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# A Critical Study of Stationary Energy Storage Policies in Australia in an International Context: The Role of Hydrogen and Battery Technologies

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**Abstract:** This paper provides a critical study of current Australian and leading international policies aimed at supporting electrical energy storage for stationary power applications with a focus on battery and hydrogen storage technologies. It demonstrates that global leaders such as Germany and the U.S. are actively taking steps to support energy storage technologies through policy and regulatory change. This is principally to integrate increasing amounts of intermittent renewable energy (wind and solar) that will be required to meet high renewable energy targets. The relevance of this to the Australian energy market is that whilst it is unique, it does have aspects in common with the energy markets of these global leaders. This includes regions of high concentrations of intermittent renewable energy (Texas and California) and high penetration rates of residential solar photovoltaics (PV) (Germany). Therefore, Australian policy makers have a good opportunity to observe what is working in an international context to support energy storage. These learnings can then be used to help shape future policy directions and guide Australia along the path to a sustainable energy future.

**Keywords:** renewable energy; electrical energy storage; battery; hydrogen; policy; Australia

## 1. Introduction

The global threat of climate change is currently driving a fundamental shift away from the incumbent energy model of centralised fossil fuel electricity generation towards a more decentralised model based on very high penetration rates of intermittent renewable energy (e.g., wind and solar) [1]. This poses a number of challenges as it is estimated that above a penetration rate of 30%, intermittent renewable energy (with no energy storage) can lead to a mismatch between supply and demand, power quality issues, network constraints and renewable energy curtailment. In smaller islanded grids or those without good interconnections, this percentage may be even lower [2].

Whilst there are a number of different technologies and methods that can address these challenges, it is likely that electrical energy storage will be the key enabler in integrating up to 100% renewable energy into the grid. This is largely because of the versatility of energy storage in that it can provide a wide range of services including demand matching and peak reduction, network congestion relief and infrastructure deferral, rapid frequency and voltage response and seasonal storage [3–5]. A review by Beaudin et al. determined that, in general, an energy storage capacity of 10%–20% of the total intermittent renewable energy generation would need to be installed to effectively integrate it into the grid, depending upon the particular grid infrastructure [6]. The current global energy storage capacity is 144 GW [7] which is approximately 22% of the total installed solar and wind energy capacity of 659 GW (227 GW solar and 432 GW wind) [8]. However, a number of the leading countries have a ratio lower than this such as Germany, which has an energy storage capacity that is 8% (7 GW) [7] of the total solar and wind energy capacity (84 GW) [8].

Furthermore, within these countries there are areas of high concentrations of intermittent renewable energy such as Texas in the USA which has an energy storage capacity that is only 1% (0.16 GW) [7] of the total wind energy capacity (17.7 GW) [9]. As such, a number of countries and states such as Germany, and the USA (California, Texas and New York) are actively supporting the development and deployment of electrical energy storage technologies through policy and regulatory changes in order to achieve and support their renewable energy targets [10–13].

Currently, the incumbent electrical energy storage technology is pumped hydro storage (PHS), which is well developed and commercially mature [7,14]. However, there are a number of emerging technologies that, whilst currently more expensive than PHS, are becoming popular and generating increasing interest. The scope of this paper is to focus specifically on two of these technologies, battery and hydrogen energy storage.

Battery storage is more suitable to be used as a short-term energy storage option. Other short-term energy storage technologies such as flywheels and capacitors can have some role to play. However, they are not favourable to be deployed on a micro-scale coupled with solar photovoltaics (PV) at a single dwelling unlike battery storage which can also be scaled up to multiple MW/MWh sized storage for transmission and distribution (T&D) and integrating large scale renewable energy. Additionally, batteries will be widely used in the transportation sector, which is currently driving significant research and development.

In terms of emerging long-term electrical storage options, compressed air energy storage (CAES) has a role to play but is limited in terms of growth due to requiring specific geological formations such as caverns and disused mines [15]. Hydrogen storage is less restricted in this sense and can therefore often be located in close proximity to large scale renewable energy facilities [16]. Hydrogen can also be used directly as a fuel source for transportation and industrial and chemical processes. Hydrogen, up to a certain concentration, can be directly injected into existing natural gas infrastructure, which has a high storage capacity. This can be particularly a potentially viable option for the local transmission and distribution of hydrogen over short distances.

Australia has some of the best renewable energy resources in the world, receiving the highest solar radiation of any continent (1.6 $MWh/m^2/year$) and the entire southern coastal region has high average wind speeds of 6 m/s–10 m/s, ideal for high yield electricity generation [17]. Combined with the highest penetration rate of residential solar PV globally, and high electricity prices [18], the country is well placed to take a leading role in the transition towards a future of decentralised renewable electricity coupled with energy storage. However, in order for this to occur, it is critical that effective government policies and regulations are established to provide the necessary support.

This paper will review the current policy frameworks, incentives and regulatory environment as they pertain to battery and hydrogen energy storage in Australia and also recent relevant international experience from the leading countries supporting the growth and deployment of these technologies. In addition, this paper will identify and suggest policy mechanisms that are applicable to Australia, which can be explored further in a separate paper.

Section 2 will provide a global overview of energy storage including an introduction of the current types of technologies available and installed capacity, the main energy market segments and how electrical energy storage is being supported in each by the leading countries through policy and regulation. Section 3 will provide an overview of the current status of support for energy storage in Australia at federal and state government levels. Section 4 will critically discuss the current policies in Australia in an international context. It will also provide an overview of hydrogen storage and how it can play a role in a sustainable energy economy. The paper concludes with a summary of how energy storage is currently being supported in Australia and the relevant policy mechanisms from the leading countries that are applicable to the Australian energy market.

## 2. Energy Storage: A Global Overview

### *2.1. Technologies and Current Global Capacity*

There are a number of energy storage technologies in various stages of development as shown in Figure 1. Of these, PHS is clearly the most dominant technology representing 98% of global grid-connected electricity storage capacity (Figure 2). PHS is a commercially mature technology that has existed for over 100 years. It uses differences in elevation to store off-peak or excess electricity for later use whereby water is pumped from a lower reservoir to a higher reservoir. During times of demand, the water is permitted to flow back to the lower reservoir via a turbine and operates in a similar manner to a conventional hydroelectric power station. There are a number of possible configurations with the upper reservoir comprising of lakes or man-made dams and the lower reservoir comprising of lakes, man-made dams, disused mine shafts, underground cavities or the sea [15].

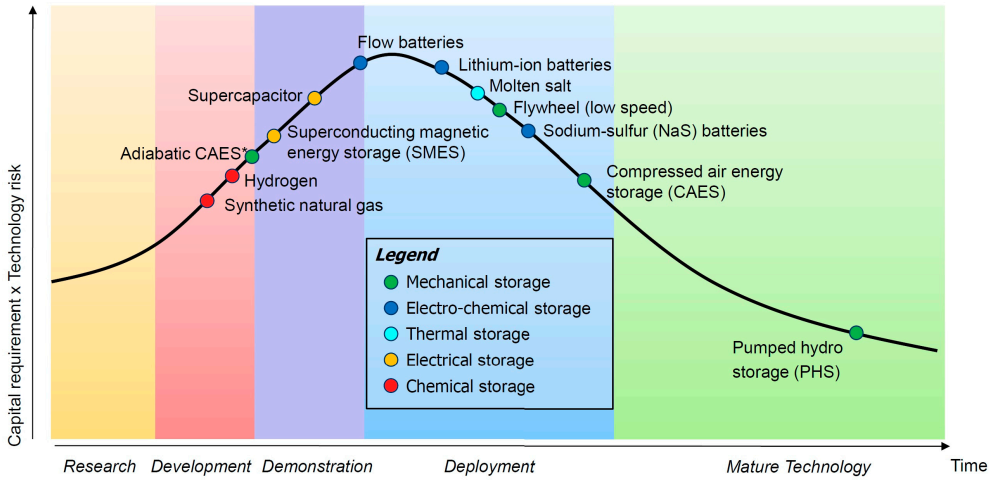


**Figure 1.** Maturity of energy storage technologies [14].

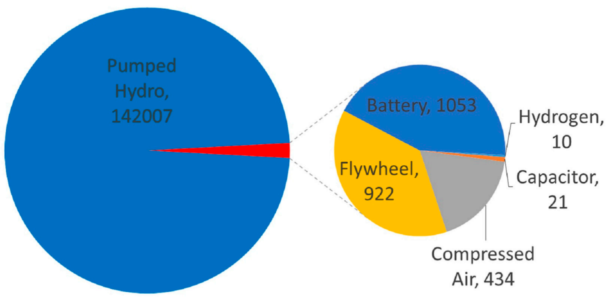


**Figure 2.** Global installed grid connected energy storage capacity in MW that can be used to supply electricity (created from data obtained from [7]).

Although not part of the scope of this paper, PHS can have a role to play in a sustainable energy future. There are approximately 10 GW of PHS capacity currently under construction in Europe and another 10 GW of capacity in China, including the world's largest, the 3.6 GW facility in Hebei [19]. However, there are challenges to the future growth of PHS including a limited number of suitable sites, long development times, large upfront capital costs, and major environmental effects [15]. This is particularly the case for Australia, where there has not been a PHS site built for 30 years [19] although there is currently a feasibility study into the construction of a 300 MW PHS reservoir at a disused gold mine for the purposes of rapid grid response [20]. Such sites potentially offer a good location for PHS as the environmental impact would be minimal and the excavation of the reservoir has largely already been completed, thus reducing capital costs.

One of the keys challenges in Australia will be integrating increasing amounts of wind energy into the grid, particularly in South Australia (SA), which currently has 1.5 GW, 40% of the country's installed wind capacity, and is forecasted to grow to 4.4 GW by 2024 [21]. A study by the Melbourne Energy Institute investigated the benefits of co-locating new PHS with wind generation, where there currently exists an electricity transmission connection and determined that no such site existed. Therefore, other technologies such as hydrogen storage will need to be deployed to provide long-term storage to integrate such large amounts of wind energy [19].

The remaining 2% of global grid-connected electricity storage capacity is comprised of various technologies including short term storage such as batteries, flywheels, and capacitors [7]. Of these, battery technology has shown so far some potential to be part of the Australian market given the high penetration of residential solar PV. It is important to note that this technology may not necessarily be the most sustainable solution to be considered for all short-term and long-term energy storage applications in Australia.

Overall, battery storage has grown almost 300% between 2014 and 2016. This trend is expected to continue with the International Renewable Energy Agency (IRENA) predicting an installed capacity of 14 GW in 2030 [22] compared to the current capacity in 2016 of just over 1 GW [7].

Despite this growth, battery storage has limitations in terms of storage capacity and so is not suitable for every application as shown in Figure 3. Large scale, long-term storage, which will be required for seasonal backup or as energy security reserves in the absence of fossil fuels [5], will require a different technology. As mentioned, hydrogen storage has the potential to fulfil this role and, therefore, the future grid is likely to be one where hydrogen plays a significant and crucial role alongside various other storage technologies, not in competition but in concert as put forward by Andrews and Shabani in their re-envisioned hydrogen economy 'Hydrogen in a Sustainable Energy' (HISE) strategy [23] and discussed later in this review.

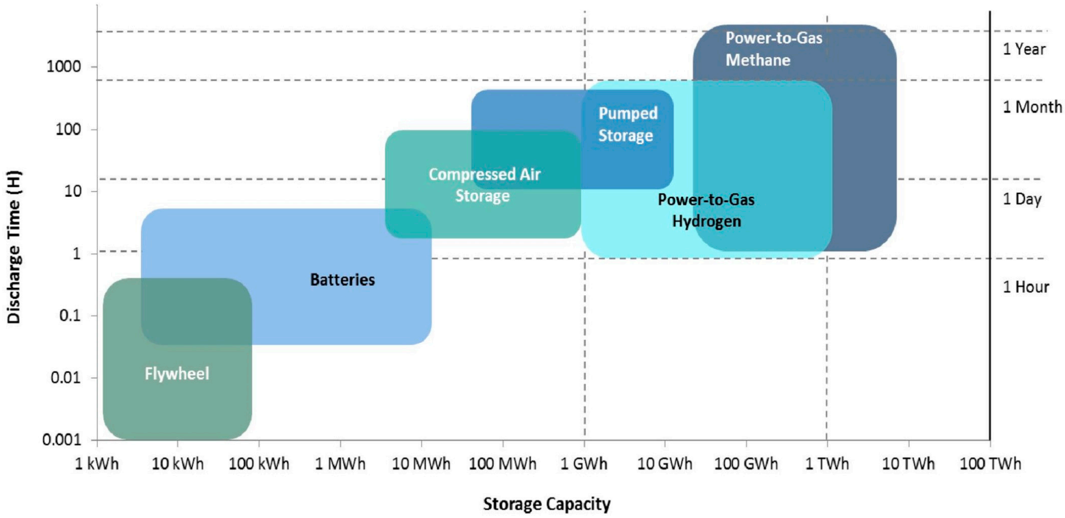


**Figure 3.** Comparison of discharge time vs capacity of energy storage technologies [24].

## 2.2. Energy Market Segments

The main energy market segments are summarised in Table 1 along with the associated benefits of energy storage and the relevance to Australia. Given the versatility of energy storage, it is able to operate in all segments and fulfil multiple roles simultaneously.

**Table 1.** Benefits of energy storage in the main energy market segments [25].

| Market | Application | Definition | Benefits of Energy Storage | Australian Context |
|---|---|---|---|---|
| Wholesale | Utility scale storage | Electricity generators which supply and sell electricity into the market, ancillary services for grid stability | Support higher penetration of intermittent renewable energy, price arbitrage, ancillary services | High state based renewable energy targets (50%–100%) |
| Transmission and Distribution (T&D) | Network management | Regulated monopolies that distribute electricity from generators to end users, ancillary services | Demand management, alleviate network constraints and power quality issues, ancillary services | Network constraints, power quality issues due to concentrations of renewable energy |
| End User | Behind the meter | Electricity consumers across the residential, commercial and industrial sectors | Support larger solar photovoltaics (PV) installations, increase solar PV utilisation, reduce network demand | High penetration of residential solar PV |
| Off Grid | Renewable energy hybridisation | Electricity systems not connected to main grid (e.g., islands, remote communities) | Support higher concentration of intermittent renewable energy to offset fossil fuels | Large off grid market |

### 2.2.1. International Policies and Plans

In terms of battery storage deployment, the U.S. and Korea are the current global leaders alongside Japan and Germany, all of which have significant numbers of projects in development. The UK has dropped in the global rankings to 8th but from a policy perspective is making progress, and China, whilst ranking highly, has a very different political system to Australia and therefore will not be discussed in this paper. The estimated installed and planned battery storage capacity is shown in Figure 4. Although, this is underestimated as it does not include the significantly smaller scale behind the meter installations such as those at residential and commercial locations.

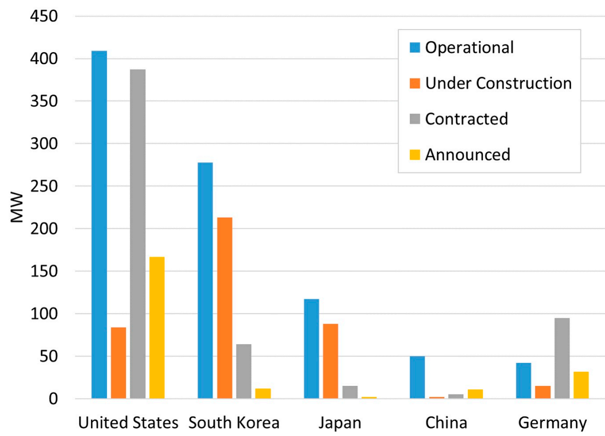


**Figure 4.** Operational and planned battery storage by country (created using data obtained from [7,26]).

Whilst many countries have supported energy storage through demonstration projects, very few have implemented the policy and regulatory changes required to facilitate market growth and development. The leading countries have each customised their investment to meet the needs of their own unique energy market which has resulted in different levels of support (low, medium and high) across the main energy market segments as shown in Table 2 [25].

**Table 2.** Level of support for energy storage in leading countries (adapted from [25]).

| Country/State | | Wholesale | Transmission and Distribution | End User | Off-Grid |
|---|---|---|---|---|---|
| **U.S.** | California | Very High | Very High | High | Low |
| | Hawaii | High | Medium | Low | High |
| | New York | Medium | Medium | Medium | Low |
| | Texas | Med- High | Low | Low | Low |
| **Germany** | | Medium | Medium | High | N/A |
| **UK** | | Medium | Medium | Low | Medium |
| **Japan** | | Medium | Medium | Medium | Medium |
| **Korea** | | Low | High | Medium | N/A |

In order to achieve high renewable energy targets—California 50% by 2030 [27] and Germany 80% by 2050 [22]—both have taken a holistic approach to supporting energy storage by implementing a comprehensive range of policies and regulations across all market segments. They have also placed the onus on utilities to facilitate the deployment of energy storage systems whilst providing residences and small businesses with financial incentives.

### 2.2.2. Wholesale Market

California recognises that energy storage is crucial to achieving its renewable energy target. In 2014, the state published a roadmap to identify the policy, technology, and regulatory changes required to address barriers with the goal of providing a strong supportive framework for future market growth in energy storage. Three key focus areas have been identified which are to improve revenue for energy storage providers, reduce grid integration costs, and streamline and define policies to increase the certainty of expected benefits from energy storage [28].

The key supporting legislation for energy storage was passed by the California Public Utilities Commission (CPUC) in 2014 that set a target of 1,325 MW energy storage capacity by 2020. Projects must satisfy at least one of three policy objectives: grid optimisation, renewable energy integration and greenhouse gas (GHG) emissions reduction. The target is spread across the three largest investor-owned utilities and also by market segment (Figure 5) with a bias towards transmission (wholesale) connected storage, although up to 80% can be shifted between this and the distribution markets to provide flexibility. Progress is being made with Southern California Edison (SCE) procuring 260 MW of energy storage in 2014, which is significant, given that it was only required to procure 50 MW. Of this, 235 MW is battery storage including a 100 MW/400 MWh system from AES Energy Storage company [11].

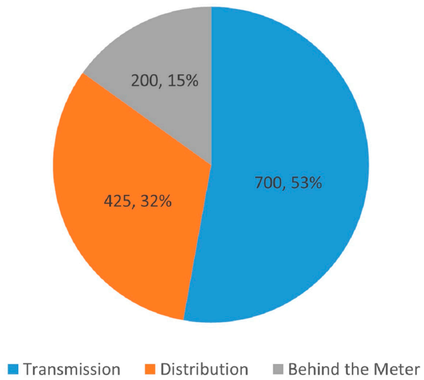


**Figure 5.** California 2020 energy storage target by network area (created from data obtained from [11]).

The U.S. state of Texas achieved its 2025 renewable energy target of 10,000 MW (approximately 10%) 15 years early in 2010. Whilst this is a small percentage, 75% of this is from wind turbines, making Texas the highest ranked state for wind energy [12]. Texas is also the only mainland U.S. state with its own grid and so the combination of these two factors poses a challenge for grid stability. To mitigate this, Texas has taken steps to support energy storage through regulatory change. In 2011, the state passed bill SB 943 which gave energy storage the same rights as generators with regard to transmission access and interconnection. In addition, the Public Utilities Commission changed regulation to allow energy storage facilities to buy and sell electricity at wholesale market rates, enabling them to compete against generators for ancillary services and longer term storage [12]. Such changes are crucial for the support of energy storage technology, as they remove key barriers that exist within outdated energy market frameworks and allow storage to participate in the provision of all market services for which it is qualified [29].

Currently, Texas has a battery storage capacity of 43 MW/59 MWh [7] with the largest contribution coming from the 36 MW/24 MWh battery installed by Duke Energy in 2012 at the 153 MW Notrees Wind Farm in West Texas to address intermittency [30]. It was funded through the American Recovery and Reinvestment Act (ARRA) of 2009 which allocated $608 million (USD) to the United States Department of Energy (USDOE) for 32 Regional Smart Grid Demonstrations and Energy Storage Demonstration projects [31]. ARRA was designed to provide economic stimulus after the Global Financial Crisis (GFC) and whilst not a long term policy solution it has helped to build capability and grow the nascent energy storage industry.

In 2010, Germany announced its national energy transition framework (Energiewende) to achieve an 80% reduction in GHG emissions by 2050, 80% renewable energy by 2050, and phase out its nuclear power plants by 2023 [32]. This will result in a fundamentally different energy market and one in which intermittent renewable energy will play a significant role.

Germany, unlike California, has no specific energy storage target but rather is relying predominantly on grants and low interest finance provided by the government owned development bank (KfW) as market support mechanisms. At a wholesale level, finance is available under KfW 291 which provides low interest loans of €25–100 million for large-scale projects and KfW 230 which provides grants of up to 30% and low interest loans for innovative large-scale pilot and demonstration projects that have substantial potential to provide environmental benefits. Some of the key battery storage projects supported by KfW are provided in Table 3.

**Table 3.** Key wholesale market battery storage projects [32].

| Capacity | Type | Year | Operator | Application |
|---|---|---|---|---|
| 5 MW/5 MWh | Li-ion | 2014 | E.ON | Grid stability in a region with 80% renewable energy, ancillary services |
| 5 MW/5 MWh | Modular (Li-ion, high-temp, lead-acid) | 2015 | WEMAG AG | Renewable energy integration, grid stability, wholesale price arbitrage, ancillary services |
| 10 MW/10 MWh | Li-ion | 2015 | 50 Hertz | Grid stability, load balancing wind energy, ancillary services |

By 2030, it is estimated that a total of 8.4 TWh of energy storage will be required in Germany to successfully integrate renewable energy into the grid. This is comprised of 16 GWh of hourly storage, 170 GWh of daily storage, 3.2 TWh of weekly storage and 5 TWh of monthly storage [15]. Given that there is currently 40 GWh of pump hydro storage, it is clear that many more energy storage projects will be required, with battery technologies likely covering the majority of the hourly and daily demand and other technologies such as hydrogen storage providing the capacity for longer durations.

Japan was an early leader in the deployment of battery storage due to concerns about the country's reliance on pumped hydro. In particular, it focused much of its efforts on the development of sodium-sulphur (NaS) battery technology with over 250 MW installed since the mid-1990s. This included a 34 MW/204MWh NaS battery used to store the energy generated from a 51 MW wind farm during periods of low demand [22].

The shutdown of the country's nuclear reactors after the 2011 Fukushima disaster has prompted the Japanese government to increase its support for renewable energy, setting a target of 20%–22% by 2030, with battery storage viewed as being critical to achieving this. In 2012, the Ministry of Economy, Trade and Industry (METI) established the Storage Battery Strategy Project Team to promote policies focusing on battery storage for numerous applications including load balancing, disaster preparedness and industrial competitiveness [33].

At the wholesale market level, METI has provided funding to battery storage demonstration projects with the aim of providing grid stability and to determine how much additional renewable energy can be added after the installation of such battery systems. Two of the key projects are listed in Table 4.

**Table 4.** Ministry of Economy, Trade and Industry (METI) battery storage demonstration projects [34].

| Capacity | Type | Year | Operator | Application |
|---|---|---|---|---|
| 15 MW/60 MWh | Redox Flow | 2016 | Hokkaido Electric | Renewable energy integration, grid stability |
| 40 MW/20 MWh | Li-ion | 2016 | Tohoku Electric | Renewable energy integration, grid stability |

### 2.2.3. Transmission and Distribution Market

In the T&D market, regulatory reform is key to supporting energy storage since the energy market framework of most countries is built around centralised fossil fuel generation. As a result, energy storage, with its wide range of applications, does not fit neatly into the existing regulations nor is it compensated fairly. Leading countries supporting energy storage in this market are progressively removing these barriers through regulatory reform to enable it to compete with fossil fuel generation.

The prime example of this is in the U.S., where the Federal Energy Regulatory Commission (FERC) issued FERC Order 755 in 2011 to recognise the added value of resources able to provide fast frequency response such as batteries and flywheels [35]. This was expanded in 2013 (FERC Order 784) to include the ancillary services market [36]. The effect of this can be seen in the PJM Interconnectio which is a Regional Transmission Organization (RTO) that manages the transmission of electricity for 13 north-eastern states and Washington D.C. It restructured its frequency regulation market in 2012 to financially incentivise fast responding resources for providing a more efficient service compared to that provided by slower responding fossil fuel generation. These faster responding resources have been assigned the classification RegD to differentiate them from the slower responding resources which are referred to as RegA resources. Since this occurred, RegD resources have increased from 11% to 48% of the market share [37] with 160 MW of battery storage being installed in 2015 out of a national total of 221 MW [38]. Also, since RegD resources are more efficient, the required MW capacity of the frequency regulation market has been reduced by 30% [39].

New York State in the U.S. is also taking steps to support energy storage through regulatory change in order to support its renewable energy target of 50% by 2030 [40]. In 2015, it released its Reforming the Energy Vision (REV) strategy which aims to provide support for numerous technologies to modernise its aging electricity grid. As part of this, the Public Service Commission (PUC) aims to better align utility interests through significant regulatory reform and changes to market design [13]. A key aspect of the REV strategy is the creation of the Distributed System Platform (DSP) provider to facilitate a market for distributed energy resources (DERs), including battery storage. By July 2016, each utility is required to submit their first Distribution Service Implementation Plans (DSIPs) which provide the framework for how DERs will be implemented [13]. One of the REV strategy pillars is the 10 year, USD $5 billion Clean Energy Fund launched in 2016. Within this fund is a USD $50,000 incentive for energy storage that is integrated with solar PV and provides a minimum of monthly peak demand reduction of 250 kW (New York State, 2016).

In 2010, New York State established the New York Battery and Energy Storage Technology (NY-BEST) Consortium, which released an energy storage roadmap in 2012 with the aim of making New York a global leader in energy storage. This includes creating new regulatory and market mechanisms and establishing financing options and incentives in order to achieve a goal of 4 GW of energy storage by 2030 to support its renewable energy target. An interim goal of 2 GW/10 MWh of energy storage by 2025 would eliminate one third of the total energy required during the state's highest 100 peak demand hours, saving billions of dollars and improving grid utilization [41].

In addition, as part of the contingency plan to close the Indian Point nuclear reactor, efforts are being made by the utility Con Edison and the New York State Energy Research and Development Authority (NYSERDA) to reduce peak demand by 100 MW. For battery storage, this means a significant increase in rebates from USD $600/kW to $2100/kW (capacity 50 kW–500 kW), $2310/kW (capacity 500 kW–1 MW) and $2415 (capacity greater than 1 MW) which is capped at $10 million USD until 1 June 2016 [42]. It is interesting to note that the incentive increases with capacity despite larger systems being less expensive on a $/kW basis and could create a bias in the market.

Korea has gone from less than 10 MW of battery storage in 2013 to being a global leader due to the installation of the world's largest battery storage project for frequency regulation by the Korea Electric Power Corporation (KEPCO). So far, 236 MW out of a planned 500 MW has been installed with the project scheduled to be completed in 2017. The project cost is estimated at USD $500 million but will save an estimated USD $320 million per year from infrastructure deferral and reduced spinning reserve from fossil fuel plants. This saving is considerable since Korea imports 97% of its energy [26,43]. Whilst the Korean energy market is different to Australia, it does highlight that in certain scenarios the business case for battery storage is already very strong.

As discussed earlier, California's energy target includes a sub target for the T&D markets. All three utilities are taking steps to meet these targets with Pacific Gas and Electric (PG&E) procuring 24 MW of battery storage projects for the distribution grid including 8 MW/24 MWh of battery storage at five separate substations that require support during peak demand. These battery systems are being deployed as an alternative to network infrastructure upgrades [44].

In Germany, the KfW has two programmes supporting energy storage projects in the T&D markets. KfW 203 provides low interest loans to municipalities to promote the extension and new construction of energy storage and KfW 204 provides low interest loans of up to €50 million to municipal utilities and medium-sized public-private partnerships. In addition, the German government has made changes to the regulatory framework to incentivise energy storage by exempting it from network and grid tariffs and the EEG renewable energy levy.

The UK has focused most of its efforts on energy storage for the T&D network with a key support mechanism being the £500 million Low Carbon Network Fund (LCNF), which ran from 2010 to 2015 and was designed to drive technological innovation in grid modernisation. It included a competitive bidding process for larger scale projects and a rebate for small scale projects implemented by network operators [45]. A number of battery storage demonstration projects were completed with a key project being the 6 MW/10 MWh Li-ion battery at a substation in Bedfordshire in 2014. The project aimed to assess the cost effectiveness of energy storage in providing ancillary services, alleviate grid congestion and integrate intermittent renewable energy and will save over £6 million on traditional network reinforcement methods [46].

Over the next 10 years, the UK plans to shut down its coal fired electricity generation and replace it with renewable energy, predominately wind, which will have a significant impact on grid stability. To address this, the transmission network service provider, National Grid, is tendering for 200 MW of energy storage to provide a new service, Enhanced Frequency Response (EFR), which will require frequency response in 1 second or less [47]. Expressions of interest resulted in 1.3 GW of submissions with 888 MW from battery projects. As part of this process, National Grid will be benchmarking the cost of energy storage against its current costs for ancillary services, which average £11/MWh ($17 USD) and can reach £20/MWh ($31 USD) [48].

#### 2.2.4. End User Market (Behind the Meter)

As part of its energy storage target, California will deploy 200 MW behind the meter by 2020 and is well on the way to achieving this through two key battery projects with SCE as shown in Table 5. These projects will reduce customers' demand charges and the multiple sites can be aggregated to alleviate grid congestion [49]. California has also made progress on regulatory change with a CPUC ruling in 2014 that exempts storage systems paired with net-metering-eligible systems from a number of fees and charges [50].

**Table 5.** Southern California Edison (SCE) behind the meter battery storage projects [49].

| Capacity | Type | Supplier | Application |
|---|---|---|---|
| 85 MW | Li-ion | Stem | Multiple locations to provide demand reduction and grid support |
| 50 MW | Li-ion | Advanced Microgrid Solutions | Multiple commercial and industrial buildings to provide demand reduction and grid support |

The Self-Generation Incentive Program (SGIP) is an incentive scheme for behind-the-meter generation that commenced in 2001 and was recently modified to include advanced energy storage systems. Rebates of up to 60% of the approved project cost are available depending on the system size; USD $1.31/W (0 MW–1 MW capacity), $0.66/W (1 MW–2 MW capacity), $0.33/W (2 MW–3 MW capacity). SGIP is scheduled to run until the end of 2019 and has an annual budget of USD $83 million [51]. Since 2014, just over 50% of the SGIP funding has gone to 709 energy storage installations, totalling 88 MW [52]. Germany is supporting energy storage in all markets but has a bias towards private consumers due to the high penetration of residential solar PV. As a result, around 35,000 residential and commercial properties had installed integrated battery storage and solar PV by the end of 2015 [32,53]. Support is provided through two KfW projects with annual budgets of €25 million and both require that battery storage is coupled with solar PV. KfW 274 provides low interest loans and KfW 275 provides low interest loans and grants of up to 30% [10] which according to HSBC results in a payback period of five years, half the expected 10-year battery life-cycle [54]. The program is scheduled to end in 2018 with grants reduced progressively to 10% to reflect changing market conditions as it is estimated that battery storage and solar PV systems could reach grid parity in 2018 as shown in Figure 6 [55]. Phasing out incentives as market conditions improve is good policy as it ensures government funds are used effectively and prevents over-subsiding, which can lead to a boom and bust scenario. An interesting condition of KfW 275 is that recipients must allow control of the battery by the local utility to enable aggregation for network services such as frequency control and ensures that all network users benefit [10].

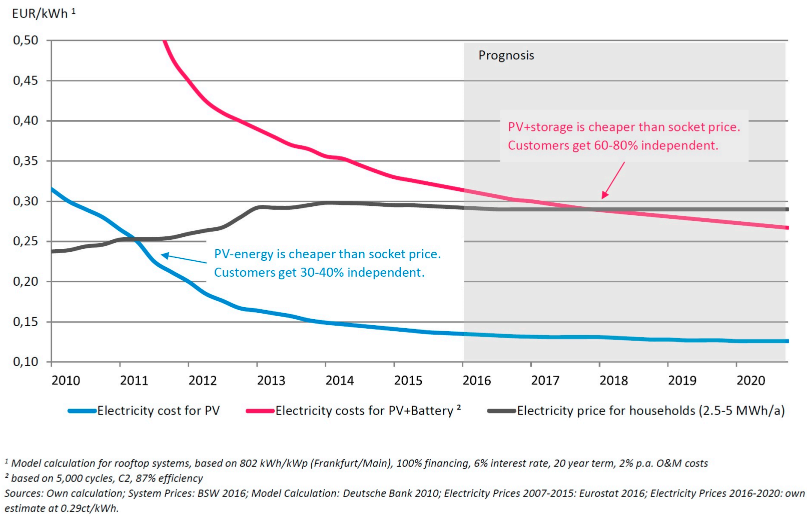


**Figure 6.** Comparison of photovoltaics (PV) grid parity and PV + battery parity in Germany [55].

Japan is another country providing generous subsidies, with METI in 2014 introducing a USD $100 million program that will pay up to two thirds the cost of a lithium-ion battery system capped at USD $10,000 for individuals and USD $980,000 for businesses. The result was a surge in applications for energy storage systems that exceeded the allocated budget well before the year finished. This was preceded by another subsidy in 2013 that resulted in over 100 MWh of residential battery storage being installed [22].

### 2.2.5. Off Grid Market

Hawaii, which consists of a number of islands, each with their own electricity grid, has a target of 100% renewable energy by 2045. The state recognises the critical importance of energy storage in achieving this and has facilitated a number of large demonstration projects that are relevant to Australia's off-grid regions. Further to this, in 2014, Hawaiian Electric requested proposals for 60 MW –200 MW of energy storage, which is expected to be operational by 2017 [56]. However, attempts to pass two policy bills to directly support energy storage technologies were unsuccessful [50].

Within this islanded system, the Hawaii Public Utilities Commission (HPUC) is working on improving the economics of small-scale energy storage through tariff reform. In October 2015, their first action was to end net energy metering (NEM) for new solar customers. This had enabled residents to sell unused solar energy into the grid at the same price the utility charged. Replacing it are three new tariff options: grid-supply which is similar to NEM but provides a lower price for excess energy; self-supply which prevents the export of excess energy; and time-of-use which provides different rates across the day. The reduced incentive to export excess solar PV to the grid, combined with time-of-use tariffs and an expedited application process in areas with high levels of solar PV (self-supply tariff only), is designed to encourage new customers to install battery storage [57]. Similar tariff reforms may be applicable to Australia in incentivising battery storage in future micro grids that have high penetration rates of solar PV.

In the Scottish Isles (part of the UK), energy storage projects are being facilitated by Community Energy Scotland, established in 2004, to provide assistance for green energy development. It has helped secure funding from numerous sources for battery projects including the LCNF on a number of islands including Shetland (1 MW/6 MWh), Orkney (2 MW/0.5 MWh), Eigg (333 kW/212 kWh) and Gigha (105 kW/1.25 MWh) [58] and its success is a model for Australian community-based groups. The first project was completed in 2008 on the Isle of Eigg, which coupled battery storage and renewable energy to provide 100% of the island's electricity. The system is operated by community-owned Eigg Electric [59] and demonstrates the success of the community-owned micro grid model which subsequently spread to other Scottish Isles and provides an example that Australian communities aiming for 100% renewable energy such as Byron Shire and Yackandandah can follow [60,61].

## 3. Australian Policies and Plans

### 3.1. Government System

The Commonwealth of Australia is both a representative democracy and a constitutional monarchy with Queen Elizabeth II as head of state. The country has three arms of government: the legislature (Parliament) which debates and votes on new laws and consists of the Senate and the House of Representatives; the executive (Australian Government) which enacts and upholds the laws established by the legislature; and the judiciary which is the independent legal arm of the federal government and is responsible for the enforcement of these laws in addition to ensuring that the other two arms of government are acting within their powers. Australia has six states which according to the Constitution have the power to pass their own laws in areas not controlled by the Commonwealth, and two territories which are self-governed but their power is defined in Commonwealth law and can be revoked by Parliament at will [62].

### 3.2. Federal Government Energy Storage Policies and Plans

Over the past few years, there has been significant uncertainty around renewable energy policy in Australia, particularly at the federal level, which has prevented the large scale renewable energy market from operating efficiently [63]. The election of the conservative Liberal Government in 2013 brought about a dramatic change in policy direction, namely through the repeal of the Carbon Tax in 2014 [64] and reducing the 2020 Large Scale Renewable Energy Target (LRET) from 41,000 GWh to 33,000 GWh (approximately 20%) in 2015 [65]. These were the key market mechanisms that formed the centerpiece of the Australian Government's clean energy policy framework as detailed in the Clean Energy Future (CEF) Plan [66] and the 2012 Energy White Paper [67].

In addition, recent comments by the Government have led to uncertainty about the future of the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC), the key technology push mechanisms designed to increase investment in renewable energy including energy storage [68]. The effect of all of this has been considerable, with investment in large-scale renewable energy decreasing by 88% in 2014 [69].

This uncertainty has also had an impact on energy storage in Australia with the country considered a minor market player with only 14 MW of battery storage and no large scale hydrogen storage, as shown in Figure 7 [7]. Furthermore, given the current policy landscape, Australia is considered by

Bloomberg New Energy Finance to remain a minor player with an estimated energy storage capacity of 104 MW by 2020 [70].

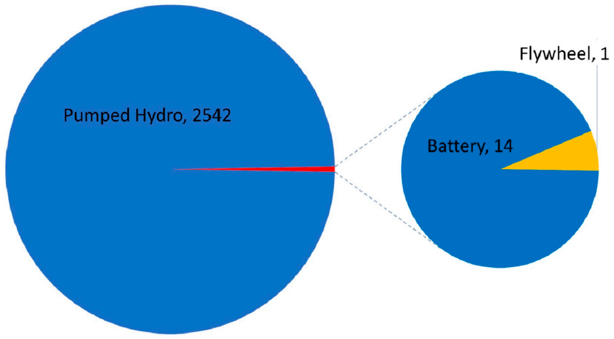


**Figure 7.** Australian energy storage capacity in MW (created from data obtained from [7,71]).

At present, the key mechanism supporting energy storage in Australia is ARENA, which was established in 2012 by the ARENA Act 2011. It has funding of AUD $2.5 billion and aims to drive down the cost and increase the use of renewable energy [72]. ARENA has five key investment focus areas that are critical to achieving its objectives: integrating renewables and grids, renewables for industrial processes, off-grid, fringe-of-grid and network-constrained areas and large-scale solar PV. These are grouped into three investment themes: addressing barriers to the long-term uptake of renewables, helping renewable energy technologies meet energy users' needs and advancing the commercial development of renewable energy and enabling technologies [73].

ARENA has identified that energy storage can play a crucial role in helping to achieve the objectives of all three investment themes and to date has invested AUD $83M in battery storage projects [71]. The majority of this funding is in commercial and utility battery storage, as shown in Figure 8, which comprises several projects involving the integration of storage with solar PV for off grid applications such as islands and mine sites. Australia has a large off-grid sector consuming over 7% of the total electricity demand and in these remote areas the cost of gas and diesel for electricity generation is very high [74]. As a result, the business case for energy storage is strong and this is why it is one of ARENA's key investment focus areas.

An example of this funding is the King Island Renewable Energy Integration Project (KIREIP), which employs a 3 MW/1.6 MWh lead-acid battery to integrate 390 kW of solar PV and 2.5 MW of wind turbines. The system, on average, provides 65% of the island's energy needs with the remainder coming from diesel generators. The success of this modular hybrid energy solution has led to a similar system being installed on neighbouring Flinders Island [75].

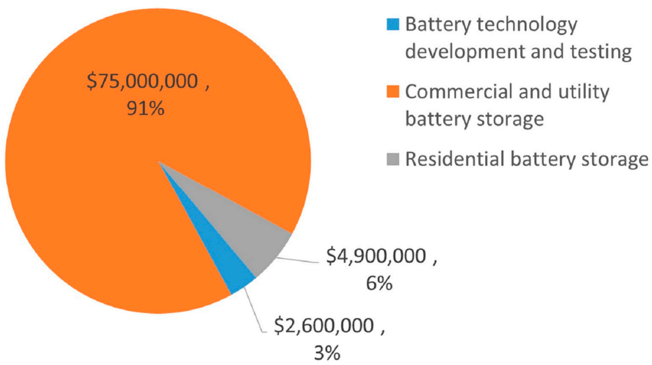


**Figure 8.** Australian Renewable Energy Agency (ARENA) battery storage funding (created from data obtained from [71]).

ARENA also supports Australian companies working on commercialising renewable energy technologies through its AUD $200 million Renewable Energy Venture Capital (REVC) Fund. To date, AUD $13 million has been provided for energy storage technology companies including AUD $6 million for Hydrexia to commercialise their hydrogen storage technology that consists of modular metal hydride storage vessels [76]. Apart from this, there are no policies or supportive mechanisms in place for hydrogen storage technology in Australia. This is disappointing given that no action has been taken since the release of the 2008 Hydrogen Technology Roadmap published by the Australian Government that was aimed at identifying key strategies and recommendations to facilitate the development of a hydrogen economy [77].

In Australia, the other key supporting mechanism for renewable energy and enabling technologies such as energy storage is the CEFC, which was established by the Government in 2012. It has funding of AUD $10 billion ($2 billion per year from 1 July 2013 to 2017) and its mission is to accelerate the transformation towards a more competitive economy in a carbon-constrained world by acting as a catalyst to increase private sector investment in emissions reduction [78]. It is technology agnostic and to date has made two significant investments in battery storage: AUD $15 million (AUD $40 million total project cost) for the largest integrated off-grid solar and battery storage facility in Australia consisting of 10.6 MW of solar PV and 6 MW/1.8 MWh of battery storage at the DeGrussa copper mine in Western Australia [79]; and AUD $100 million for Origin Energy to expand its solar and battery storage Power Purchase Agreements (PPAs) for commercial and residential customers [80].

Another aspect that impacts the development and deployment of energy storage in Australia is the regulatory framework of the energy market. This was defined in the 2004 Australian Energy Market Agreement and encompasses a mixture of federal and state responsibilities and intergovernmental arrangements leading to a complex regulatory environment for the National Electricity Market (NEM) as shown in Figure 9 [81]. The NEM is the largest electricity market in Australia and interconnects five regional market jurisdictions (Queensland, New South Wales (MSW), Victoria, SA and Tasmania) which combined provide 80% of the country's electricity [82]. To add further complexity, the other two regulatory environments in Western Australia and the Northern Territory have completely separate and independent institutional frameworks [67].

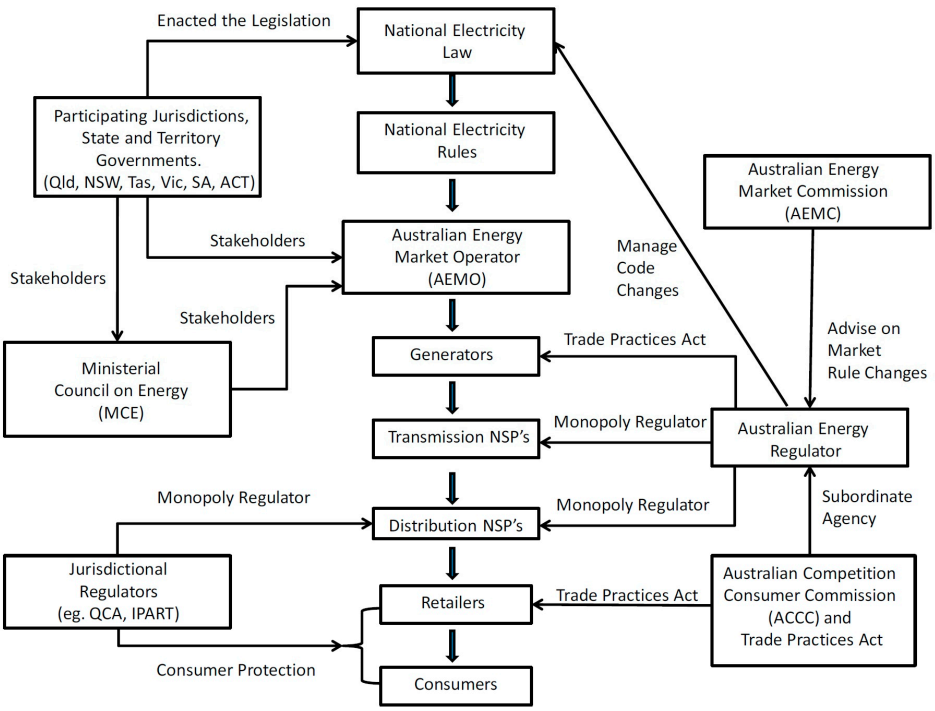


**Figure 9.** Net energy metering (NEM) regulatory environment [81].

These regulatory environments were designed for the incumbent centralised, fossil fuel energy generation model and as such there are a number of barriers for energy storage. However, the Australian Energy Market Commission (AEMC), which is the statutory rule maker for the Australian electricity and gas market, is beginning to address these barriers with a number of rule changes and guidelines under review that would benefit energy storage (Table 6).

**Table 6.** Rule changes and guidelines currently under review by Australian Energy Market Commission (AEMC).

| Title | Description | Benefits for Energy Storage |
| --- | --- | --- |
| Demand Response Mechanism rule change [83] | Establish a new class of market participant, a demand response aggregator (DRA), to allow consumers to participate in the wholesale market | Aggregation of small-scale battery storage units to act as one generator |
| Local Generation Network Credits (LGNCs) rule change [84] | Incentivise networks to recognise the benefits of local generation by requiring them to implement a LGNC | Financial incentive |
| Demand Management Incentive Scheme (DMIS) rule change [85] | Reward networks to deliver non-network options that deliver cost savings to customers through demand management | Financial incentive |
| Demand Management Innovation Allowance (DMIA) rule change [85] | Provide funding for research and development projects that have the potential to reduce long term network costs via demand reduction | Financial incentive |
| Electricity ring-fencing guideline [86] | Enable networks to provide behind the meter services through third party contractors or ring fenced businesses | Competitive market development |

The rule changes to the Demand Management Incentive Scheme (DMIS) and the Demand Management Innovation Allowance (DMIA) are being made since these schemes have been in operation for several years but have had minimal participation from Distribution Network Service Providers (DNSPs). Despite this, there are some notable projects involving battery storage:

- A 2 MW/2 MWh battery installed in 2016 in Buninyong, Victoria which is the largest grid connected battery in Australia. It is equivalent to 20% of the current powerlines' capacity and will run automatically to reduce peak demand and provide emergency backup (Powercor, 2016).
- Ergon Energy's Grid Utility Storage Solution, which is being deployed in constrained fringe-of-grid regions in Queensland to improve power quality and regulate demand. The network expects to deploy hundreds of these 25 kW/100 kWh units in the coming years and estimates it will reduce network infrastructure investment by over 35% [87].

### *3.3. State and Territory Government Energy Storage Policies and Plans*

In 2009, as part of a deal between the state and federal governments for a national renewable energy target of 41,000 GWh, the Renewable Energy (Electricity) Act 2000 was modified to prevent states and territories from imposing binding obligations on energy retailers and energy users to meet state-based renewable energy targets [88]. Therefore, for states aiming to achieve renewable energy penetration greater than the current federal target this can only be met by a scheme that does not impose such obligations.

Currently, there is a significant mismatch in state and territory-based renewable energy policy with some states such as NSW having no renewable energy target whilst the leading state and territory have targets significantly higher than the Federal Government, 50% by 2025 for SA [89] and 100% by 2025 for the Australian Capital Territory (ACT) [90]. The Queensland Government recently announced a renewable energy target of 50% by 2030 but no specific policies have been enacted for energy storage and so it will not be considered in this paper.

The SA Government has taken measured and considered action to modify its regulatory framework to remove barriers to renewable energy investment and provide investment clarity and certainty. The release of 'A Renewable Energy Plan for SA' in 2011 detailed the policy strategy to achieve a target of 33% renewable energy by 2020, which was so successful that it was reached six years early [91]. As a result, the state has received a disproportionate amount of investment in renewable energy, AUD $5.5 billion since 2003, including approximately 40% of national wind power investment [92]. The effect of this is that SA has an installed renewable energy capacity greater than maximum demand and this was demonstrated for the first time in 2014 when it provided 100% of demand for an entire working day [93].

However, such a high proportion of intermittent renewable energy can result in curtailment and power quality issues. To prevent these from arising, the SA Government believes that energy storage is crucial and is providing support through its 2015 policy strategy, 'A Low Carbon Investment Plan', which outlines how the state will achieve AUD $10 billion of investment in low carbon energy generation to reach its 50% renewable energy target by 2025. The policy framework comprises four key strategic pillars, and in each of these, support for energy storage is being provided as shown in Table 7 [94].

**Table 7.** A Low Carbon Investment Plan key strategies [94].

| Key Strategy | Relevance to Energy Storage | Specific Project/Funding |
|---|---|---|
| Clear policy and efficient regulatory environment | Creation of an Investment Attraction Agency to attract new businesses | AUD $200,000 grant for ZEN Energy Systems to support the further development of its battery storage system |
| Information to inform investment | Improve information to assess project viability | Update existing directory of diesel generation to assess opportunities for hybrid renewable energy and storage projects |
| Sponsoring uptake and government procurement | Financial incentives and market development support | - AUD $1.1 million to demonstrate battery storage on government buildings<br>- AUD $3 million for a mobile energy storage testing facility for battery technology and grid integration |
| Facilitating projects to leverage funding and support | Financial incentives | - Subsidise Coober Pedy Council PPA for electricity produced by a hybrid renewable energy and battery storage project<br>- Funding to assess feasibility of medium-large scale battery storage (5 MW–30 MW/25 MW–300 MWh) to integrate intermittent renewable energy |

Of particular importance is the Energy Storage for Commercial Renewable Integration–South Australia (ESCRI-SA) project, led by a consortium including the Australian Gas Light company (AGL) (electricity retailer and generator owner), ElectraNet (SA transmission network owner and operator) and Worley Parsons (engineering consultancy). Phase 1 of the project was to assess the feasibility of medium-large scale battery storage (5 MW–30 MW/25 MW–300 MWh) to integrate intermittent renewable energy. The outcome was a recommendation for 10 MW/20 MWh of battery storage next to the 91 MW Wattle Valley wind farm to reduce transmission losses, provide load shifting, frequency control and emergency power. Phase 2 is to build this as a demonstration project, but given the lack of current policy drivers the business case is not favourable and would require almost AUD $15 million (63% of the Capex) in funding from ARENA or other sources to be commercially viable. Despite this, it is hoped that the project will attract the required finding as it is seen by the consortium as being very valuable for building capability and establishing a market for battery storage [95].

In addition to the state based strategies and incentives outlined above, local government in SA is also taking the lead in facilitating the uptake of battery storage. In July 2015, the Adelaide City Council became the first government at any level to offer a direct financial incentive for battery storage integrated with solar PV. The Sustainable City Incentives Scheme provides up to AUD $5,000 for building owners and tenants such as businesses, residents, schools and community groups. Shortly after the scheme commenced, the SA Government announced it would match the Adelaide City

Council funding resulting in a combined budget of $300,000, which is enough to install up to 600 kWh of battery storage [96].

The ACT has the most ambitious renewable energy target of any Australian state or territory, 100% by 2025. This is supported by its 2011 sustainable energy policy framework, which consists of four key targeted outcomes: secure and affordable energy, smarter use of energy, cleaner energy and growth in the clean economy. Battery storage is viewed by the government as playing a critical role in achieving the latter two of these objectives [90].

One of the programs the government is implementing in order to achieve the objective of cleaner energy is Next Generation Renewables. This will facilitate the installation of 36 MW of battery storage across more than 5000 homes and businesses between 2016 and 2020, which will be funded through a fourth reverse auction for 109 MW of renewable energy in 2016. The program will commence in the same year with the Next Generation Renewables Energy Storage Pilot that will award up to $600,000 through a competitive grants process to companies installing distributed solar storage in the territory [97].

To achieve growth in the clean economy, the ACT Government has established the Renewable Energy Innovation Fund, which will allocate AUD $12 million over the next 5 years to support existing renewable energy business and attract new business. This fund has four key focus areas: trades training innovation, energy research partnerships, energy innovation precinct and technology demonstration. Whilst it is feasible that all of these have the potential to support battery storage, there is a specific reference made to this technology in the first two areas, which highlights the importance of battery storage to the ACT government [98].

Another initiative designed to support growth in the clean economy is the Renewable Energy Industry Development Strategy (REIDS). This focuses on solar, wind and energy storage and aims to accelerate the growth of the renewable energy industry in the ACT through the development of a business research precinct and renewable energy test facilities that involves the collaboration of industry, government, and research and training organisations [98].

## 4. Discussion

### *4.1. Australian Policy in an International Context*

Australia currently has a renewable energy target of 20% by 2020 but no target beyond this date, a significant point of difference compared to global leaders such as Germany, which has a 2050 target of 80% renewable energy. As mentioned earlier, the significant changes to federal policy including the repeal of the Carbon Tax and reduction in the LRET resulted in an 80% decrease in large scale renewable energy investment in 2014 compared to 2005 [70], whereas in Germany investment increased by 58% over the same period [99]. Such uncertainty in Australia, coupled with a lack of a long-term target, means that there is less of an incentive to drive investment in renewable energy and consequently energy storage.

As such, there is also a disparity between Australia and the leading countries supporting energy storage, who view these technologies as being critical in facilitating a significant increase in intermittent renewable energy penetration. Again, this is reflected in increased levels of investment with Bloomberg Finance forecasting that 11.3 GW of energy storage will be deployed by 2020 which is a 900% increase compared to 2013 [70]. Approximately 77% of this will be deployed in only four countries, U.S.A, Germany, Japan and Korea which are all countries strongly supporting energy storage through effective policy and regulation as outlined earlier. In contrast, Australia is predicted to remain a minor player with 104 MW of capacity installed by 2020 [70].

However, should Australian policy makers decide to increase support for energy storage it would be advisable for them to study and learn from the leading states and countries supporting energy storage such as California and Germany. This is because that whilst Australia has its own unique energy market, there are aspects that are similar to these global leaders including areas of high concentrations of intermittent renewable energy (Texas and California) and high penetration of residential solar PV (Germany).

Furthermore, with SA and the ACT pursuing very high renewable energy targets [90,94] and continued growth in residential solar PV [100], these aspects are only going to become more of an issue in the future in terms of electricity grid management. Therefore, it is imperative that steps are taken to address these through the implementation of technologies such as energy storage.

As has been demonstrated in this paper, there are a number of mechanisms available to policy makers to support energy storage, including, but not limited to, mandatory targets, financial subsidies or grants and energy market regulatory reform. The following section will briefly outline how each of these may play a role in Australia.

California's energy storage target is particularly relevant to SA given that they have similar renewable energy targets. Subject to NEM rules, Australia could implement a similar policy mechanism although more emphasis would need to be placed on behind the meter storage due to the higher proportion of small-scale residential solar PV in SA compared to California. There is no doubt that significant amounts of energy storage will be required in SA given that is it estimated that by 2024 the installed capacity of small-scale solar PV will be in the range of 1.5 GW–2.3 GW, sufficient to meet 100% of the state's electricity demand at certain times. This combined with a forecast wind capacity of 4.4 GW would mean that at times electricity supply will greatly exceed demand and without energy storage would result in significant curtailment as the interconnector with the neighbouring state, Victoria, does not have the capacity to transmit that amount of electricity [21].

Based on this forecast and an estimated storage capacity 10%–20% of the intermittent renewable energy capacity [6], a 2024 target in the range of 150 MW–230 MW for end user storage and approximately 450 MW–900 MW for wholesale/(T&D) storage would be required. This is not unachievable as shown by the progress made to date toward meeting California's 1.3 GW energy storage target. Furthermore, such a possible future scenario could present a good case for hydrogen storage as will be discussed shortly. Currently, the only such target or goal that exists in Australia is in the ACT which aims to install 36 MW of small-scale battery storage by 2020 [97]. This is a commendable first step and one in which the Federal Government should replicate and build upon.

In Australia, it is likely that one of the earliest markets for battery storage systems will be the residential sector as has occurred with solar PV due to excellent solar resources and high electricity prices. Current financial analysis of payback periods for a typical residential battery storage system in Australia varies widely from 6 to 35 years [70,101,102]. However, it should be noted that the lower range was calculated based on an assumed installed cost of AUD $4000–5000 for the 7 kWh Tesla Powerwall but the actual cost ended up being around AUD $12,000 [103]. Based on this, the current payback periods for a residential battery storage system in Australia are greater that its lifespan of 10 years and are therefore uneconomical. Therefore, Australia should look to leaders such as California and Germany and offer a financial rebate until such time that battery storage costs decrease and become economically viable without subsidy. In California, the SGIP funding has resulted in the installation of 88 MW of battery storage.

Currently, the only rebate on offer in Australia is Adelaide's Sustainable City Incentives Scheme which provides 50% of the system cost up to AUD $5,000 [96]. Using the 7 kWh Tesla Powerwall as an example, this would reduce the cost by AUD $3,500 almost 30% but not quite enough to reduce the payback period below 10 years. It is interesting to note that the level of rebate is identical to that which would be offered in California (AUD $3,500) and Germany (AUD $3,600) for the same product when using the Australian price for the Tesla unit. However, the rebate in Germany brings the payback period to 5 years due to higher electricity prices and a lower installed cost [54] and so to be more effective a higher initial rebate would need to be offered in Australia before being scaled back as battery costs decreased as per the German policy [55].

One area where Australia is making progress to support energy storage is through regulatory reform with the AEMC currently reviewing a number of rule changes and guidelines [83–85]. These are designed to recognise the benefits of energy storage for the electricity grid as a whole and for all stakeholders (consumers, transmission operators, DNSPs, etc.). Such reforms are crucial in ensuring that these micro grids, in which the energy storage systems are situated, remain connected to the grid and do not opt to become permanently islanded. The consequences of increasing numbers of defections from the grid is significant and includes the possibility of shutting down grid power generation and increasingly underused grid assets. As a result, the entire system could become unsustainable to maintain financially by the remaining connected consumers [104].

### *4.2. Hydrogen as an Alternative Energy Storage Solution*

As mentioned earlier in this paper, hydrogen storage can play an integral role alongside various other storage technologies in a future where renewable energy provides up to 100% of the world's electricity needs. This may be difficult to envisage at present since this technology is still in the development phase and is less advanced and more expensive than other storage technologies such as PHS. However, as this section will show, recent pioneering studies and technological advancements have meant that hydrogen storage is beginning to be perceived as a viable solution to integrate the significant amounts of intermittent renewable energy required for a sustainable energy future. Whilst much of this research is focused on the use of hydrogen for the transport sector, it is worth discussing briefly as the required infrastructure is very similar to that which would be required for stationary energy use.

Jacobson and Delucchi conducted a comprehensive study in 2011, which demonstrated that renewable energy (wind, water and solar), from a technology and economic perspective, is capable of providing the global primary energy requirements in 2030. In this future, a significant percentage of the transportation sector would use hydrogen, created from renewable energy, as a fuel [105].

The Intergovernmental Panel on Climate Change (IPCC) published a report in 2012 entitled Renewable Energy Sources and Climate Change Mitigation which analysed the role of renewable energy in providing the majority of global primary energy supply in order to limit carbon dioxide emissions. Within this report, the IPCC identified that hydrogen, created from renewable energy, could play a significant role as a fuel in the transport sector of the future alongside battery electric vehicles [106].

More recently, Balta-Ozkan and Baldwin modelled a hydrogen network within the UK MARKAL Energy System model to investigate whether this technology could contribute towards the UK's $CO_2$ emissions reduction target of 80% by 2050. They demonstrated that hydrogen appears to be a competitive fuel for the transportation sector and could lead to a 74% reduction in emissions by 2050 [107].

Research into addressing the knowledge gap around the role of hydrogen for stationary energy has been recently conducted by Andrews and Shabani who have proposed a strategy for a re-envisioned hydrogen economy. This Hydrogen in a Sustainable Energy (HISE) strategy outlines the crucial role hydrogen can play in the transportation sector and also in longer-term seasonal storage for electricity grids. Additionally, this bulk hydrogen storage would replace fossil fuels as a strategic energy reserve to ensure national and global energy security [16]. Crucial to the strategy is that the hydrogen would be produced exclusively by a variety of renewable energy sources, making it a truly sustainable energy carrier. Due to the wide distribution of these renewable energy sources, a hierarchy of production, storage and distribution centres would be established in order to produce the hydrogen as close as possible to where it will be consumed as shown in Figure 10. The benefit of this is that it would minimise the necessity of an expensive long-distance hydrogen pipeline network. Importantly, the strategy recognises that hydrogen energy is not the best solution for all applications and as such it will work alongside other energy storage technologies such as batteries, in a symbiotic role to meet the needs of a sustainable energy future [16].

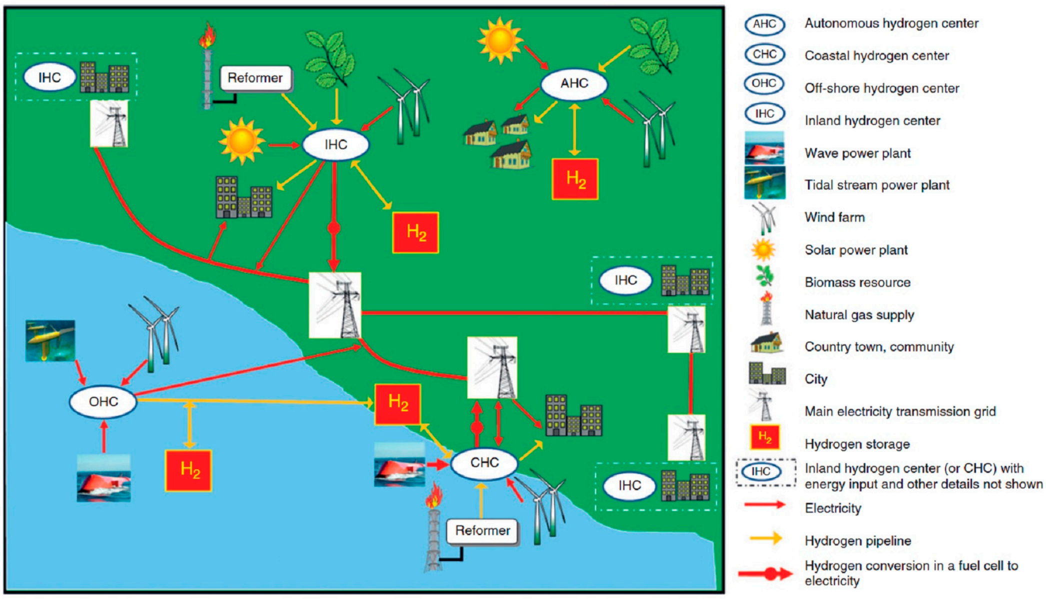


**Figure 10.** A schematic illustration of the sustainable hydrogen hierarchy proposed by Andrews and Shabani [16].

However, in order for hydrogen to fulfil this crucial role, there are a number of barriers that must be overcome including technology-lock in or entrenchment, political and economic resistance, lack of a strong industry body and community support, poor understanding about the role of hydrogen and limited funding for research and development [1]. Efforts to address these barriers are currently being undertaken and a few countries have emerged as the global leaders in advancing hydrogen technology.

In terms of large-scale hydrogen storage, Germany is at the forefront of research and development as it is looking to this technology for a number of key reasons. This includes as an alternative to pumped hydro, which is limited in terms of future growth in the country due to a lack of suitable sites and to support the decarbonisation of its industrial sector.

The latter is critical for Germany to achieve its 2050 target of an 80% reduction in $CO_2$ emissions [10] whilst maintaining the capability of its industrial sector. This is particularly the case for the state of North Rhine-Westphalia (NRW), which is home to one of the most important industrial regions in Europe. Lechtenböhmer et al., in consultation with industry stakeholders, developed three long-term technology scenarios to determine the ability to meet this target. One of these, the low carbon technology scenario, has the potential to achieve a 50% reduction in $CO_2$ emissions by 2050. The backbone of this scenario is the establishment of a hydrogen infrastructure with electrolysers and storage located close to areas of consumption and excess renewable energy supplied via high voltage direct current (DC) lines, already under construction, from northern Germany. Hydrogen would also be used directly in the steel industry and for various processes in the chemical industry. Although considered an ambitious scenario by industrial firm stakeholders, it is nonetheless an important study into the role that hydrogen can play in a low carbon economy [108].

Germany is focusing on Power-to-Gas (P2G) technology, which has a variety of applications including electricity and heat generation and transport as shown in Figure 11 [109]. The process firstly involves using excess renewable electricity to electrolyse water into oxygen and hydrogen [5]. The hydrogen is then either stored directly before being converted back into electricity via a fuel cell or alternatively converted into methane (methanisation) and stored in the existing natural gas infrastructure for later use in a variety of applications including electricity, heat generation and transportation [109]. The supporting argument about the advantage of P2G technology is that the gas transmission grids have a huge storage capacity, approximately 200 TWh in Germany [15]; this is while the parasitic losses of using the natural gas pipelines in large scales as well as the conversion to methane and back to hydrogen must be taken into consideration. Overall, the electricity-gas-electricity process has a round trip efficiency of approximately 40% and so increasing this is one of the main research and development objectives [109].

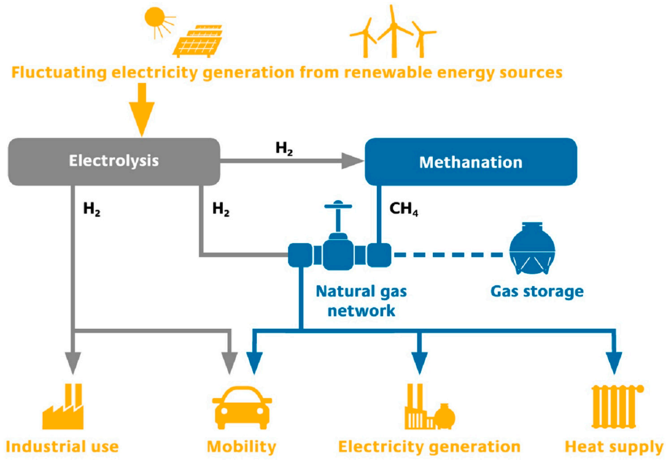


**Figure 11.** Power-to-gas (P2G) process and applications [109].

Despite the yet-to-be-addressed low round-trip energy of this approach, P2G is being supported through the Germany Energy Agency (Deutsche Energie-Agentur GmbH-DENA), which established the Power to Gas Strategy Platform in 2012 in partnership with industry and research stakeholders. Key to this is the Roadmap Power to Gas which sets out the pathway to achieve large-scale, economically viable use of this technology, including a very ambitious goal of 1 GW of installed capacity by 2022 [109]. Project funding is being provided through the €200 million Energy Storage Funding initiative which aims to support research projects to develop a broad range of storage technologies for electricity, heat and other forms of energy [32]. Additionally, the German Federal Energy Industry Act contains a provision for hydrogen and hydrogen-based gas facilities to be exempted from network access charges [110].

Currently in Germany there are 14 operational P2G demonstration projects with an installed capacity of just over 10 MW (key projects listed in Table 8) and more than 17 facilities under construction [109]. This represents over 95% of the global installed capacity of P2G.

**Table 8.** Current operational power-to-gas (P2G) projects in Germany [7].

| Capacity | Year | Utility | Technology Provider | Electrolyser Type |
|---|---|---|---|---|
| 6 MW | 2015 | Stadtwerke Mainz AG | Siemens | PEM |
| 1 MW | 2015 | E.ON | Hydrogenics | PEM |
| 150 kW | 2015 | RWE | ITM Power | PEM |
| 300 kW | 2014 | Mainova AG | ITM Power | PEM |
| 2 MW | 2013 | E.ON | Hydrogenics | PEM |
| 1 MW | 2013 | UNK | Hydrogenics | PEM |
| 400 kW | 2013 | EnBW | Hydrogenics | PEM |

Some other European countries are also looking to P2G technology and this is being facilitated through the European Power to Gas Platform, which is a joint body, based on an integrated network of industry and government stakeholders [111]. At present, a number of demonstration projects have been completed throughout Europe with key examples listed in Table 9.

**Table 9.** Key P2G projects in Europe [111].

| Capacity | Year | Country | Project Name | Application |
|---|---|---|---|---|
| 1 MW | 2016 | Denmark | Bio Cat | Combined heat and power (CHP) |
| 1.2 MW | 2016 | Italy | INGRID | supply-demand balancing |
| 48 kW | 2004 | Norway | Utsira | Micro-grid (island) |
| 1 MW | 2012 | France (Corsica) | Jupiter 1000 | Island grid stability |
| 70 kW | 2010 | Spain | ITHER | Mobility |
| 400 kW | 2006 | Spain | HyFLEET:CUTE | Mobility |
| 400 kW | 2003 | Netherlands | HyFLEET:CUTE | Mobility |
| 12 MW | 2016 | Netherlands | Delfzijl | Chemical processing |

As shown in Table 9, there are some P2G projects being installed to fuel vehicles with hydrogen fuel cells and this is another technology that will play an important role in the future alongside hydrogen storage. For stationary energy applications, the current global leaders are Japan for micro fuel cells (less than 5 kW) and Korea, USA and Germany for larger units (greater than 100 kW).

In Japan, over 100,000 micro fuel cells have been installed since 2009, which is impressive but well short of the government target of 5.3 million units by 2030. This target is being supported through the Ene-Farm program, which was launched in 2009 and provides a subsidy on each unit sold. This was initially set at ¥1.7 million (~USD $15,000) but has been progressively reduced over time as unit prices decreased and is currently ¥350,000 (~USD $3,000) compared to a cost of about USD $167,000 [112].

The emerging market for large fuel cell units has similarly been supported through government subsidies. For example, in the U.S., there is a federal tax credit of up to 30% or $3000/kW (whichever is less) with an additional 10% for Combined Heat and Power (CHP) applications. In California, the SGIP provides $4,500/kW for fuel cells fuelled by biogas, nearly double the rebate for those using natural gas as a fuel source [113].

Ideally, the long-term goal is to move away from using natural gas as a fuel source for hydrogen fuel cells and use hydrogen P2G technology. Australia has an extensive natural gas pipeline distribution network (Figure 12) and, importantly, this covers the majority of the populated areas of the country where the hydrogen would be consumed. Therefore, potentially an interim step on the road to a sustainable hydrogen future is, at a local level, to use the gas pipeline infrastructure to store and distribute the natural gas created from hydrogen close to where it will be consumed. This would be in place until such a time that a localised hydrogen pipeline infrastructure is constructed which would eliminate the necessity to convert the hydrogen into natural gas, which has inefficiencies.

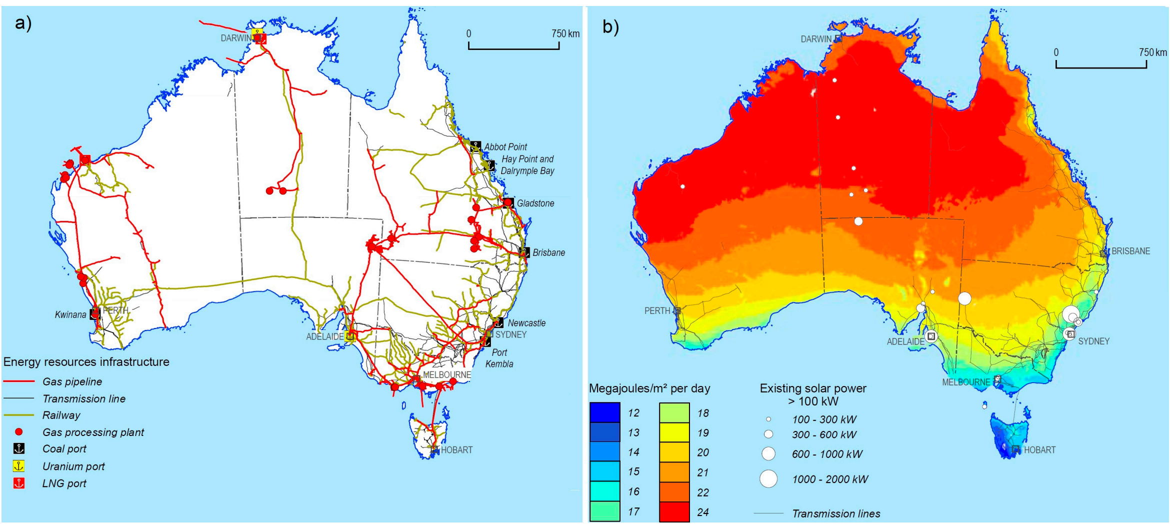


**Figure 12.** (**a**) Australian natural gas pipeline network and (**b**) Australia average annual solar radiation and electricity transmission lines [17].

An alternative approach is to use the national gas grid to distribute the natural gas created from hydrogen over long distances instead of using the electricity grid. However, the merits of hydrogen distribution at a national level was studied by Andrews and Shabani who concluded that limiting hydrogen distribution to local pipelines was the preferred option [16]. To ascertain the advantages and disadvantages of each solution specifically for Australia, it is recommended that a detailed quantitative study be conducted.

Hydrogen storage would also be well suited to regions of the country where the intermittent renewable energy capacity is forecast to greatly exceed electricity demand such as in SA as discussed earlier [21]. The excess energy can be stored locally in the form of hydrogen and used when required, thus flattening out the variation in renewable energy supply, particularly at the seasonal level.

## 5. Conclusions

It is clear that Australia can do more from a policy and regulation perspective to support energy storage technologies and arguably renewable energy in general. Whilst ARENA has identified energy storage as being crucial to increasing renewable energy penetration and has provided grants for a number of demonstration projects, there is little else occurring at a Federal Government level. The most active area of investment at present is in the off-grid market with a number of battery storage projects in various stages of development on islands, remote communities and mine sites.

In terms of reforming the regulatory framework of the energy market to support energy storage, recent rule changes to the DMIS and DMIA have had a positive impact in supporting demonstration projects. However, further reform is required to establish a market for energy storage and this could be achieved through a number of pending rule changes. This includes the Demand Response Mechanism and the creation of the Demand Response Aggregator (DRA) as a new market participant, which would enable energy storage to be used to generate income in the wholesale market. Also, pending rule changes could change how networks operate by permitting them to provide behind the meter services such as energy storage through third party business and also incentivising them to substitute Opex for Capex by installing local generation to reduce costs and defer network infrastructure investment.

Globally, it is evident that some countries' and states' significant efforts to support energy storage are directly relevant to Australia. Key to this support is having a framework in place that provides a pathway to address barriers to energy storage and establish a self-sustaining competitive market as is being achieved in California, New York and Germany.

A number of states and countries including California, New York, Germany and Japan are providing financial incentives for battery storage through grants, rebates and low interest loans in order to stimulate market growth. This is similar to what the Adelaide City Council has implemented and is an indication that at least a part of Australia is looking to learn from the global leaders.

Texas has made progress with regulatory reform to enable battery storage to compete in the wholesale market and has successfully demonstrated how battery storage can mitigate intermittency issues from high concentrations of wind energy. This is a challenge that SA will also need to address in the near future.

The Scottish Isles are an example of how battery storage coupled with renewable energy can successfully provide 100% of the electricity required by an off-grid community. Whilst Australia is investing in the off-grid market, Scotland has demonstrated the success of the community-owned micro grid model that is relevant to a number of communities in Australia looking to achieve 100% renewable energy and own and manage their own electricity grid.

Hydrogen technology has significant potential to provide large-scale, long-term storage that will be critical to support high renewable energy targets. This is currently being demonstrated in Germany, who is leading the world in Power to Gas technology and has an ambitious target that would set it well on the pathway to commercialisation. Australia has an abundance of natural resources to generate renewable electricity that can be stored or transmitted in the form of hydrogen. There are two potential options for hydrogen distribution and storage: generate and store the hydrogen close to where it is consumed and use the national and local grids to transmit renewable electricity, as recommended in an earlier study [16]; or use national pipeline infrastructure to distribute hydrogen (i.e., either as pure hydrogen or in the form of natural gas). A quantitative analysis is recommended to further study these options in an Australian context.

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