-2 for bidirectional EVSE. There is also an interpretation that AS/NZS 5139 conformance is required for bidirectional EVSE. These issues mean that V2G EVSE cannot get CEC Approved Inverter listing at this time.

Table 2 – US National Electric Vehicle Infrastructure technical requirements for EVSE interoperability [4]

Domain	Required immediately	Required in one year
EVSE to EV communications	Conform to ISO 15118-3, Hardware capable of ISO 15118-2 and ISO 15118-20 ← V2G ready!	Conform to ISO 15118-2, Capable of 'Plug and Charge'
EVSE to CSMS communications	Conform to OCPP 1.6J	Conform to OCPP 2.0.1
CSMS to CSMS communications	-	Capable of OCPI 2.2.1

[1] Announcement from Korea's Ministry of Trade, Industry and Energy [2] Californian Public Utilities Commission
[3] biden-harris-announcement [4] common-smart-inverter-profile-australia *Not yet a formal standard.

The standards testing and certification process

Standards testing and certification are key processes for product homologation in any given market. Processes can be broadly differentiated as:

- **Debugging** – some markets provide test labs where EV and EVSE OEMs can test and debug equipment against design intent and test standards in an informal setting (e.g., the ElaadNL Testlab in Arnhem)
- **Certification** – a process by which an independent, accredited body assesses if a product satisfies the requirements of formal standards.

Typically, EVSE is certified in dedicated e-Mobility certification labs. While more generalised certification facilities can sometimes test products to electrical standards (e.g., AS/NZS 4777.2 for grid connected inverters), they often lack domain expertise and specialised testing equipment and infrastructure (e.g., to physically provide for cars entering a lab). Conversely, specialised facilities can help debug and/or certify for compliance across the full gamut of communications and power flows inherent to V2X.

Australia is perceived as very immature in our approach to testing and certification of EVSE. These issues are reported by international OEMs as an impediment to local market entry which means **Australia is likely to lag other markets in relation to V2G-capable product supplies, competition and price reduction.** The reasons for this are:

- Unlike some major overseas markets (e.g., UK, EU, UK, Korea, India, etc) Australia has not standardised many key aspects of EVSE design (e.g., CCS and its dependent standards, or smart grid requirements). As a result, **there is no definitive, 'Australian specification' for an EVSE** in relation to standards certification to support local market use cases. Whilst some local requirements are defined (e.g., AS/NZS 4777.2), parties bringing V2G products to Australia assume higher risks and costs than in other markets where local specifications are more definitive.
- There are **limited testing facilities** for local or international OEMs to debug smart and bidirectional EVSE against Australian use cases or to perform certification testing against relevant standards. Other markets provide access to test pre-commercial EV and EVSE for free, as an industry development measure, and as a way of supporting their broader energy transitions.

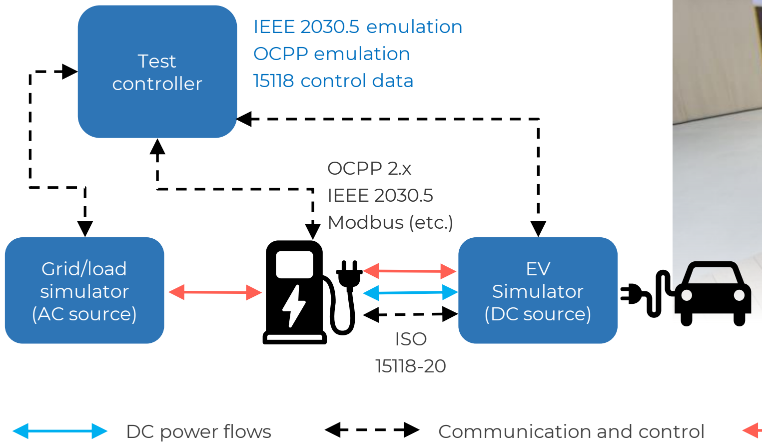
Examples of EVSE test labs

Specialised facilities can test and certify EVSEs and EVs against a broad range of standards covering the EVSE itself, charging cables, communications to the EV, connectors/inlet/plugs, charge station management system communications, grid connection, safety, security, and model-specific features.

Dekra is a leading firm with various facilities globally, and describes a viable infrastructure requirement for automated, bidirectional EVSE test and certification, which is scheduled for deployment in mid-2023. Fully-certified V2G remains a rapidly maturing space.

ElaadNL is a partnership consisting of Dutch grid operators founded as a knowledge-sharing and collaborative innovation centre for smart charging and related knowledge domains. Elaad provides test facilities allowing EVs, EVSEs and related systems to be evaluated. Testing is free of charge. ElaadNL also hosts the Open Charge Alliance, which created (and maintains) both the Open Charge Point Protocol (OCPP) the Open Smart Charging Protocol (OSCP).

Figure 4 – Generic EVSE test lab schema



ElaadNL test lab in Arnhem, Netherlands

V2G via different EV charger types

IEC 61851 is an international standard for EV conductive charging systems. It is the work of IEC Technical Committee 69 of which Australia is a participating full member. Within IEC 61851, various charging modes are defined:

- **Mode 2** – where an EV is connected to an AC grid though a cable incorporating protection and charging control infrastructure; the cable is in turn connected to an electrical outlet
- **Mode 3** – where an EV is connected to an AC grid through a hard-wired EVSE incorporating relevant protection and charging control infrastructure, and
- **Mode 4** – where an EV is connected to an EVSE through DC, and the EVSE handles protection, charging control and current conversion.

Mode 2 charging cannot support V2G or V2H/B due to requirements of the Australian/New Zealand Wiring Rules which prohibit two-way power flows through standard power outlets. In effect, this means that V2G can only be operated through an EVSE that is hardwired to an electricity mains. Mode 3 (AC V2G) and 4 (DC V2G). Architectures are summarised in Figure 5.

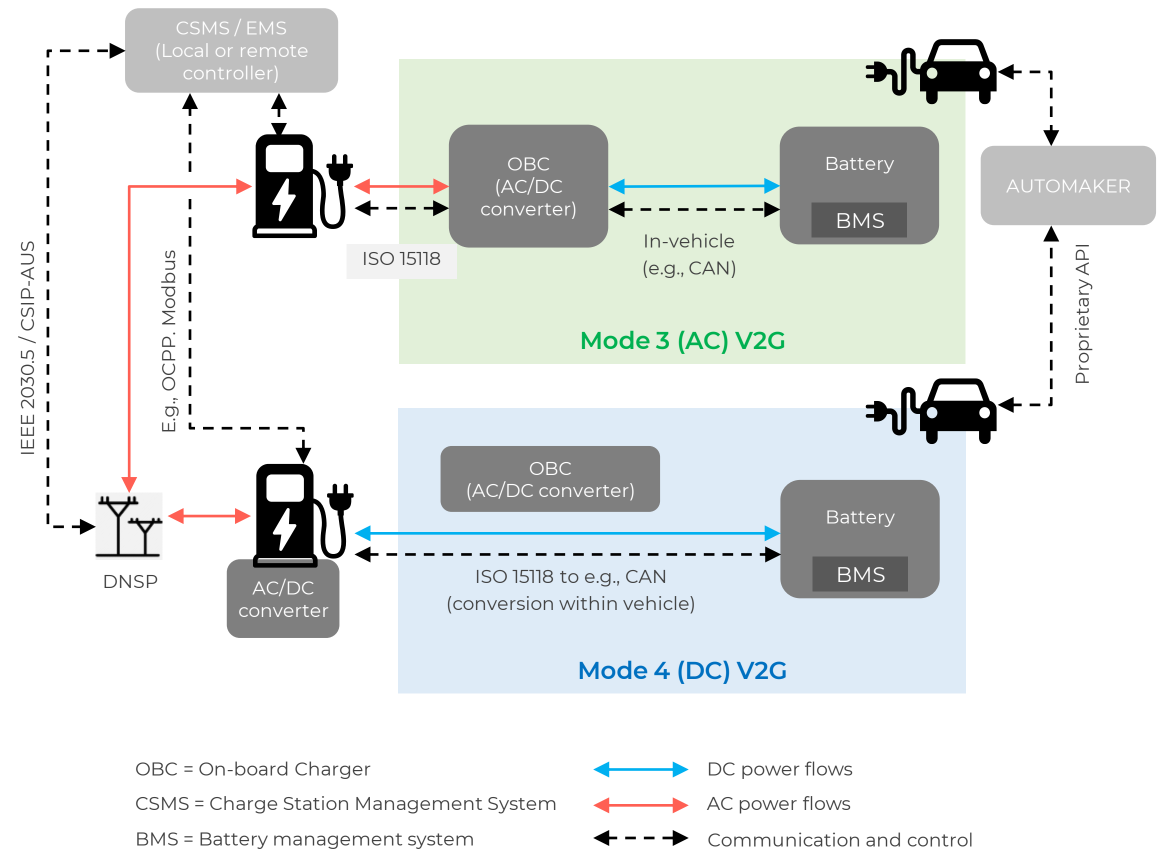
Regulatory frameworks

V2G capable charging systems classify as an *embedded generating unit* under Chapter 5A of the National Electricity Rules and they are subject to *basic connection service* and *model standing offer* arrangements as if they were a solar or battery installation.

While no specific national requirements have been developed for V2G, they must comply with all relevant national and jurisdictional regulations that apply to solar and stationary battery generating systems. This includes AS/NZ 4777.2:2020 Grid connection of energy systems via inverters, Part 2: Inverter requirements, which applies to the inverter irrespective of whether it is in the vehicle (AC V2G) or external to the vehicle (DC V2G).

At the time of connection to an electricity distribution network, network operators must ensure that V2G capable charging systems are compliant with AS/NZS 4777. This is typically by reference to the Clean Energy Council Approved Inverter List, though in special circumstances DNSPs deem products to comply even when they are not listed. This approach may not be possible for AC V2G due to challenges to achieving full compliance for on-board chargers.[1]

Figure 5: Generic depiction of potential power and communication flows in a CCS-based V2G charging system



[1] In the early days, DNSPs may layer in additional unique requirements until such time as effective national frameworks are developed

V2H/B and V2L architectures and regulatory frameworks

V2H/B in grid island mode

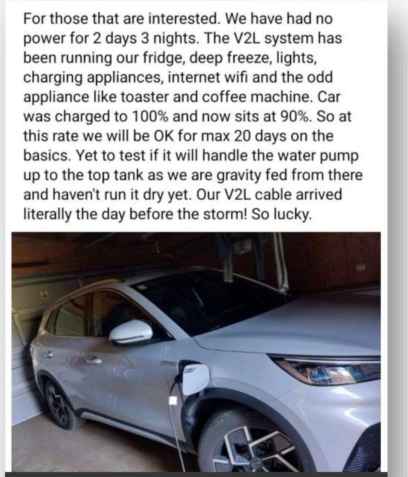
In this report, V2H/B is a technology model which allows consumers to source electricity from their vehicle via a power circuit within a building that *is not simultaneously connected to the grid* (i.e., not V2G). V2H/B could be highly valued by consumers in areas where grid reliability is low, or in remote locations where grid connection is not feasible. For example, V2H/B could provide a back-up power supply during a blackout, or a temporary power supply for buildings that don't have a grid connection (e.g., a shed). This is differentiated from V2L which is where one or more appliances connect directly to the vehicle via a general-purpose power outlet (i.e., not via a hard-wired building circuit).

Figure 6 provides simplified examples of potential power flows in a CCS-based V2H/B charging system compared to V2L. A 'Home Integration System' is required with appropriate circuit protection and an automatic transfer switch. Depending on customer needs, it may require the switchboard to be configured with circuits separated so that only a sub-set of priority loads run off power from the EV.

Table 3 provides a summary of V2L-capable models 'available' or 'announced' for the European market. Around 15% of EVs have V2L although details for some announced models have not been published. The max power output ratings of V2L will limit applications to a small number of low/moderate power appliances. There are very few homes or buildings with an instantaneous peak load of less than these maximum capacity limits.

Table 3: Summary of EV models homologated for the European market with V2L, grouped by maximum power output capacity

Max capacity (kW)	Number of EV models	Example brands	Average usable battery (kWh)	Average run hours at peak kW
3.6	18	BYD, Genesis, Hyundai, Kia	71	20
3.3	8	XPENG	82	25
2.4	2	MG	65	27
2.2	6	MG	56	25
No data	11	Lucid, Polestar, Volvo	104	N/A

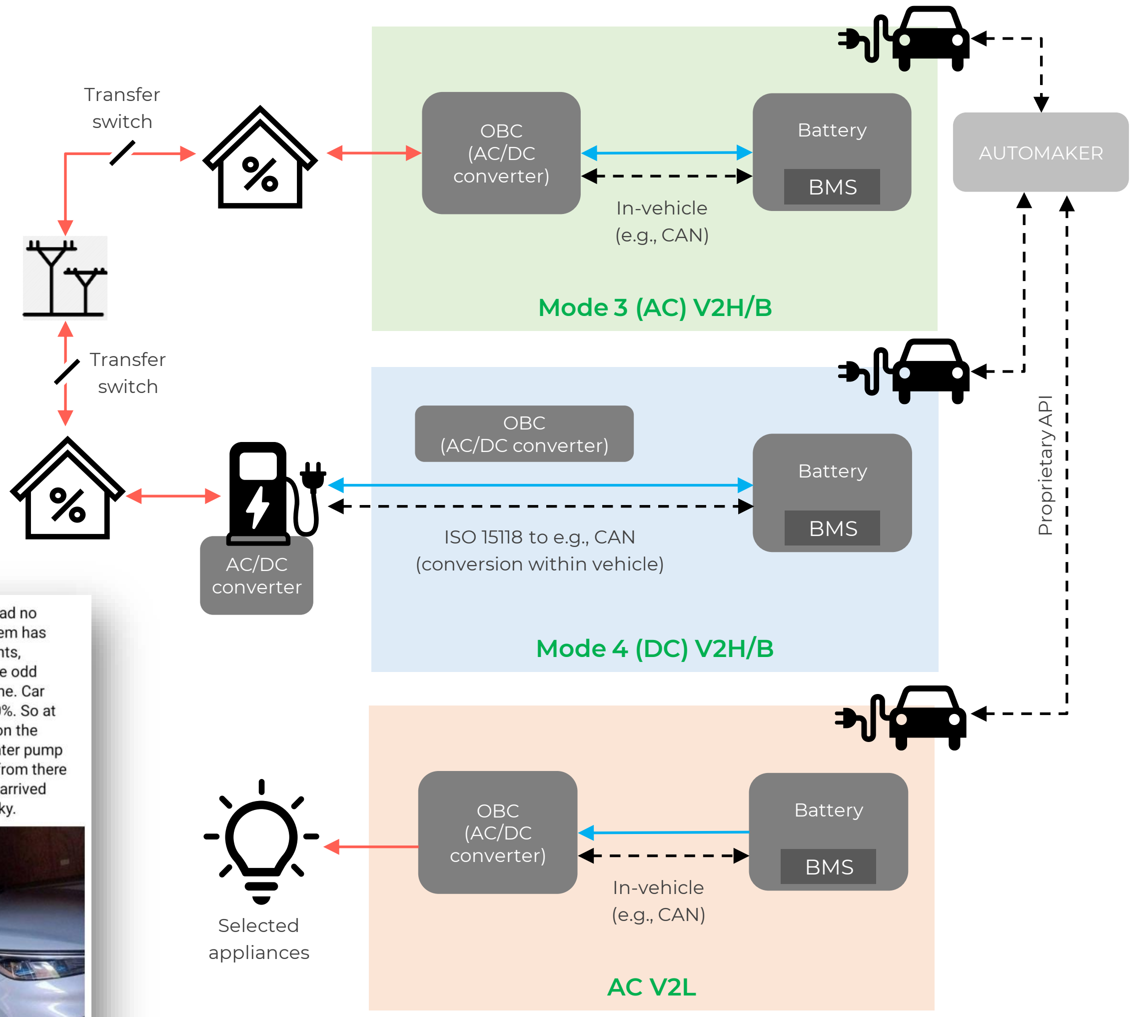

For those that are interested. We have had no power for 2 days 3 nights. The V2L system has been running our fridge, deep freeze, lights, charging appliances, internet wifi and the odd appliance like toaster and coffee machine. Car was charged to 100% and now sits at 90%. So at this rate we will be OK for max 20 days on the basics. Yet to test if it will handle the water pump up to the top tank as we are gravity fed from there and haven't run it dry yet. Our V2L cable arrived literally the day before the storm! So lucky.

LinkedIn post from BYD NZ

Regulatory frameworks

V2H/B applications are exempt from local grid codes (e.g., AS4777.2:2020) and National Electricity Rules requirements. They do need to meet a range of other standards that apply to standalone power systems including AS/NZS3000:2018 (and local Service and Installation Rules where not fully off-grid).

Figure 6: Generic depiction of potential power and communication flows in a CCS-based V2H/B charging system (See also the F150 case Study at Appendix B)



OBC = On-board Charger
CSMS = Charge Station Management System
BMS = Battery management system

DC power flows
AC power flows
Communication and control

International Trials

V2G Hub is a global database of international V2G trials providing statistics for 117 projects (>6,600 EVSE installations) and detailed knowledge sharing reports. Europe is the global epicentre of V2G trials (see Figure 7) with over 80 project starts since 2009. By contrast, Australia and New Zealand have only two recorded trials including the ActewAGL/ANU-led REVs V2G trial (Canberra, AU) and Vector's Piha V2H trial (Piha, NZ).

Analysis of the database indicates that the fundamental benefits of V2G and V2H/B are well established, and capabilities are well demonstrated in relation to frequency control, time shifting and grid service (peak shaving) provision.

The majority of international trials have used RNM Alliance vehicles that employ the CHAdeMO connection standard, however industry is shifting to CSS-based V2G. V2G Hub lists at least 11 CCS-based trials covering over 350 charge points. Further industry experience in the use of the CSS/ISO 15118-20 will help build industry alignment around a common standards framework. Future CCS-based field trials can inform industry's understanding of customer preferences and behaviour, inform product design and marketing, and power system planning.

Policies to support V2G

In many jurisdictions, policies to support V2G uptake remain focussed on funding proof-of-concept and early commercial trials. This reflects the nascent supply of capable vehicles, especially those using CSS-based connection standards. This is expected to change rapidly in the coming 12 months with several major automakers announcing V2G capable vehicles from 2024. A wider range of bidirectional chargers are also expected to be available at that time, making vehicle supply, and V2G marketing, the critical paths to mainstream uptake in Europe and the US.

NEVI is expected to supercharge the shift to 15118-20 (the EVSE-to-EV comms protocol that underpins CCS-based V2G)[2], with all publicly funded chargers needing to have that 'capability' from 2023/24. California's Senate Bill 233 (2023) would require that beginning in model year 2027, all new EVs sold in California be bidirectional capable, including school buses and light-duty vehicles. If passed, SB233 is likely to have a profound effect on US, and consequentially global markets, with respect to automaker adoption of V2G.

Figure 7: The location of international V2G trials[1]

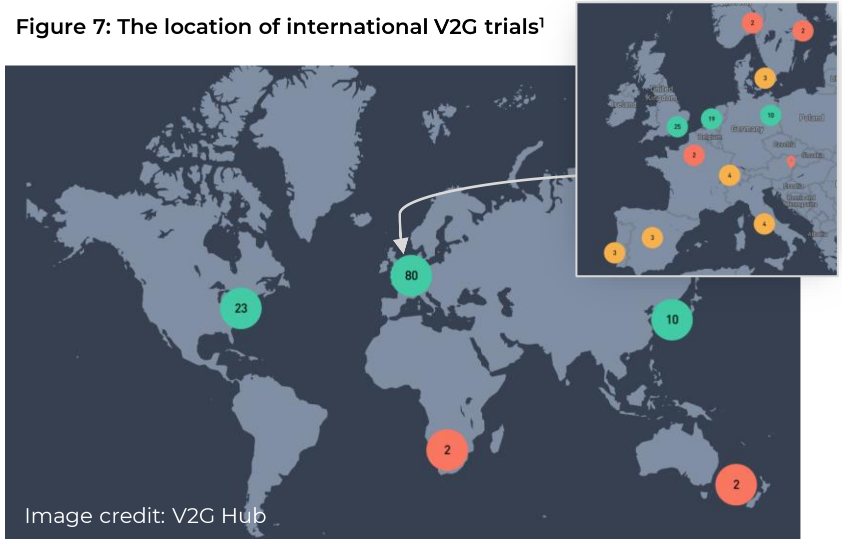


Figure 8: Breakdown of trials by type[1]

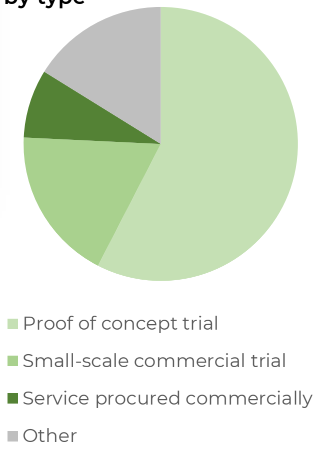
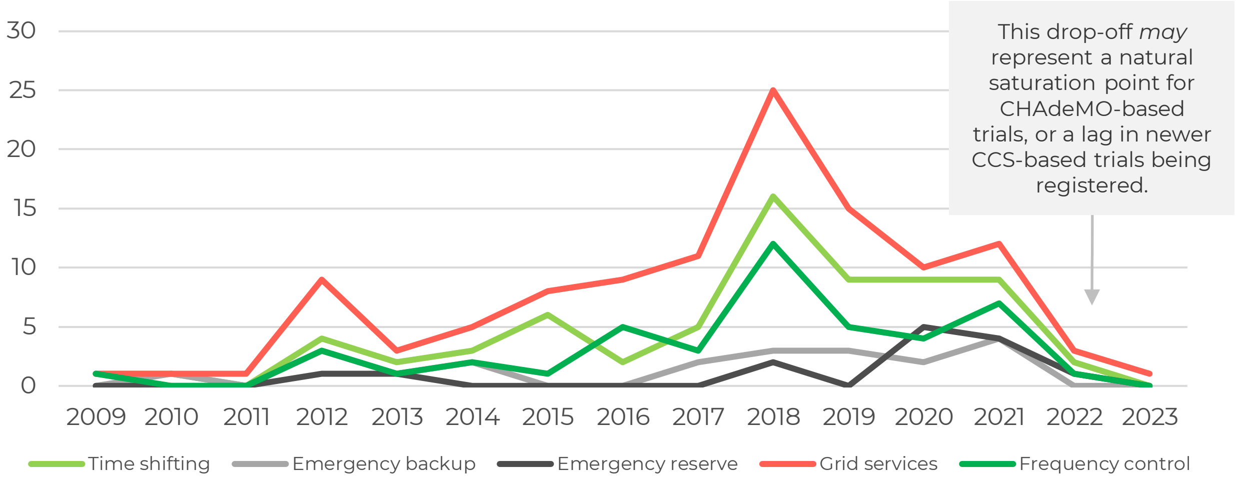


Figure 9: Commencement year of international V2G trials and capabilities demonstrated[1]



[1] v2g-hub.com [2] note there is currently a potential drift away from CSS in the US

V2G-capable vehicle supplies

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EV model availability

Australia sits at the end of international EV supply chains. To date, only Nissan and Mitsubishi (both part of the Renault-Nissan-Mitsubishi (RNM) Alliance) have supplied V2G capable vehicles in the Australian market. Since launching in 2012, Nissan has sold over 2,150 V2G-capable Leafs in Australia (compared to 600,000 globally).[1] The V2G capability of these vehicles largely sits dormant, limited to trials, due to local barriers to bidirectional EVSE certification/listing.

A much wider range of vehicles will become available over the next two years. As shown in Figure 10, 36 models in the European market have been announced as having current or future DC V2G capabilities. Of these, 11 also have AC V2G capability.

The battery capacity (kWh) of V2G-capable vehicle batteries is typically larger (24% overall) and the models more expensive (11% overall). The premium price and larger battery size is considered coincident and related to product marketing, rather than any underlying technology requirements or additional production costs.

The incremental hardware cost required to enable DC V2G at scale is negligible (much less than other advanced features like 'Plug & Charge'), and principally associated with one-off testing and certification. Conversely, AC V2G requires an onboard power converter that is compliant with local grid codes. While this can add cost, weight and volume to the vehicle power electronics system, AC V2G is considered supportive of automakers adopting more integrated service models, providing them more direct access to operational revenues.

New EVs in Europe will use the CCS Type 2 plugs and ISO 15118 suite of communications standards to enable V2G, as will Australia. CharIN, the global association helping drive the CCS charging standard, has referred to 2025 as the 'go-live year' for CCS-based V2G (including derivative charging standards such as MCS). This timing aligns with announcements by automakers (including Volkswagen, Skoda, Polestar and Volvo) to unlock V2G capability by 2024. Tesla has announced plans to bring bidirectional functionality to all its vehicles in the next two years, while reducing the overall cost of power electronics in the vehicle.[2]

Roev is an Australian company that converts popular ute models to electric. It is currently working to integrate DC V2G into the next generation of its Roev EV Drive power electronics platform, due for release to existing customers in late 2023. This could make Roev utes among the first CCS-based V2G-capable EV models in the Australian market.

Roev converted Toyota Hilux

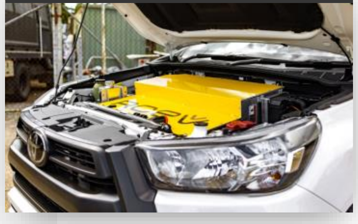


Figure 10 – Summary of EU homologated models with 'announced' or 'available' V2X capability (Source: ev-database.org, accessed 14/5/2023). 15+ bidirectional-ready EV models have been announced for the US market[3]. The Ford F-150 Lighting (North America only [4]) is an important early DC V2G/H product and it is case studied at Appendix B).

Automaker	DC V2G	AC V2G	V2L	Average V2G battery (kWh)	Average non-V2G battery (kWh)	Average V2G EV price premium
Audi	6	0	0	76.6	87.6	-38%
BYD	0	0	2	N/A	75.7	-
CUPRA	1	0	0	77.0	58.0	16%
Genesis	0	0	3	N/A	75.7	-
Hyundai	0	0	8	N/A	62.1	-
Kia	2	2	7	99.8	63.4	30%
Lucid	5	5	5	104.8	N/A	N/A
MG	0	0	8	N/A	57.9	-
Nissan	2	0	0	51.0	81.0	-62%
Polestar	2	2	4	107.0	81.5	56%
Skoda	6	0	0	77.0	56.0	34%
Volkswagen	10	0	0	77.0	56.1	27%
Volvo	2	2	2	107.0	74.7	100%
XPENG	0	0	6	N/A	85.2	-
All	**36**	**11**	**45**	**85.9**	**69.4**	**11%**

Factors driving V2G-capable vehicle supply

Our industry consultation indicates the local supply of V2G-capable vehicles will be completely dependent on global automaker decisions regarding the timing of V2G capability activation. Their decisions will be shaped by:

1. The overall supply of electric vehicles in Australia, which is growing rapidly
2. Automaker perception of the underlying financial value of V2G in Australia, their ability to capture it, and consumer readiness to engage in innovative new service offerings
3. The receptiveness of Australia's policy and regulatory environment, including in relation to the ease of certification, and regulatory approvals.

[1] drive.com.au [2] insideevs.com [3] Kaulza – Vehicle-to-Everything [4] Ford Media Center

V2G-capable EVSE supplies

enx

Figure 11 – Electric Vehicle Supply Equipment (EVSE) system configurations

Types	Description	Cost considerations	V2X type and notes
AC-AC	The vehicle is AC export-capable. The EVSE passes through the AC power to an electrical mains. In the case of V2G, the vehicle needs to have an inverter system that meets relevant grid codes.	EVSE • Minimal hardware costs System • EV must have grid compliant inverter	• AC V2G • AC V2H/B
DC-AC	The vehicle is DC export-capable. The EVSE converts power to AC and supplies it to an electrical mains. The inverter system must meet relevant grid codes.	EVSE • Must have grid compliant inverter System • No EV inverter requirement	• DC V2G • DC V2H/B
DC-DC	The vehicle is DC export-capable and the EVSE passes DC power to a hybrid inverter for conversion to AC either directly, or via DC bus that may be feed by other DC power sources (e.g.,' solar, batteries or other DC-DC chargers.) The Honda Power Manager was an example of this before being discontinued.	EVSE • Minimal hardware costs System • No EV inverter requirement • Requires separate hybrid inverter.	• DC V2G • DC V2H/B • Suited only to sites with multiple DC generation sources (e.g., solar and batteries) or multiple DC V2G end points such as commercial / apartment charging

EVSE supplies and likely pricing

enX has identified that at least 21 EVSE OEMs are developing bidirectional chargers in the European market. Most of these appear focussed on DC-AC chargers suited to DC V2G-capable vehicles. This aligns with a general expectation among EVSE OEMs that European and Chinese automakers will seek to reduce vehicle costs by utilising external power conversion equipment. The US market has greater interest in AC V2G indicating AC-AC EVSE may become more common there.

While high upfront costs are associated with development and testing, the underlying costs of building a DC-AC charger at scale is similar to conventional hybrid inverter plus galvanic isolation and charge cabling. One international OEM reported the at-scale bill-of-materials cost for their DC-AC bidirectional charger at €550 ($895 AUD).

Overall, our industry consultations suggests that by 2026, several 5 kW (or greater) V2G-capable DC-AC chargers could be available in the Australian market, at around $3500 (plus installation and cable costs)[1]. Prices have the potential to drop to as low as $2200 (plus installation and cable costs) in the longer term with strong competition between EVSE OEMs.

Figure 12 – Count of OEMs identified as developing AC-AC vs DC-AC bidirectional charging equipment (not including second-source vendors). No DC-DC chargers were identified. Most data from The Mobility House (accessed 15 May 2023).

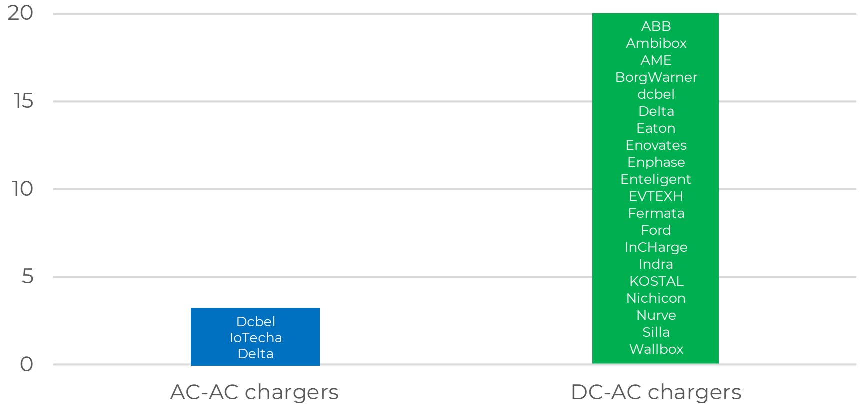
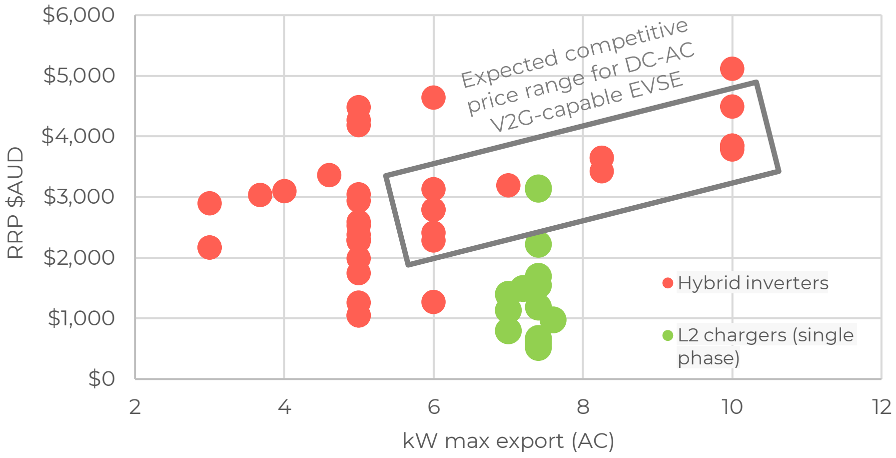


Figure 13 – The cost of common hybrid (solar and battery) inverters and 'smart' chargers in Australia. Hybrid inverters provide a benchmark for likely DC-AC EVSE prices when produced at scale. These prices exclude installation (~$1500) and the charger cable (~$300). The charger cable is needed regardless of V2G capability.



[1] Subject to accelerated market development, competition and exchange rates

Support for Australia's energy transition

Bidirectional EV charging represents the single biggest flexible (and as yet untapped) resource in Australia's energy transition. Figure 14 illustrates this point, with the *total* storage capacity in EVs outstripping all other forms of storage in the NEM from the early 2030s.

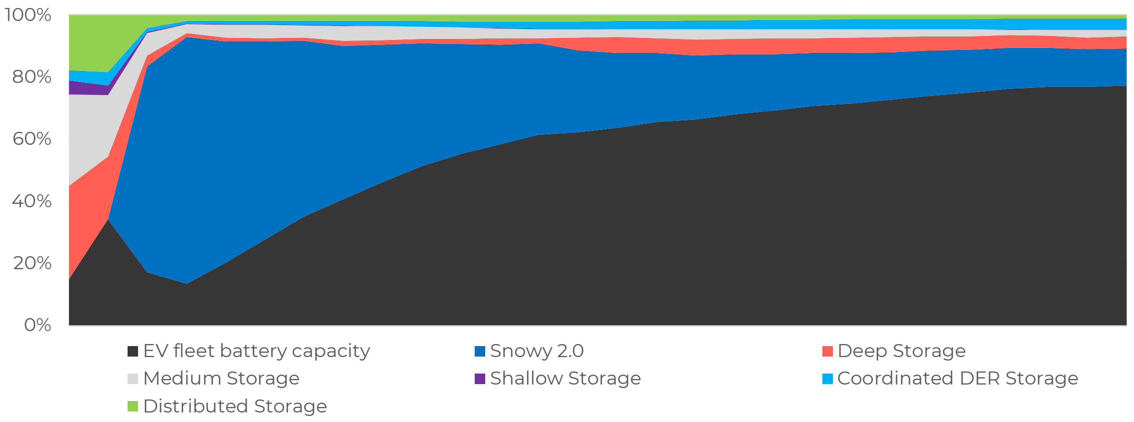
A number of international studies have explored the role of V2G in the transition to renewables. One 2022 study published in Nature Communications, demonstrated electric vehicle batteries could satisfy short-term grid storage needs in most regions of the world as early as 2030, at a fraction of the cost of providing the same service with large-scale batteries[2].

Compared to other markets internationally, several factors suggest Australia has *the potential* to become a relatively rapid adopter of V2G and V2H/B technologies:

1. The NEM has extremely dynamic wholesale electricity, high FCAS prices, variable retail prices, and dynamic network constraints, all of which increase the value of flexible resources such as V2G. Market signals to support flexible storage (including V2G) can be expected to intensify with the irreversible trends toward wind and solar, and electrification.
2. NEM market frameworks readily facilitate DER participation in FCAS and wholesale markets.
3. The introduction of dynamic operating envelopes (DOEs) will greatly increase V2G power export capability at times of peak demand. Australia is the first jurisdiction internationally to implement DOEs.
4. Australian consumers have led the world in DER uptake to-date (solar and batteries) and the same consumer sentiment could apply to V2G technologies.
5. Australia's pioneering small-scale inverter grid connection standards (AS 4777.2) supports high levels of inverter-based distributed generation in the power system.

Like other new energy technologies, we can expect uptake to be initially limited to early adopters and for this to expand into the broader market as industry mitigates product and integration costs and complexities. While there is some uncertainty in the timing of mass market uptake, it is increasingly clear there will be substantial value on the table for individual EV owners (within the next two years) and ultimately, for the power system as a whole.

Figure 14: Estimated <u>gross</u> energy storage capacities in the NEM 2024 to 2050 (%GWh).[3] Note this does not represent likely V2G enablement rates, or resource availability for any form of storage.



The challenge for Australia is establishing an effective framework to access the capacity that will already exist in our EV fleet. The marginal cost of this is relatively low. Based on an incremental cost of purchasing an DC-AC EVSE, we can expect capital costs in the order of $25,000/MWh, or 6% of current large-scale battery costs (~$400,000/MWh)[4 5] on a simple per MWh basis. The basis of this advantage is that the cost of enabling V2G is only a marginal increase in the cost of installing a V2G-capable EVSE. The battery comes with the car.

Despite the size of the prize, no Australian jurisdiction has policies or programs designed to promote V2G capability in our vehicle fleet, or consumer uptake. This is understandable given the nascent state of vehicle and equipment supply chains however the headline from our analysis is that this will change quickly over the next two years, and it is time for Australian governments and regulators to get their skates on, and prepare the policy and regulatory frameworks, and industry support infrastructure, that will enable the benefits of V2G to be realised.

[1] AEMO 2023 Electric Vehicle workbook [32] Nature Communications, see also this Californian study [3] Data sources: chart data for total NEM storage volumes with enX EV fleet battery capacities added. *See Appendix C for further details.* [4] Based on an $1500 price premium for installed EVSE [5] CSIRO GenCost 2022-23 consultation (p.18)

Customer value of V2G

enx

enX used the Gridcog[1] platform to model 24 different residential case study scenarios to determine the customer financial value of V2G relative to other charging modes.

Key scenario variables:

- **NEM regions**: ACT, NSW, QLD, SA, TAS, VIC
- **User type / load profiles**: Economy, Mega, Commuter, Sponge
- **Charge mode**: Convenience, Smart Charging, V2G
- **Tariff arrangements**: ToU vs dynamic pricing (variable network pricing and spot pass-through retail tariffs)

Further details on the modelling inputs and assumptions are provided at Appendix A.

Caveats

These modelling results relate to 'case studies' used to elucidate basic trends and sensitives, to inform further modelling work. A more market-representative range of scenarios (especially in relation to consumer charging behaviour, load profiles and tariff structures) is needed to develop more generalisable results.

For simplicity, we have assumed all users are disconnected from the grid between 6AM and 6PM weekdays and 9AM and 3PM weekends, and available at all other times. While it is not clear whether this results in an overall positive or negative bias, vehicle availability assumptions may be a key driver of user cashflows. Availability can be expected to be highly variable across users and sensitive to incentives.[2]

Modelling outputs

Figures 15 to 20 (next page) illustrate the range of charging costs across the use types in each jurisdiction, with either a TOU or dynamic tariff arrangement. The green shading indicates potentially preferential arrangement across the user types (noting the best charging mode or tariff option can differ substantially by user).

Key modelling results

1. Smart charging is always cost-beneficial, compared to convenience charging, across all user types and regions.
2. V2G is highly preferential for *some* users in *all* jurisdictions. **The *average* of net benefits of V2G compared to smart charging across all jurisdiction ranges between $1,560 (TAS) and over $6000 in NSW and SA.** These differences are partly the result of different network tariff arrangements that appear to reinforce or dampen energy spot market or retail tariff arbitrage behaviours. Larger energy users generally have the most to gain from V2G.
3. V2G customers are nearly always better off on a dynamic pricing. Smart charging customers may be better off on dynamic pricing depending on their household energy usage patterns and local network tariff arrangements.
4. The extent of benefit associated with V2G with dynamic pricing is highly sensitive to:
    - Forward wholesale market price curves
    - Local network tariff arrangements
    - Customer load shape (which impacts overall price exposures under ToU and V2G)
5. The strongest benefits for V2G were in areas with simple bidirectional network support tariff arrangements (e.g., under the Ausgrid (NSW) and SAPN (SA) trial tariff arrangements). In NSW and QLD, charging a V2G enabled EV can have a negative net cost (i.e., it can make you money).

Summary results are reported on the next page and individual case study results are summarised at Appendix A.

Other results, not reported, included load and generation profiles associated with the individual case studies, or in aggregate. This is an important area for further research not within the scope of this study.

We have not reported FCAS earnings, and these were found to be marginal (<$150 NPV for the 'slow' and 'delayed' market categories) we have assumed V2G generally not capable of 'fast' FCAS provision however this needs to be tested through further analysis of the CCS technology stack.

[1] Gridcog website [2] Project Scurus found 75% of V2G trial customers with incentives said they plugged in after every trip.

Customer value of V2G

The height of the bar represents the range of outcomes across the four user types
The black line is the average of the user types
Green indicates a potentially preferential arrangement
Positive results are net income

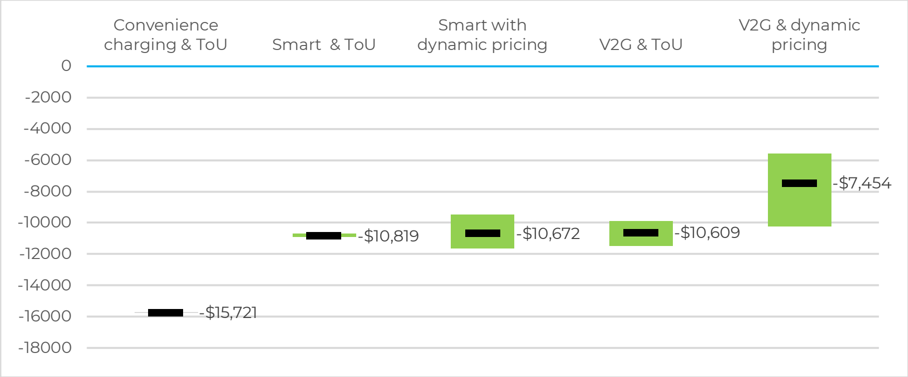


Figure 15

ACT – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: $1,715

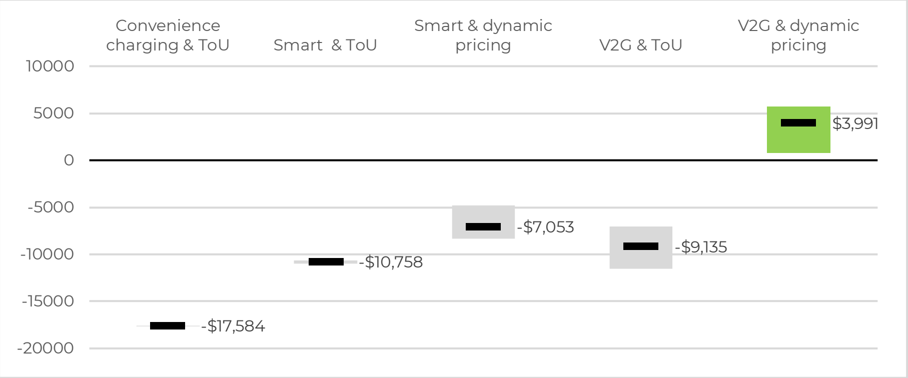


Figure 16

NSW – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: **$6,728**

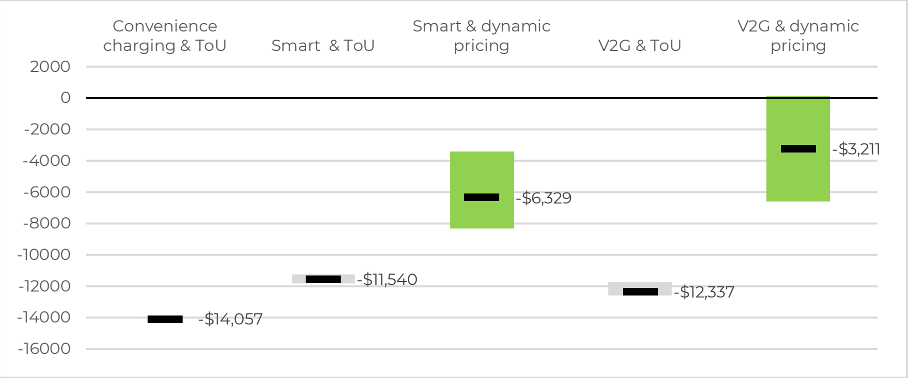


Figure 17

QLD – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: $1,161

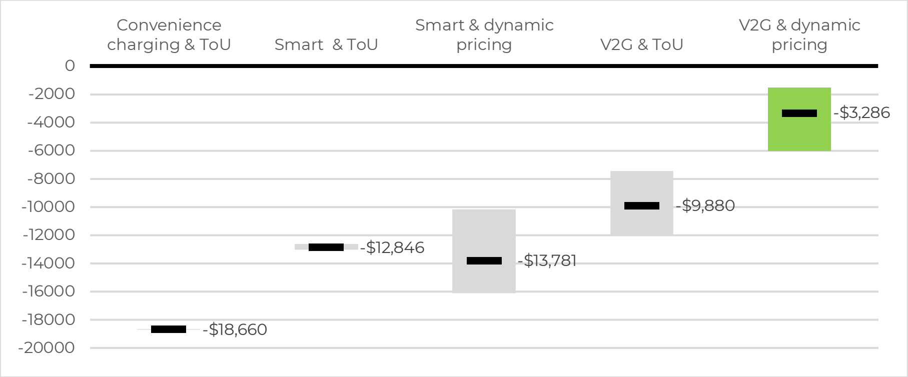


Figure 18

SA – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: $6,329

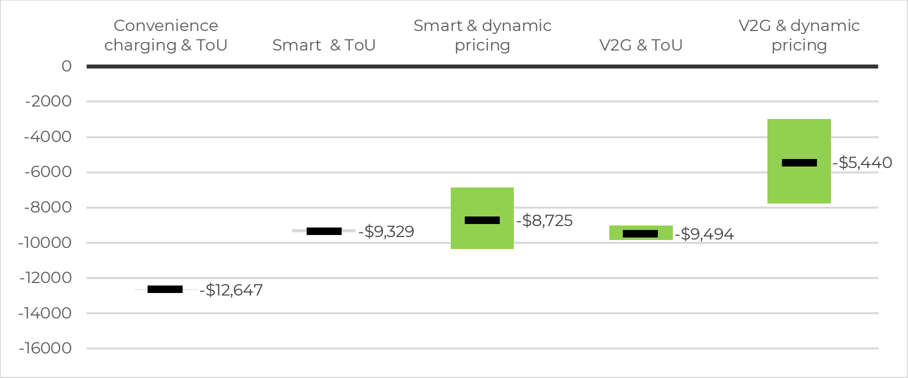


Figure 19

TAS – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: $1,560

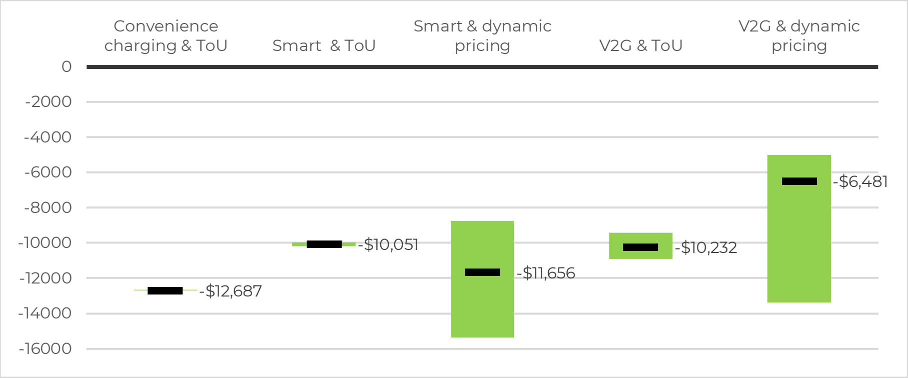


Figure 20

VIC – NPV of charging costs across user types (range across the 4 user types and average)

Average benefit of V2G relative to smart charging: $3,817

V2G for distribution networks

DNSP reference group

Findings in the report are based on interviews with a range of national and international supply chain stakeholders. DNSPs have contributed through a reference group process. Internationally, network business collaborations, such as ElaadNL in the Netherlands, have spearheaded standards development and product testing processes to accelerate V2G homologation and market readiness. In Australia, DNSP engagement currently, remains focussed on developing trials and connection standards and tariff products.

What DNSPs can do…

1. **Technical standards** – ensure nationally consistent, and permissive approaches to the application of grid connection standards including AS4777.2:2020.
2. **Load modelling** – develop a deeper understanding of the likely real-world charge and discharge cycles of V2G as an input into network planning and real time operations.
3. **Smart grid architectures** – work towards convergence on smart grid architecture models accounting for the potential conflict of alternative control schemes (e.g., dynamic operating envelopes, dynamic tariffs, charge point operator and direct load control).
4. **Performance standards** – define the risks associated with highly coincident response of V2G and smart charging resources to wholesale pricing events and retail TOU price change overs, and strategies to mitigate these.
5. **Export limits** – ensure that export limits, intended to manage peak solar generation, do not overly limit the ability of V2G (or stationary batteries) to export to the grid at times of peak demand (i.e., apply daily-shaped or dynamic export limits).
6. **Incentives** – collaborate to ensure network tariffs and network support service arrangements adequately incentivise exports at times of peak demand (e.g., via dynamic and/or bidirectional pricing) and that these are broadly consistent and value-apparent to international OEMs.
7. **Back-up power and resilience** – develop advice and (potentially) targeted incentives for customers to adopt V2H/B solutions to enhance community resilience in high risk / low reliability areas, and to assist in disaster recovery.

Figure 21 –A reference group was formed for this project including representation from nine distribution network businesses).

Powercor Australia · united energy · Ergon Energy Network · energex (Part of Energy Queensland) · SA Power Networks · essential energy · CitiPower · evoenergy · Ausgrid

Figure 22 – Surveys and group discussions with the reference group indicated a strong interest V2X applications, especially in relation to the areas listed below.

Current challenges reported by DNSPs	Emerging and potential strategies
Technical challenges • Overcoming current inverter standard CEC product listing barriers for EVSE • Ensuring effective interoperability of behind-the-meter devices to manage export limits • Customer knowledge and engagement • Lack of V2X equipment supply and high costs • Understanding of customer value and preferences (e.g., V2H vs V2G) • Dynamic tariff implementation to support efficient operation • EV battery warranty concerns related to V2G usage • Uncertainty around the scale and timing of uptake • Supporting customers to use grid-friendly charging • Immaturity of CSS-based V2G technology • Understanding of technical capabilities (e.g., reactive power) • Privacy and data security • Grid stability and coincident load/exports • Coordinating industry stakeholders	• More cost-reflective / dynamic tariffs • Consumer information and education on V2X operation, challenges and benefits • Optimised and technology neutral pricing and connection processes • Bidirectional DOEs • Network visibility of smart and bi-directional charging • Understanding and comparing V2X and non-V2X profiles for network impact • Understanding the relative priority of device management for grid protection vs customer value purposes • Procurement of flexibility services to help manage minimum and peak demand

Getting the NEM market settings right

Modelling undertaken for this report highlights V2G has enormous, latent value potential for EV customers and the community as a whole. Regulatory frameworks and electricity market design will play a critical role in enabling or limiting consumer value realisation.

In particular, our study reveals that the value of V2G can be greatly enhanced by vehicles being exposed to real-time spot market signals, supported by bidirectional time-varying network tariffs. This kind of dynamic pricing however creates a range of risks that need to be carefully managed:

- Consumer benefits from dynamic pricing are not evenly spread and are highly sensitive to a customer's load shape. This suggests that there are benefits in providing flexibility for customers to opt in or out of these arrangements and to have, in some cases, EVSE circuit loads being able to be registered for settlement independently of other loads, as being considered under the AEMC's flexible trading arrangements rule change consultation.
- Dynamic pricing increases the risk of coincident response from customer devices creating risks to system security within distribution networks, and ultimately, at the transmission scale. Given the multi-GW potential of V2G, this suggest that some controls will be needed in relation to ramp rates for EV charging and discharging and to dampen potential oscillatory effects at different system levels and timescales. This could be achieved through a mix of EVSE technical standards and market participation arrangements, potentially as envisaged under the AEMO's scheduled lite rule change proposal.
- Traditional electricity retailing arrangement may not be the best fit for dynamic loads that are separately settled in the market. The Integrating Energy Storage Systems rule change, and the creation of the new Integrated Resource Provider (IRP) category of market participant, provides a potential avenue for direct participation of V2G resources in electricity markets. This could support commercial models whereby automakers, or other parties, provide discounted or free charging services for customers on the basis that bidirectional EV charging are separately metered and settled as an IRP load, and that market revenues from V2G offset the cost of charging.

Appendix A – Modelling assumptions and results by location

Case study modelling approach (1/2)

Scenarios – enX has undertaken 'case study' modelling to determine the customer financial value of V2G under a range of different scenarios:

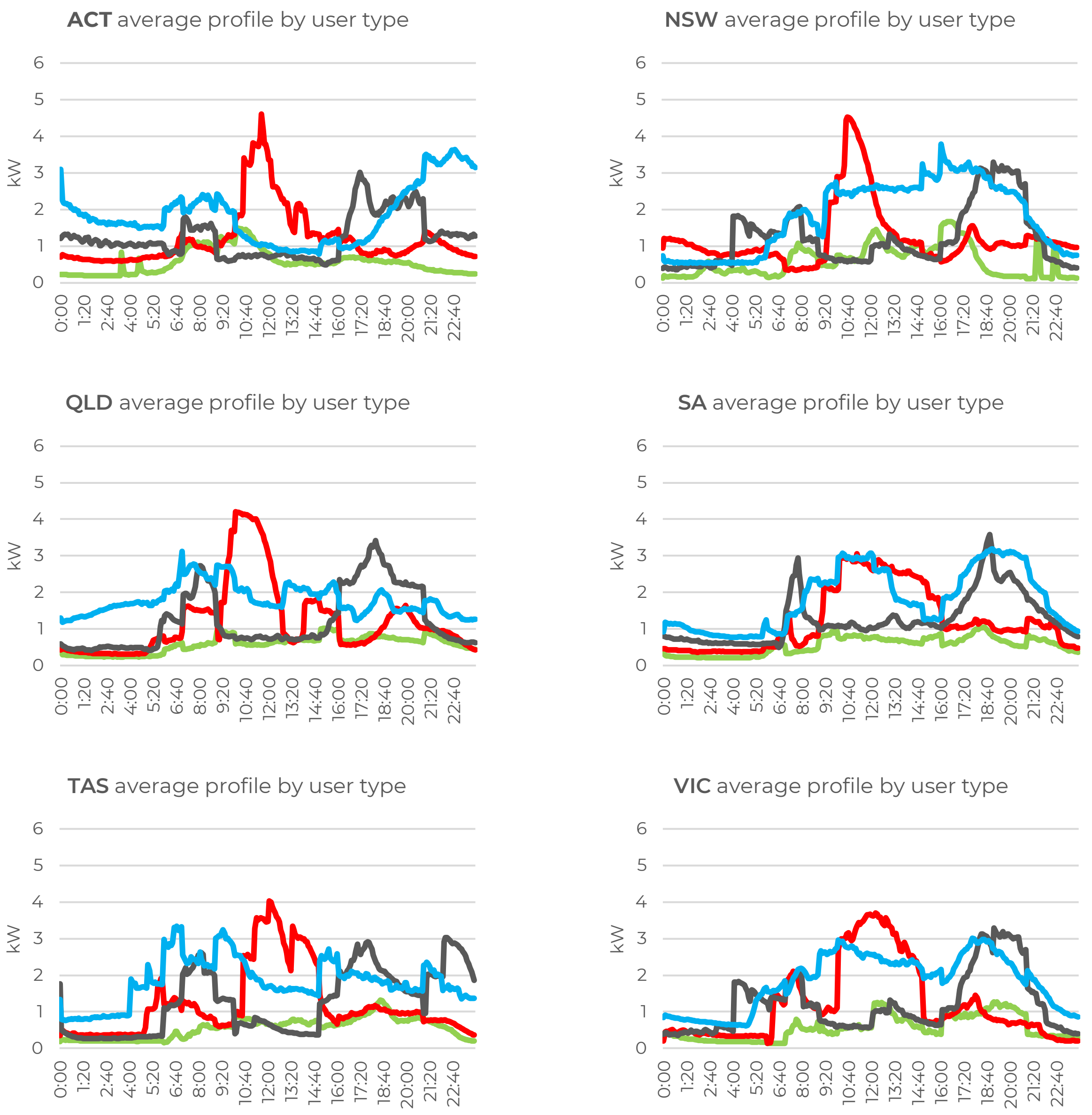
- NEM region: ACT, NSW, QLD, SA, TAS, VIC
- User type / load profile: Economy, Mega, Commuter, Sponge
- Charge mode: Convenience, Smart Charging, V2G
- Tariff arrangements: TOU vs dynamic pricing (see next page for details)

Load profiles – Five-minute customer load profiles were sourced from Solar Analytics and normalised and somewhat shaped (by using peak and off-peak demand multipliers) to achieve more consistent total annual consumption and average shape for each user type. Daily averages of the final load profiles are summarised on the right.

Solar households only – Each site was assumed to have 7.7.kW of solar effectively meaning the case studies mostly relate to standalone owner-occupied dwellings. This is assumed to be a key early adopter cohort.

Travel energy and vehicle availability – Vehicles are assumed to be disconnected each day from 6AM to 6PM weekdays and 9AM to 3PM on weekends, using 11.6 kWh each day while driving. No further discounting was applied for vehicle availability, and this is an important focus area for future modelling.

Site export limit – A 5kW static export constraint was applied at each site which applied to both solar and V2G. Future modelling can look at the value of V2G under lower static limits, or dynamic export limit arrangements.



- **Economy user** (~ 5 MWh p.a)
- **Mega user** (~ 16 MWh pa.)
- **Commuter** user (~ 11 MWh pa.)
- **Sponge user** (~ 11 MWh pa.)

Figure A1 – Average daily residential load profiles for the customer groups prior to adding solar and EV charging

Case study modelling approach 2/2

Charger (installed) costs –

- Convenience charger: 7.4 kW at $2500
- Smart charger: 7.4 kW at $3500
- Bidirectional charger (assumes DC V2G): 7.4 kW at $5000

EV charging constraints –

- EV usable battery capacity: 60 kWh
- Minimum battery state of charge: 40% (used to limit exports)
- Losses: 7% energy losses were applied to both the EV charge and discharge cycle

Other modelling parameters –

- Timeframe: 01/01/2023 to 01/01/2033 (10 years)
- Price forecast accuracy: 80%
- Discount rate for future cashflows: 3.5%

The Gridcog modelling platform was used to –

- Produce location-specific solar generation profiles for each user site
- Simulate the optimisation of smart charging and V2G against the relevant tariff arrangements. This forecasts and optimises a week ahead
- Calculation of resulting EV load (and generation) profiles for each user site
- Calculation of discounted cashflows

Tariff arrangements

EnergyAustralia's residential flexi plan ToU tariffs were used wherever available.

Dynamic pricing was based on:

- Amber Electric whole spot passthrough cost structure (30-minute settlement) using Endgame Economics 2022 (Q3) central case forward spot price trace for each NEM jurisdiction.
- Amber Electric jurisdictional regulatory cost passthrough structure and fees
- The most dynamic network tariffs we could find in each region, unless a specific tariff was nominated by a DNSP reference group member. These are listed in Table A1.

Table A1 - Tariffs applied to the modelling scenarios

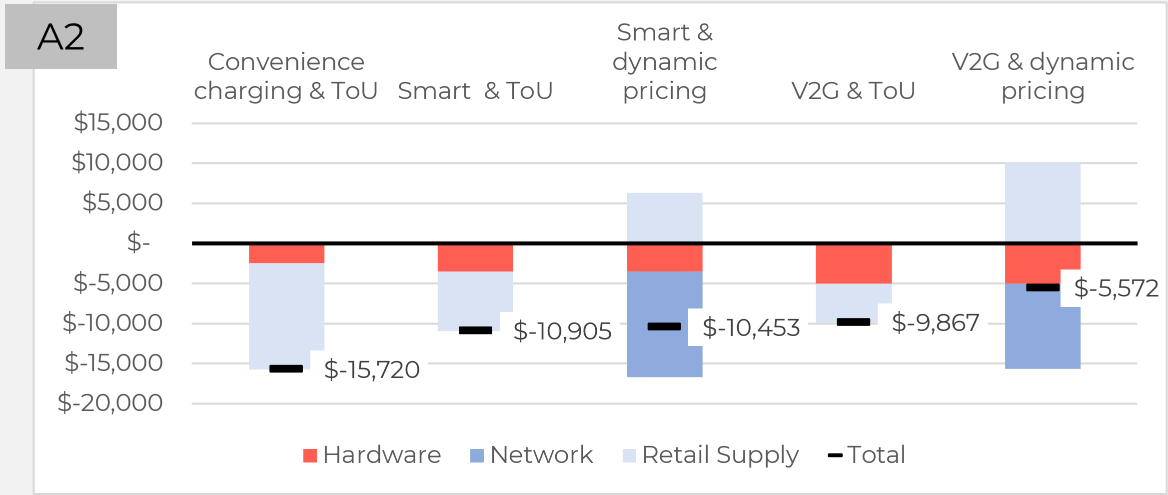
Region	ToU retail tariff	Dynamic retail tariff	Network tariff (for dynamic pricing)
ACT	EnergyAustralia's Residential Flexi Plan (ACT 2602)	Amber Electric with relevant fees and cost passthrough	Evoenergy's 015 residential ToU
NSW	EnergyAustralia's Residential Flexi Plan (NSW 2031)	Amber Electric with relevant fees and cost passthrough	Ausgrid's EA960 two-way residential tariff
QLD	AGL's Residential Basics Plan (QLD 4156)	Amber Electric with relevant fees and cost passthrough	Energex's NTC6900 residential ToU tariff
SA	EnergyAustralia's Residential Flexi Plan (SA 5011)	Amber Electric with relevant fees and cost passthrough	SAPN's electrify two-way trial tariff
TAS	Aurora Energy's Aurora+ Plan (TAS 7000)	Amber Electric* with relevant fees and cost passthrough	TASNetworks TAS93 residential consumption tariff
VIC	EnergyAustralia's Residential Flexi Plan (VIC 3149)	Amber Electric with relevant fees and cost passthrough	CitiPower's CRDS trial tariff

*Amber Electric does not have an available retail plan in Tasmania, however the tariff structure is estimated based on Amber's standard cost structure and NEM Tasmania's wholesale spot prices.

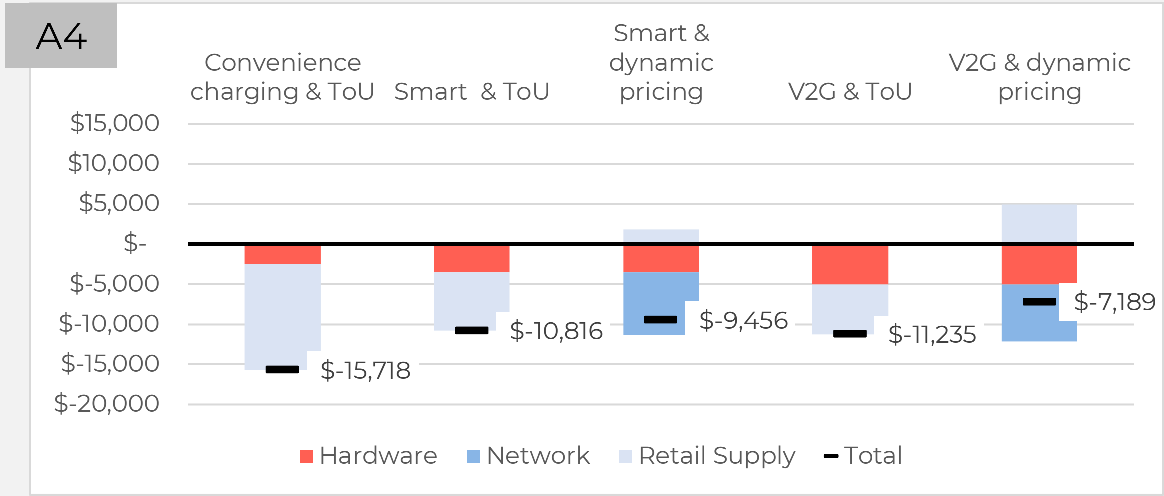
Australian Capital Territory - case study results

Figures A2 – A5
Positive results are net income

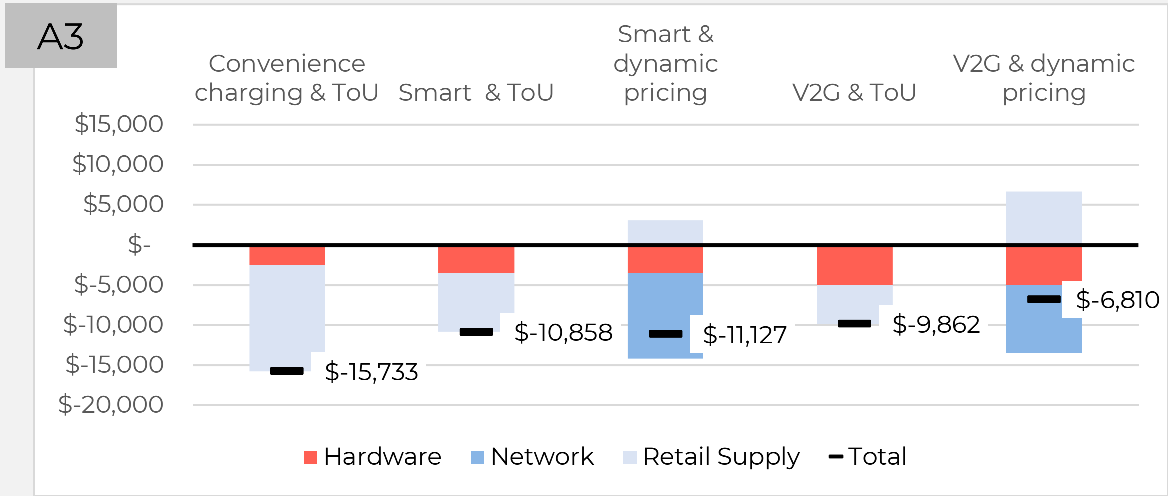
Mega user (16 MWh per annum) – Total cost of charging (NPV)



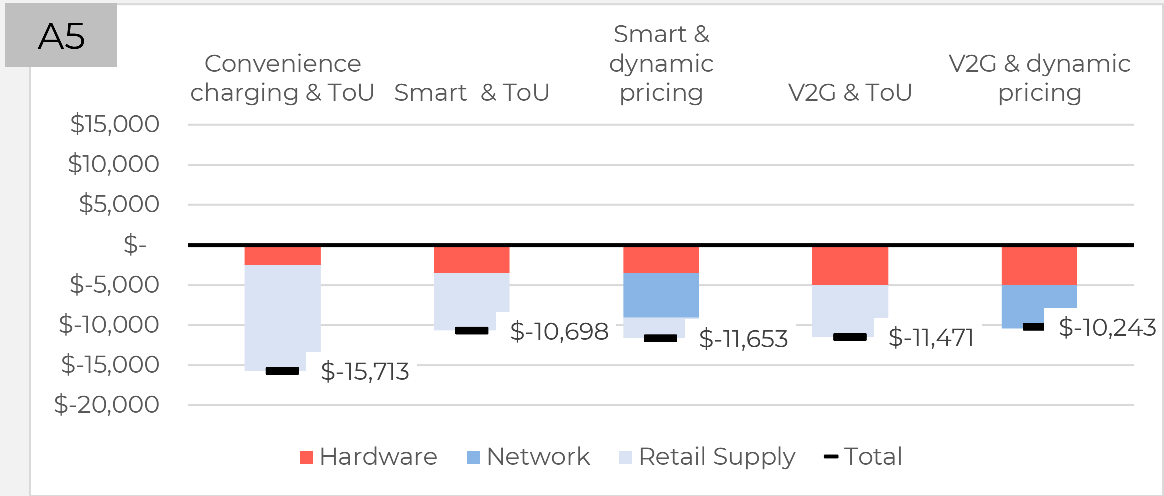
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging (NPV)



Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging (NPV)



Economy user (5 MWh per annum) – Total cost of charging (NPV)



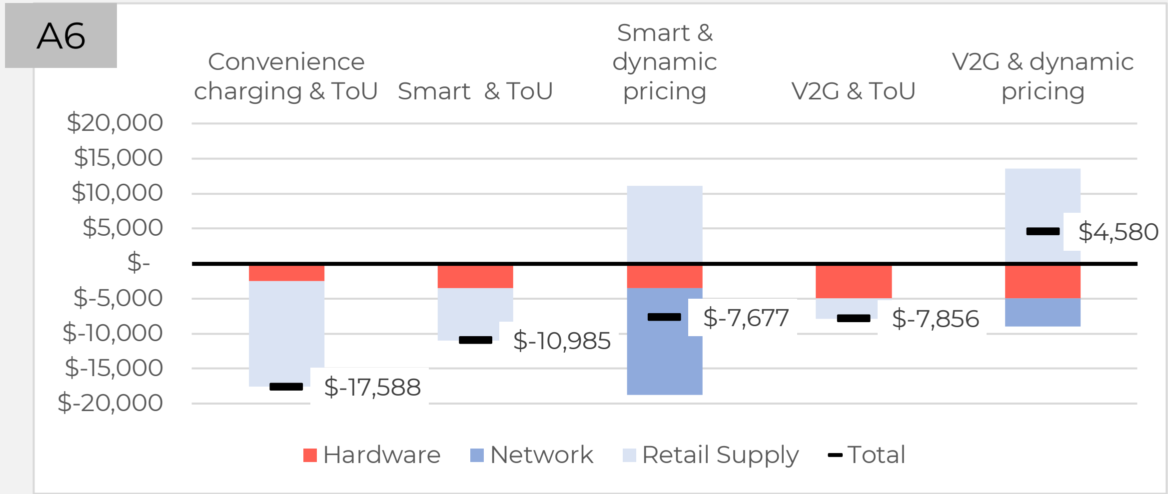
Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional)   TOU Tariff = EA's residential flexi plan (ACT 2602)   Dynamic pricing = Amber + Evoenergy 015 residential TOU network tariff

New South Wales - case study results

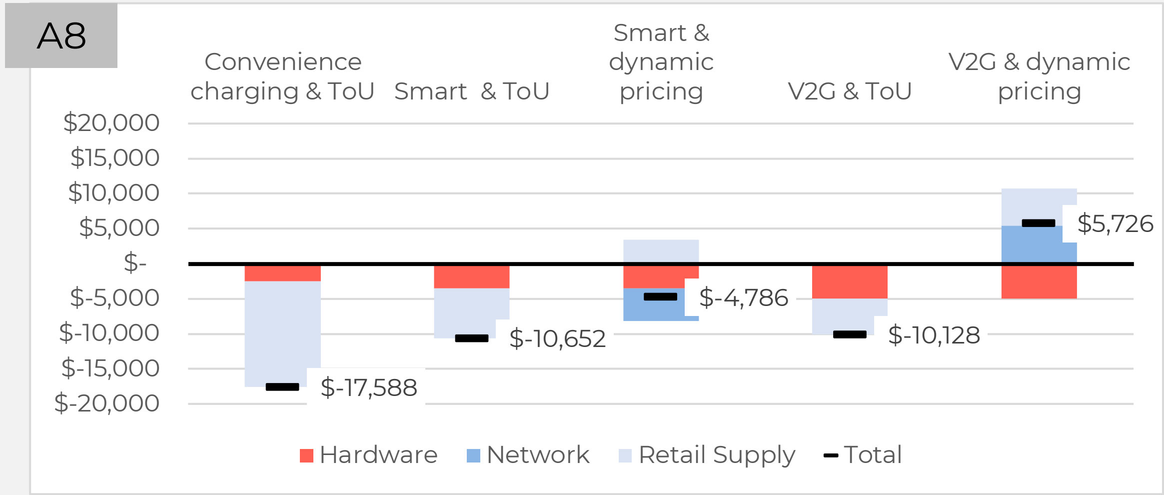
Figures A6 – A9
Positive results are net income

enx

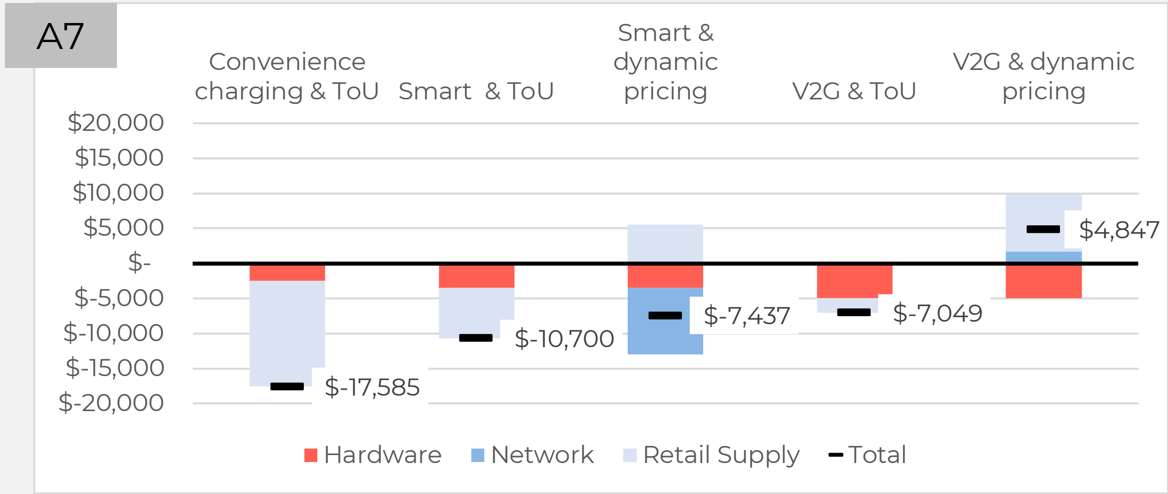
Mega user (16 MWh per annum) – Total cost of charging (NPV)



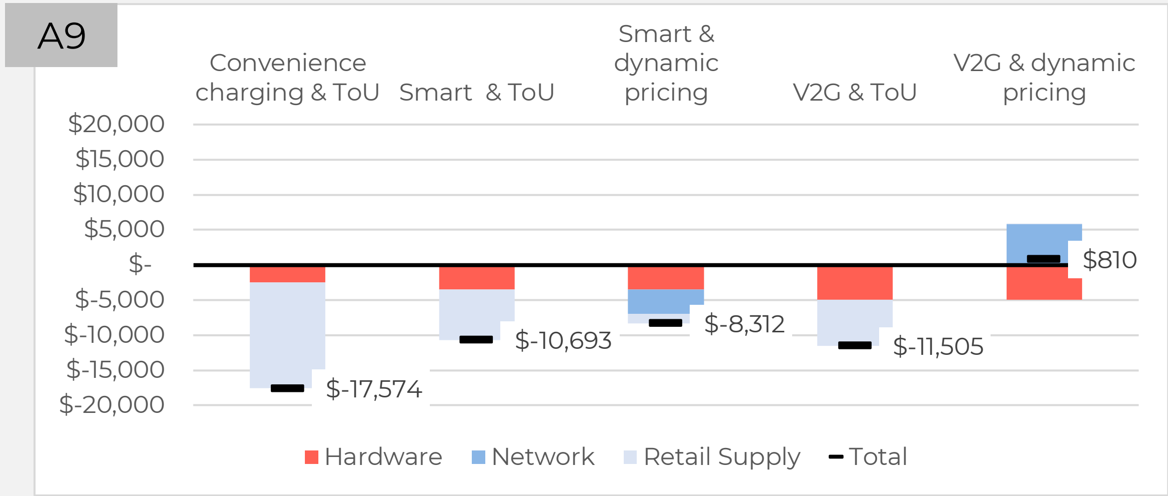
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging (NPV)



Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging (NPV)



Economy user (5 MWh per annum) – Total cost of charging (NPV)

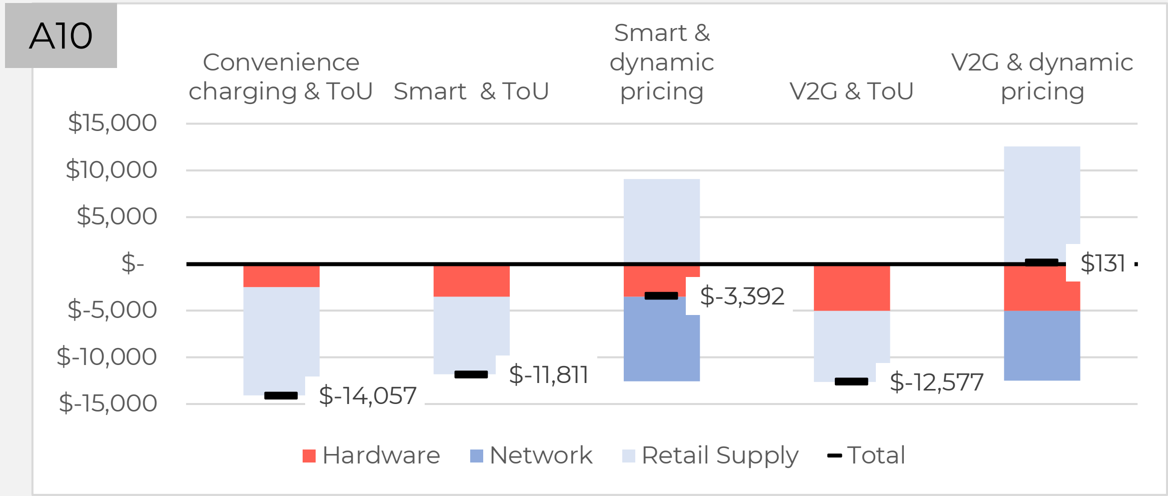


Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional) TOU Tariff = EA's residential flexi plan (NSW 2031) Dynamic pricing = Amber + Ausgrid EA960 two-way tariff

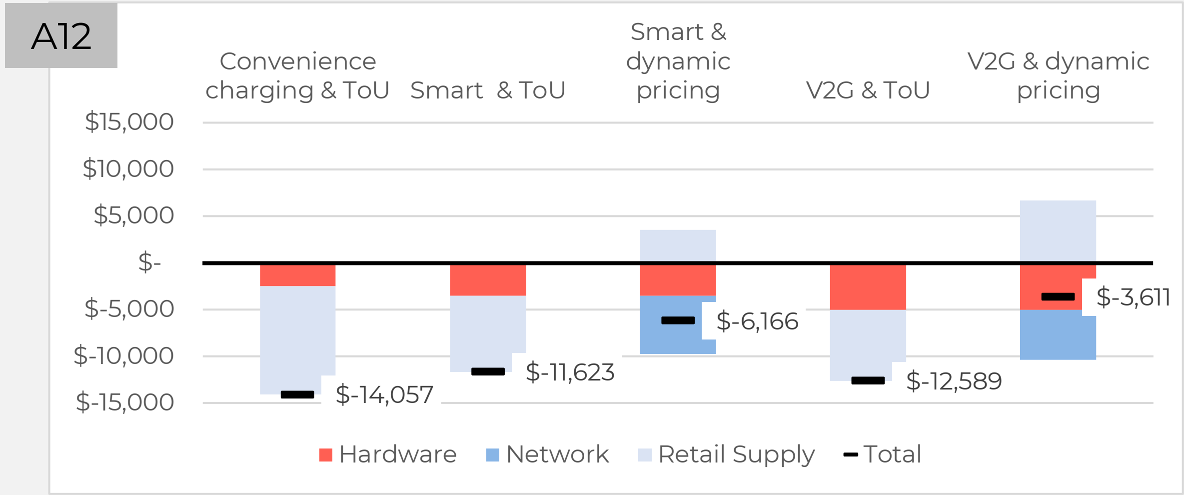
Queensland - case study results

Figures A10 – A13
Positive results are net income

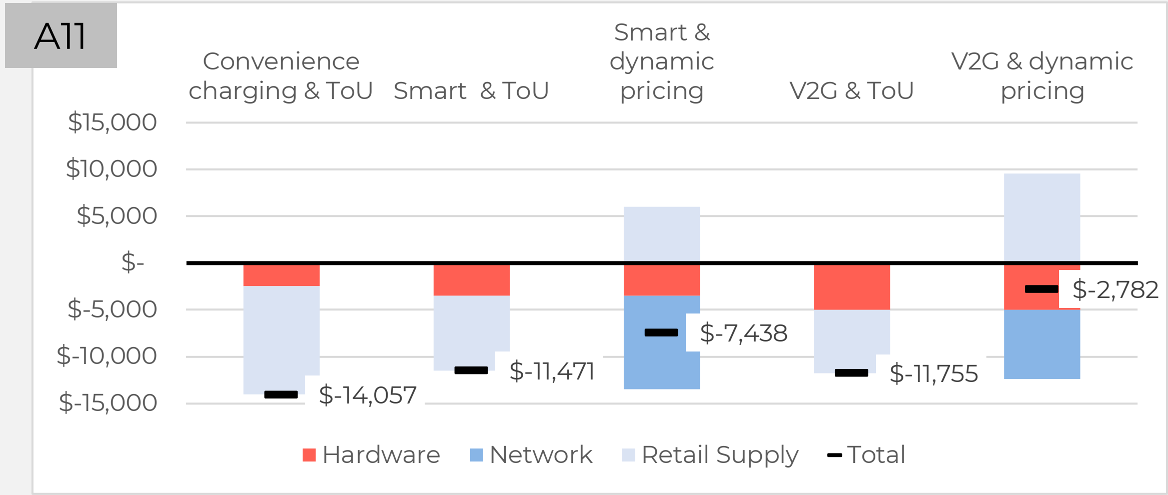
Mega user (16 MWh per annum) – Total cost of charging (NPV)



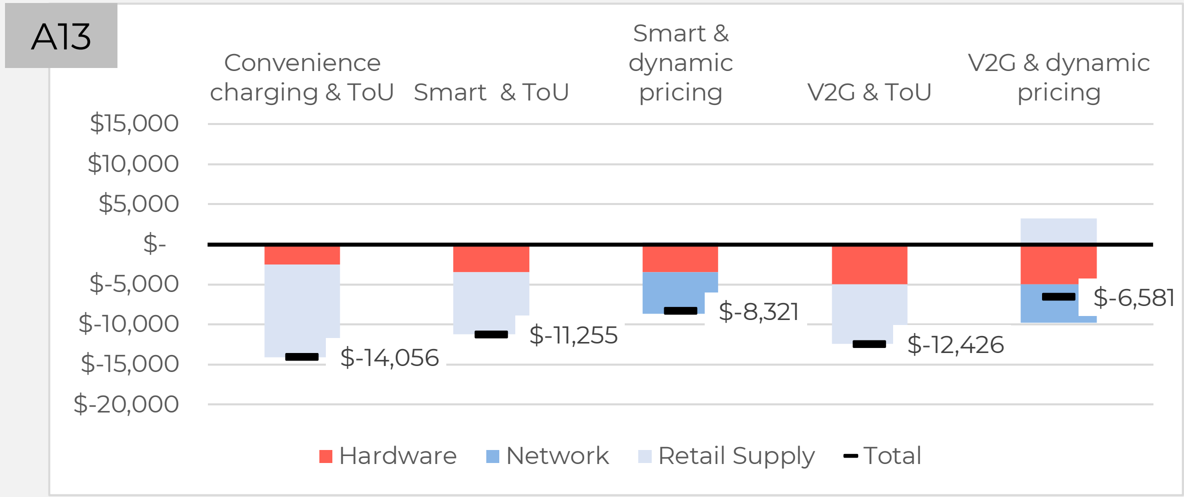
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging (NPV)



Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging (NPV)



Economy user (5 MWh per annum) – Total cost of charging (NPV)



Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional) TOU Tariff = AGL's residential basics plan (QLD NTC6900) Dynamic pricing = Amber + Energex's demand network tariff

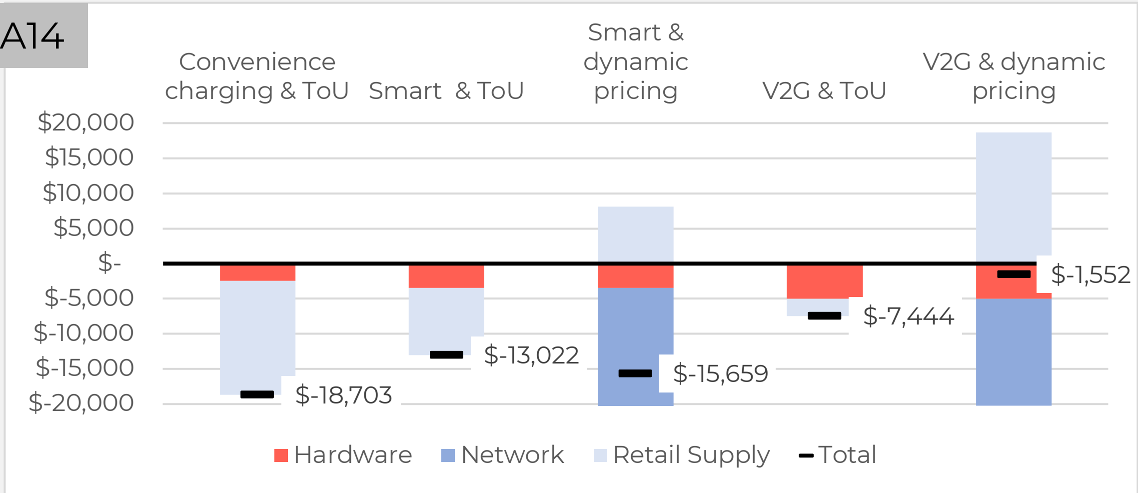
South Australia - case study results

Figures A14 – A17
Positive results are net income

enx

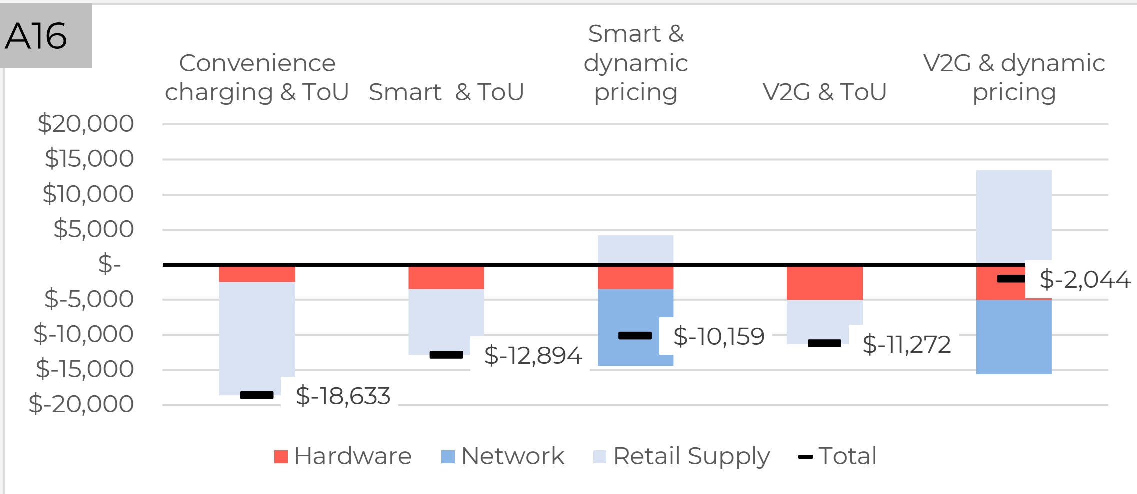
Mega user (16 MWh per annum) – Total cost of charging (NPV)

A14



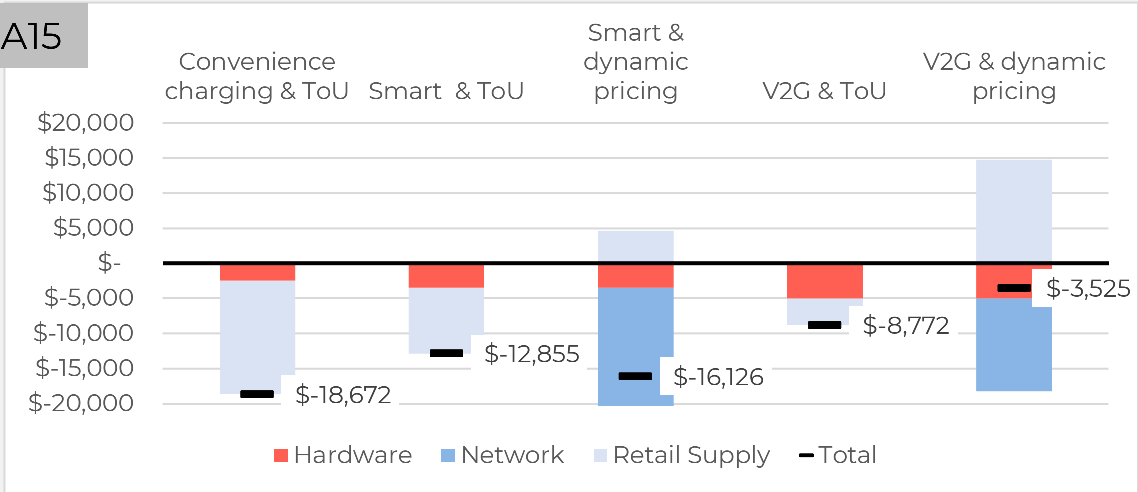
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging (NPV)

A16



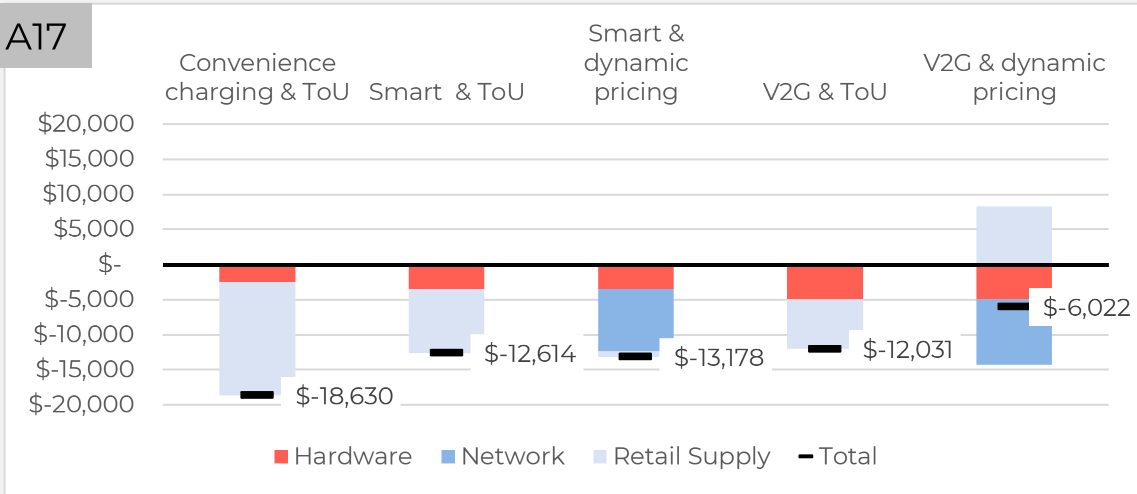
Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging (NPV)

A15



Economy user (5 MWh per annum) – Total cost of charging (NPV)

A17



Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional)

TOU Tariff = EA's residential flexi plan (SA 5011)

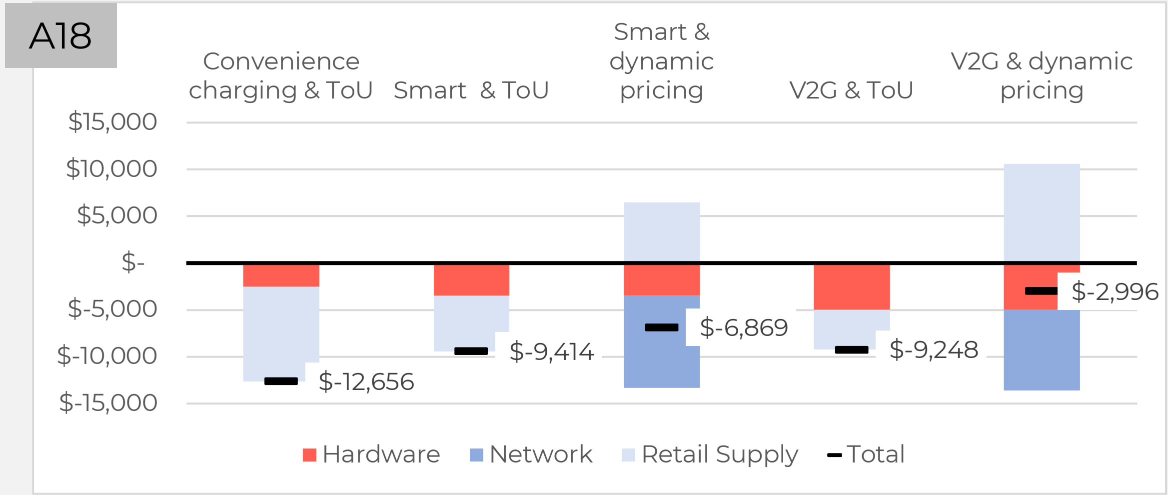
Dynamic pricing = Amber + SAPN electrify two-way trial network tariff

Tasmania - case study results

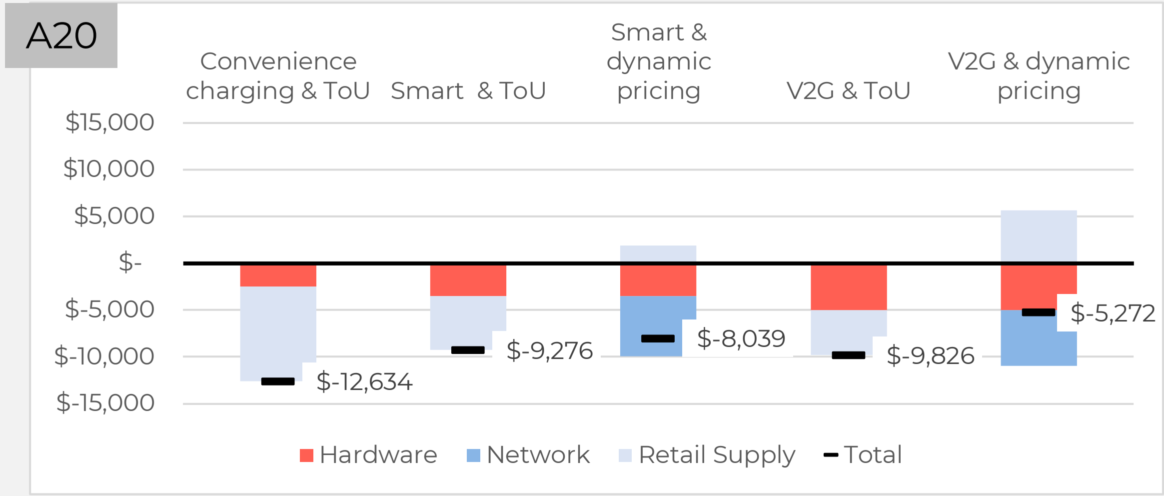
Figures A18 – A21
Positive results are net income

enx

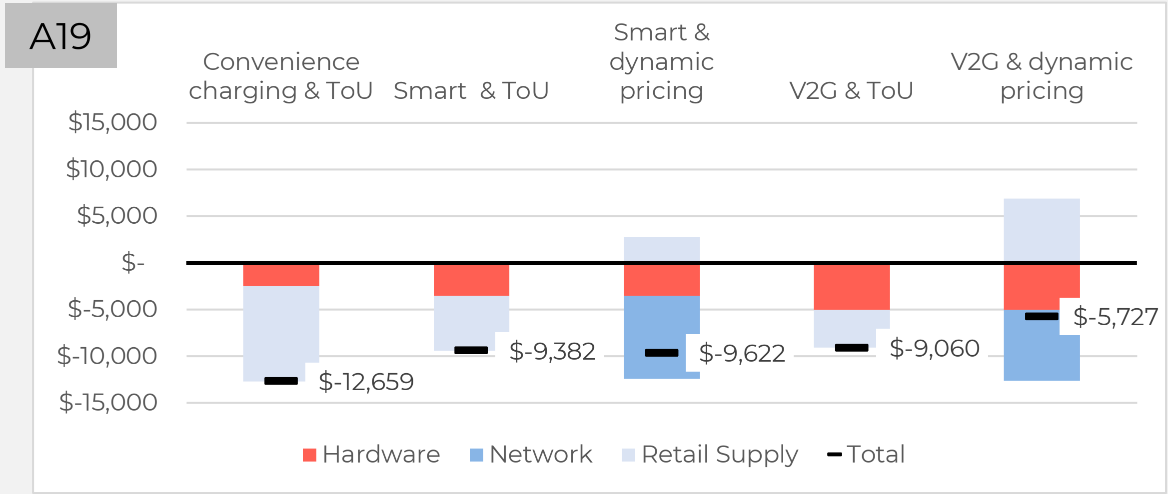
Mega user (16 MWh per annum) – Total cost of charging (NPV)



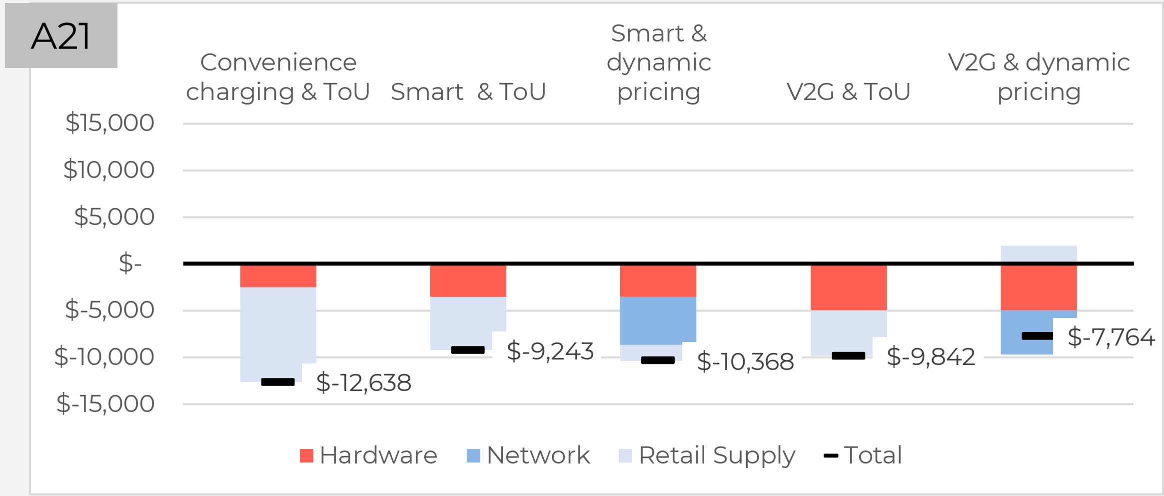
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging (NPV)



Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging (NPV)



Economy user (5 MWh per annum) – Total cost of charging (NPV)



Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional)

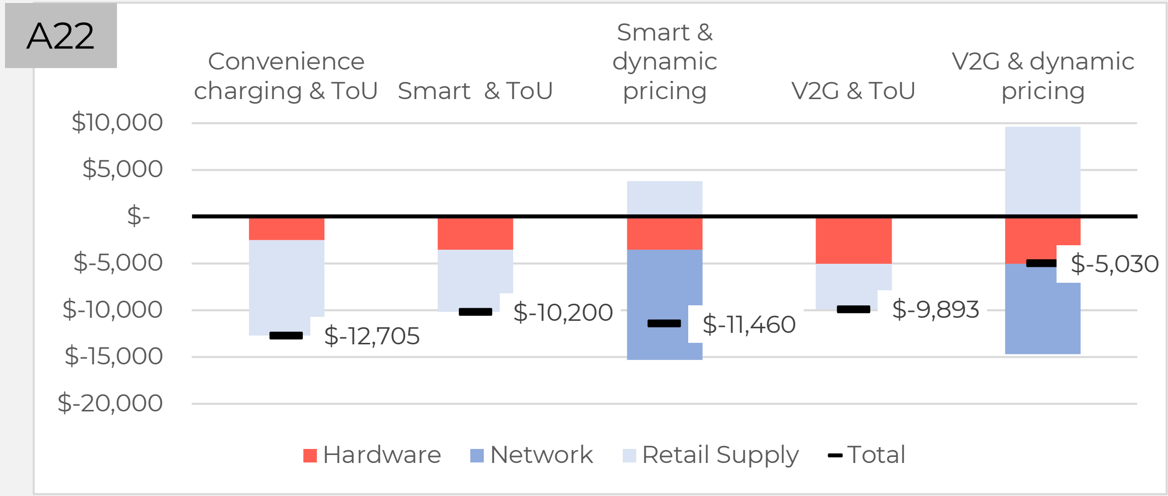
TOU Tariff = AE's aurora+ residential plan (TAS 7000)

Dynamic pricing = Amber + TASNetworks TAS93 network tariff

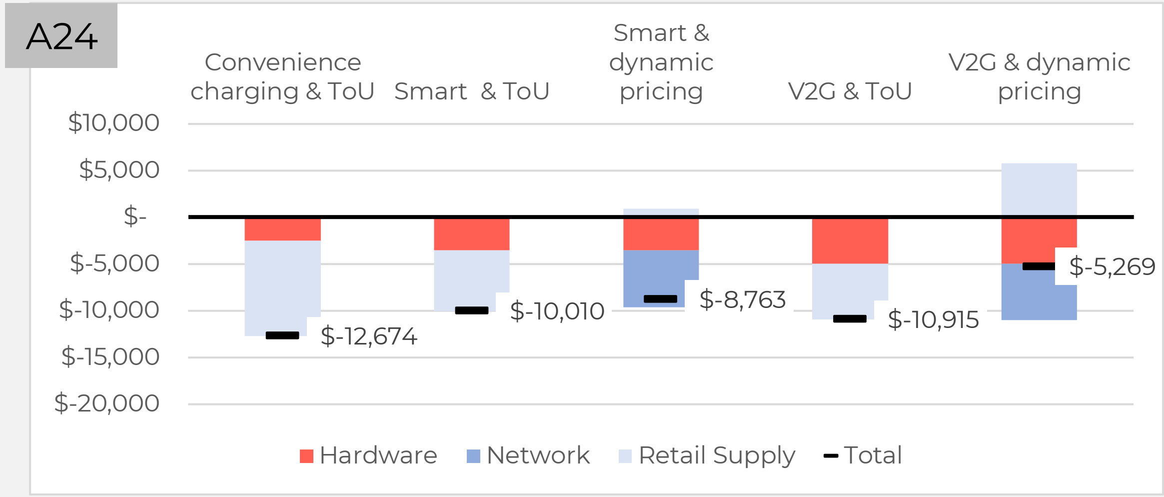
Victoria - case study results

Figures A22 – A25
Positive results are net income

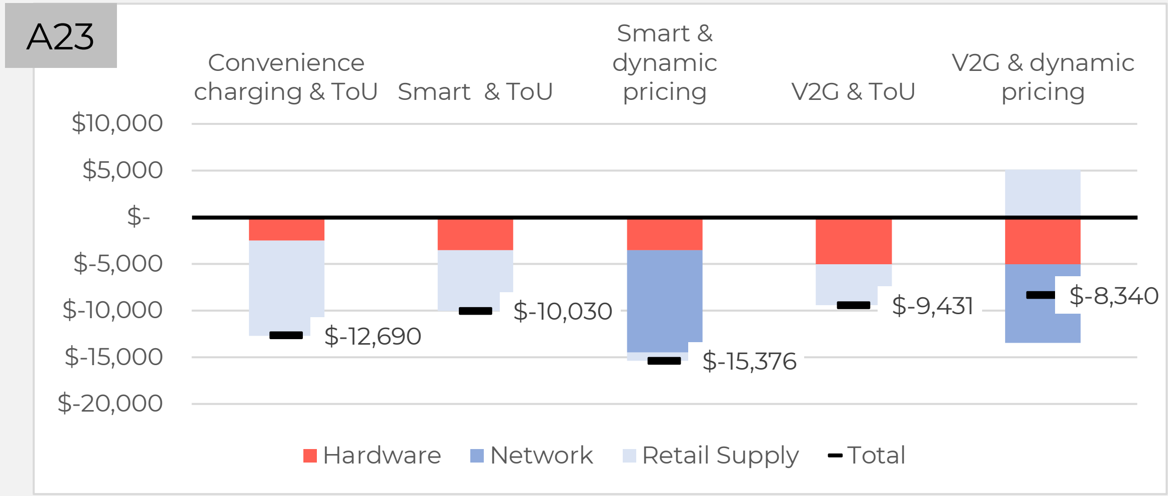
Mega user (16 MWh per annum) – Total cost of charging



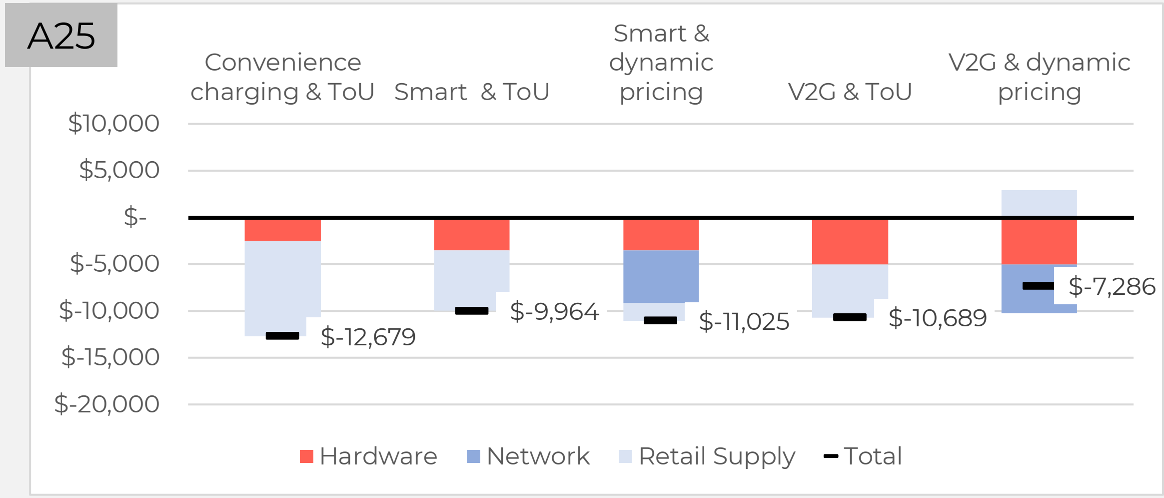
Sponge user (11 MWh per annum, high daytime use) – Total cost of charging



Commuter (11 MWh per annum, high morning and evening peaks) – Total cost of charging



Economy user (5 MWh per annum) – Total cost of charging



Charging scenarios: Convenience charging vs. Smart charging vs. V2G (bidirectional)   TOU Tariff = EA's residential flexi plan (VIC 3149)   Dynamic pricing = Amber + CitiPower CRDS trial network tariff

Appendix B – Ford F150 Lighting case study

Ford Charge Station Pro

In North America, Ford is offering an early V2H/B product that allows a home to run off the Ford Lighting F150 in grid islanded mode. This may serve as a prototype that is replicable by other OEMs as market maturity develops.

Essentially:

- Ford offers an EVSE to suit the F150 Lightning EV
- The EVSE is electrically connected to, and communicates with, a supplied 'Home Integration System' comprising a bidirectional DC-AC inverter compliant with local wiring codes (e.g., appropriate circuit protection, etc)
- The inverter is not grid synchronised as this stage, and only operates when the mains power is not connected (i.e., it provides 'backup power')
- Switching from mains to backup power is automatic and managed by the Home Integration System. A small "dark start" battery is provided to manage system operation independently of mains or EV power sources
- The backup power capacity is large (9.6kW, and up to 151 kWh) – suited to electrified homes. The power transfer capacity is limited by the capacity of the inverter
- The DC side of the inverter has a DC bus to connect DC power sources common to residential settings (e.g., solar PV, stationary batteries)

Critically, the entire product offering is tested, certified and ultimately homologated in market by Ford and provided through a dedicated sales channel using an approved partner (Sunrun) to access skills and knowledge in residential energy systems. This model is readily replicable in Australia, subject to previously identified issues with EVSE testing and certification.

Figure B1: Ford Charge Station Pro operation in grid connected mode

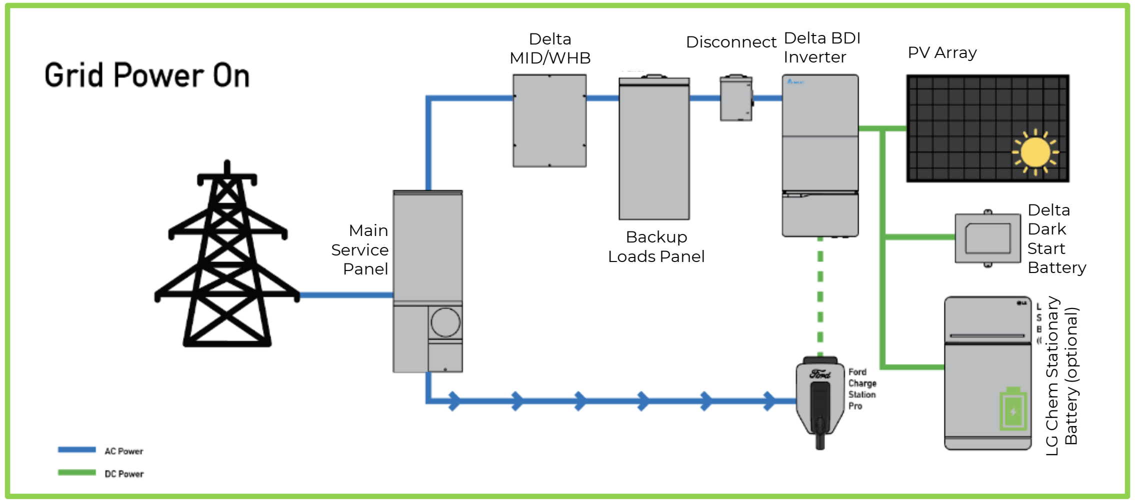
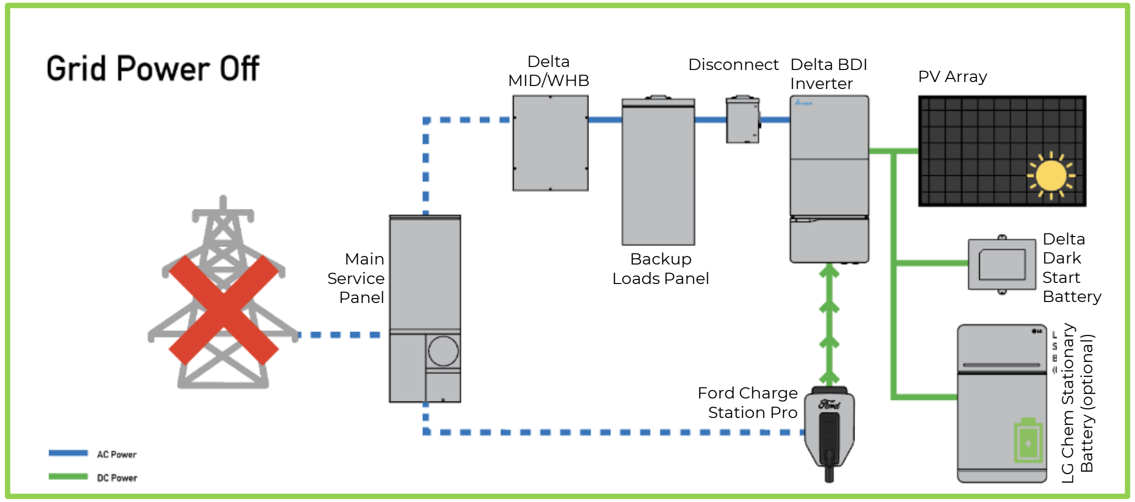


Figure B2: Ford Charge Station Pro operation in grid island mode



[1] Field Website - Ford EV Charger

Appendix C – Long-term battery fleet GWh estimates

Long-term battery fleet GWh estimates

enx

Estimating EV fleet size and energy storage capacity

Estimating the long-term energy storage capacity in Australia's EV fleet requires taking a view of a range of factors that are inherently uncertain:

- **EV uptake in different market segments** – We have taken Battery Electric Vehicle (BEV) fleet numbers from AEMO's Electric Vehicle workbook 2023 (1.8°C Orchestrated Step Change) scenario. This represents a relatively bullish view of EV adoption, although not as aggressive as the 1.5 °C Green Energy Exports scenario.
- **Future battery technology improvements** – We have assumed a continuation of the growth trends in gravimetric energy density from König et al (2021) for pouch format batteries (~10% pa., see Figure C1). Volumetric density gains are considered positive external externality. While these assumptions are considered reasonable (and conservative), there is inherent uncertainty about the rate of future innovation and very different approaches could also be considered reasonable.
- **Market pressures** – A key variable to consider is the extent to which automakers use gains in battery energy densities to increase kWh-per-vehicle storage capacity, versus achieving cost, weight or volume reductions. As most vehicle market segments are very cost competitive, it is likely that once customer range anxieties are satisfied, battery improvements will focus on cost and vehicle weight reduction rather than just ever-increasing battery sizes. We have assumed that 30% of gravimetric energy density increase is used to increase range leading to a ~3% per annum increase in usable battery size per vehicle.

Overall, this works out to an 80% average increase in per vehicle kWh, from current segment averages, by 2050. This results in an average of 350Wh/kg for new vehicles by 2050 - a density already being demonstrated for pouch format batteries in early production. This analysis *could* therefore be considered highly conservative.

The multiple of AEMO's vehicle numbers, and our per-vehicle energy storage growth analysis, is shown in Figure D2.

Figure C1 – Analysis of trends in battery energy density (Source: König et al, 2021)

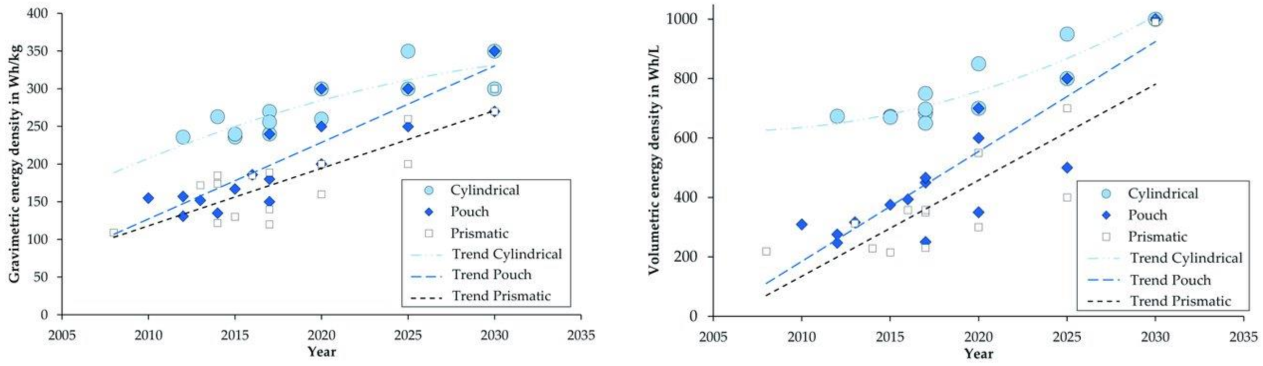
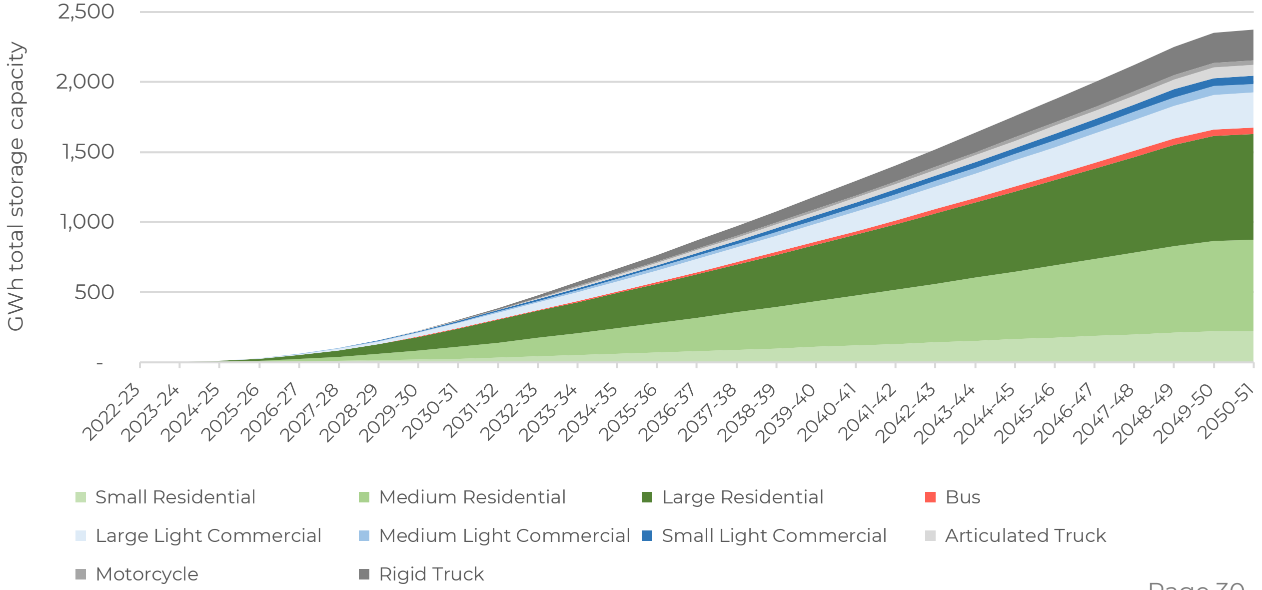


Figure C2 – Modelled growth in EV fleet usable battery capacity over time



Appendix D – URLs for references

URLs for reference

enx

These long-form URLs are provided to fulfil ARENA's report accessibility requirements

Report reference	URL
AEMO 2022 Integrated System Plan	https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-
CSIRO GenCost 2022-23 Consultation	https://publications.csiro.au/rpr/pub?pid=csiro:EP2022-5511
ARENA Commercial Readiness Index	https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf
AEMO Integrating Energy Storage Systems Rule Change	https://aemo.com.au/initiatives/submissions/integrating-energy-storage-systems-iess-into-the-nem
AEMC Unlocking CER benefits through flexible trading	https://www.aemc.gov.au/rule-changes/unlocking-CER-benefits-through-flexible-trading
AEMC Scheduled Lite Mechanism	https://www.aemc.gov.au/rule-changes/scheduled-lite-mechanism
Announcement from Korea's Ministry of Trade, Industry and Energy	https://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=166562&bbs_cd_n=81&currentPage=1&search_key_n
Decision Adopting Plug-In Electric Vehicle Submetering Protocol And EVSE Communication Protocols	https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M496/K405/496405751.PDF
Biden-Harris Administration Announcement	https://highways.dot.gov/newsroom/biden-harris-administration-announces-latest-steps-deliver-national-network-convenient
Common Smart Inverter Profile Australia	https://arena.gov.au/assets/2021/09/common-smart-inverter-profile-australia.pdf
Dekra E-mobility testing	https://www.dekra.com/en/e-mobility-testing/
ElaadNL	https://elaad.nl/en/
Chapter 5A of the National Electricity Rules	NER Chapter 5A: Electricity connection for retail customers - AEMC Energy Rules
AS/NZ 4777.2:2020 Grid connection of energy systems via inverters, Part 2: Inverter requirements,	https://infostore.saiglobal.com/en-au/standards/as-nzs-4777-2-2020-101208_saig_as_as_2906527/
Clean Energy Council Approved Inverter List	https://www.cleanenergycouncil.org.au/industry/products/inverters/approved-inverters
Vehicle-to-Grid (V2G) charging approved for South Australia	https://jetcharge.com.au/v2g-charging-approved-for-sa/
SA Electric Vehicle Supply Equipment (EVSE) standards	Electric Vehicle Supply Equipment (EVSE) standards | Energy & Mining (energymining.sa.gov.au)
V2G Hub	https://www.v2g-hub.com/
REVs V2G trial	https://arena.gov.au/news/world-leading-electric-vehicle-to-grid-trial-in-act/
Piha V2H trial	https://www.vector.co.nz/news/vector-to-explore-benefits-of-vehicle-to-home-tech
Senate Bill 233 (2023)	https://legiscan.com/CA/text/SB233/2023
Electric Vehicle Database	https://ev-database.org/#sort:path~type~order=.rank~number~desc|range-slider-range:prev~next=0~1200|range-slider-acceleration:prev~next=2~23|range-slider-topspeed:prev~next=110~350|range-slider-battery:prev~next=10~200|range-slider-towweight:prev~next=0~2500|range-slider-fastcharge:prev~next=0~1500|paging:currentPage=0|paging:number=9
Drive.com	https://www.drive.com.au/news/nissan-leaf-sales-in-reverse-four-years/
Tesla Models To Offer Bi-Directional Charging Capability By 2025	https://insideevs.com/news/655334/tesla-lineup-get-bi-directional-charging-capability-by-2025/
Kaulza – Vehicle-to-Everything	https://info.kaluza.com/hubfs/Vehicle-to-Everything%20Inflexion%20survey%20findings%20-%20Kaluza.pdf
Ford Media Center - Iconic F-150 Lightning Goes Global	https://media.ford.com/content/fordmedia/feu/en/news/2023/04/20/electric--iconic-f-150-lightning-goes-global-as-ford-announces-a.html
The Mobility House	https://www.mobilityhouse.com/int_en/
AEMO 2023 Electric Vehicle workbook	https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/2023-inputs-assumptions-and-scenarios-consultation/supporting-materials-for-2023/aemo-detailed-electric-vehicle-workbook---draft-2023-iasr.xlsx?la=en
Nature Communications	https://www.nature.com/articles/s41467-022-35393-0
Clean vehicles as an enabler for a clean electricity grid	https://iopscience.iop.org/article/10.1088/1748-9326/aabe97/pdf
ISP 2022 results workbook	https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp
Gridcog website	https://www.gridcog.com/
Project Scurus	https://www.cenex.co.uk/app/uploads/2021/05/Sciurus-Trial-Insights.pdf
Field Website - Ford EV Charger	https://sites.google.com/sunrun.com/sop/sops/ev-chargers/ford-ev-charger
CATL Promises Solid-State Battery With More Than 350 Wh/kg	https://insideevs.com/news/483085/catl-solid-state-battery-350-wh-kg/