# 'CALIFORNIA DREAMIN' – AMBITIOUS OBJECTIVES AND RAPID TRANSITION IN THE ELECTRICITY MARKET

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## EXECUTIVE SUMMARY

California has been able to set ambitious environmental policies due to broad based electoral support over a sustained period. Stringent state regulations combined with federal incentives have been the harbinger of significant changes to the Californian energy mix. In the near term, environmental policy goals are likely to be evermore ambitious, especially given discussions on a 100% renewable standard and a potential 'battle of wits' with the federal administration. Past experiences, such as the 2001 electricity crisis, serve to illustrate the risks to consumers of having too rapid a transition timeline.

The pace of renewable development is also likely to stretch the operation of the grid to the limit of its current capability. The grid operator has already highlighted risks relating to system balancing and frequency response. To its credit, the California system operator has instituted new services and market frameworks to encourage competitive responses to the problem. By contrast, California's economic regulator has established a central planned procurement of energy storage. To date, California has benefited from high levels of interconnection and excess capacity reserves that has allowed the state to tolerate current levels of renewable penetration. Going forward, forced fossil power plant retirements are likely to impact capacity reserves leaving the system with less safety margin to tolerate the variability from renewable generation.

Technology is seen as the great enabler of reform, providing a bridge between current operation and ambitious policy objectives. However, while existing technologies such as storage can assist with grid balancing, further innovation of grid-forming inverter technology is required to bridge the gap to a grid that is dominated by asynchronous technology. With a doubling of renewable penetration expected over the next thirteen years further compression of transition timeframes could introduce additional operational and financing risks.

While ambitious goal setting can incentivise adaption and new business models, given the essentiality of electricity service, government and regulators must tread a fine line, so as not to push the system beyond its operating bounds and thus risk failure of the reform agenda.

The next phase of work will conduct a detailed examination of risks identified in relation to frequency response, dispatchable reserves, inverter-grid technology development and venture financing and propose a comprehensive transition management framework that integrates policy setting, grid operations and technology development.


## 1 Introduction

California energy policy could well be thought off as a *laboratory experiment* in political will, commercial adaptation and technological enablement. The state has set a goal of sourcing 50% of its electricity generation from renewable resources[2] by 2030, currently the most ambitious of any state in

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[2] Renewables are defined, per California Code, Public Resources Code § 25741, as facilities that use biomass, solar thermal, photovoltaic, wind, geothermal, fuel cells using renewable fuels, small hydroelectric generation of 30MW or less, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, or tidal current, and any additions or

the US.  Senate bill 584, which is currently being debated, proposes to increase the requirement to 100% by 2045 [1]. In many respects California leads the world in environmental goal setting.

The traditional and more sobering view of energy transition is that they are "are prolonged affairs that take decades to accomplish" [2].  Inertial factors such as political and public acceptance, the long lives of electricity infrastructure assets and existing business models often act to slow the rate of change.

California is clearly seeking to break this mindset, by accelerating the pace of change through a host of renewable energy incentives and mandates and ever stricter regulation on pre-existing fossil technology. It relies on technology development as a key enabler of change across both the supply side and the demand side.  The rapid pace of transition has major impacts on stakeholders across the value chain including businesses, government, system operators and consumers. Does technology enablement lead to large shifts in grid operating frameworks or are we at the limit of tolerance for change?

If the experiment succeeds it could set an example for the world to follow. If it fails, the repercussions are likely be harsh and broad based. The 2001 electricity crisis, still fresh in many minds, is an example of the deep sustaining impact of electricity market and grid failure.

This paper will examine the long term prospects for the electricity market and the impact on stakeholder operating models.  This is discussed under three core themes: policy setting, market operation and technological enablement.  The critical interactions and risks that are identified will provide the contextualisation for further work. Section 2 will provide a brief description of the regulatory and market structure in California, while Section 3 will explain the assessment framework. Section 4 will outline key stakeholders and business models.  Section 5 to 7 will examine the key themes of policy and regulatory design; grid operation and renewable integration; and technological development. Finally, Section 8 will discuss the implications for stakeholders, and adaptation of new business models.

## 2 A Californian Electricity Market Primer

California's electricity market is governed by a mix of Federal and state regulation. At a federal level, regulatory policies, rules and frameworks are governed by the Federal Energy Regulatory Commission ("FERC") while on a state level, the regulation and operation of the market sits with three governing institutions [3]:

- The California Independent System Operator ("CAISO") is responsible for operation of the wholesale market, central dispatch and reliability management.
- The California Public Utilities Commission ("CPUC") sets regulates utilities and retail markets.
- The California Energy Commission ("CEC") implements energy efficiency and renewable policies.

Environmental issues are regulated on multiple levels.  The Federal Environmental Protection Authority ("EPA") sets federal environmental regulations, while the California Environmental Protection Authority ("Cal EPA") is responsible for state environmental regulations. The California Air Resources Board ("CA-ARB"), a division of Cal EPA, responsible for air quality and the greenhouse gas cap-and-trade program.  In many respects, California environmental policy leads national policy [4].

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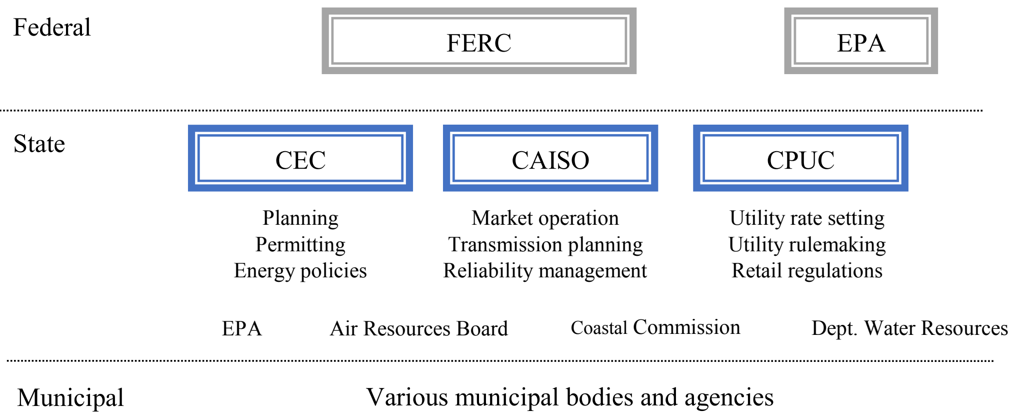
enhancements to the facility using that technology.  Importantly this excludes large scale hydropower generation, which comprised 12.3GW of capacity in 2015 [8].

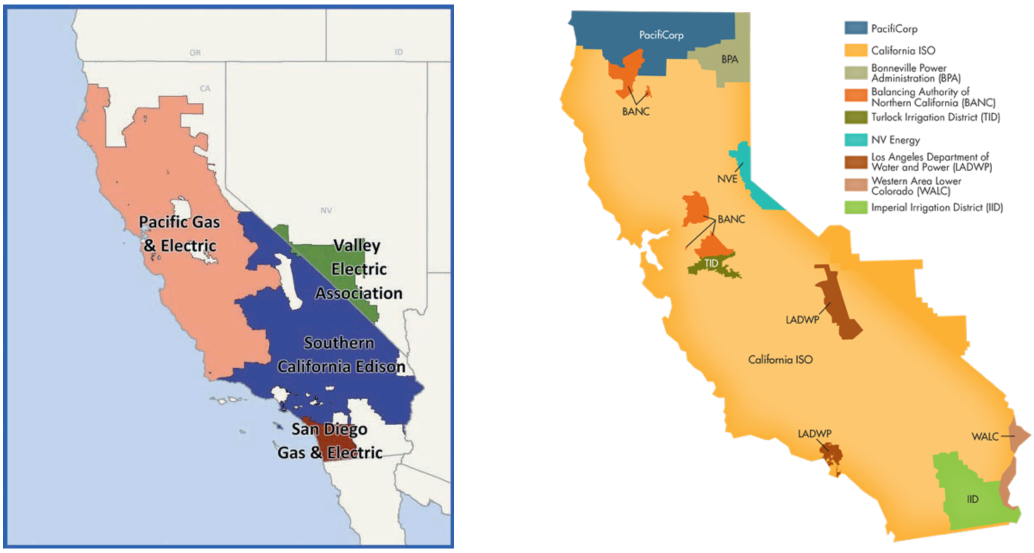
Specialised state agencies also have roles in permitting and regulation, such as the California Coastal Commission (coastal land use) and the Department of Water Resources (water usage). Municipal bodies can also have authority over local environmental and planning issues.

**Figure 1: Governance Model**




California's electricity market is a hybrid system of regulation and deregulation with a competitive wholesale spot market administered by CAISO and regulated retail markets overseen by the CPUC [5]. Today, electricity is primarily supplied via one of three large utilities who also own transmission and distribution.[3]

**Figure 2: Major Utility Operating Regions and CAISO region**




Source: CAISO

CAISO runs an electricity spot market with a capacity overlay. While there is no formal capacity market or auction there is a resource adequacy requirement on load serving entities ("LSEs") to contract for capacity. CAISO also has a backstop authority to procure additional capacity through 'reliability must run' contracts.

[3] There are mechanisms for alternative third-party service providers of electric service, including community choice aggregators (CCAs) or energy service providers (ESPs) serving direct access (DA) load.

**Figure 3: California market design relative to major markets**

| Market | Capacity Mechanism | | | | Energy Pricing | Day ahead market |
|---|---|---|---|---|---|---|
| | Energy Only | Administered Contracting | Resource Adequacy Requirement | Capacity Market | | |
| **CAISO** | | ✓ | ✓ | | **Nodal** | ✓ |
| NEM (Australia) | ✓ | | | | Zonal | × |
| ERCOT | ✓ | | | | Nodal | ✓ |
| Ontario | | ✓ | | | Zonal | ✓ |
| NYISO | | | | ✓ | Nodal | ✓ |
| PJM | | | | ✓ | Nodal | ✓ |
| UK | | ✓ | | ✓ | Zonal | ✓ |

## 3 Perspectives on the future of electricity in California

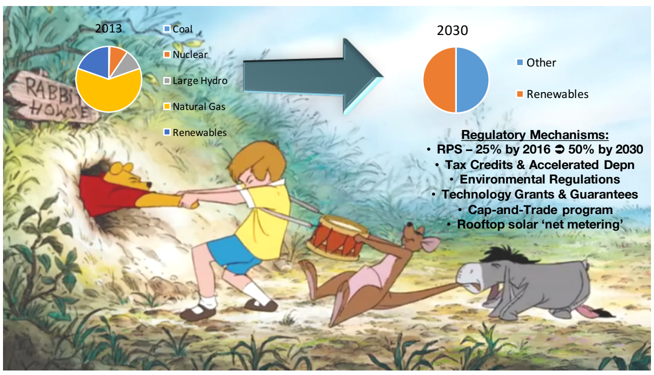
California has long been considered a national pace setter in the area of environmental policy. In the area of climate change, California has set its own goals for decarbonisation with a legislated goal of reducing greenhouse gas ("GHG") emissions 40% below 1990 levels by 2030 [6].

The electricity sector, with around 19% of emissions [7], has been specifically targeted for change. California renewable portfolio standards ("RPS") mandate electricity retailers to source over 50% of their electricity demand from renewable sources by 2030 while a GHG emissions trading scheme covering $CO_2$ emissions, administered by the CA-ARB, applies to electricity generators (including imports). There are a host of additional regulatory and policy mechanisms on a federal and state level that have applied over time, including:

- federal renewable tax incentives introduced during the Obama administration; and
- state prohibitions on once-through cooling ("OTC") for electric generation; and
- federal environmental regulations including Best Available Control Technology ("BACT") standards and the Clean Power Plan.

The effect of this package of measures has been to encourage and accelerate deployment of renewable or low-carbon forms of electric generation and to limit the growth of or force the retirement of fossil fuelled generation. As a consequence renewable generation in the state has grown from 40 TWh in 2010 to over 69 TWh in 2016, which is around 27% of total annual electricity generation [8].

**Figure 4: Policy and Regulatory Drivers**




The California Senate is currently debating Senate Bill 584, which would increase the RPS requirement to 100% by 2045 [1]. The Senate is also considering Senate Bill 775, which would restructure the existing cap-and-trade program post 2020 and establish an escalating price collar for carbon beginning at \$20 to \$30 per metric ton of $CO_2$ [9]. These measures, the latter in particular, could further accelerate the transition over the short to medium term. The risks of accelerated change from an implementation and design perspective however need to be identified and addressed.

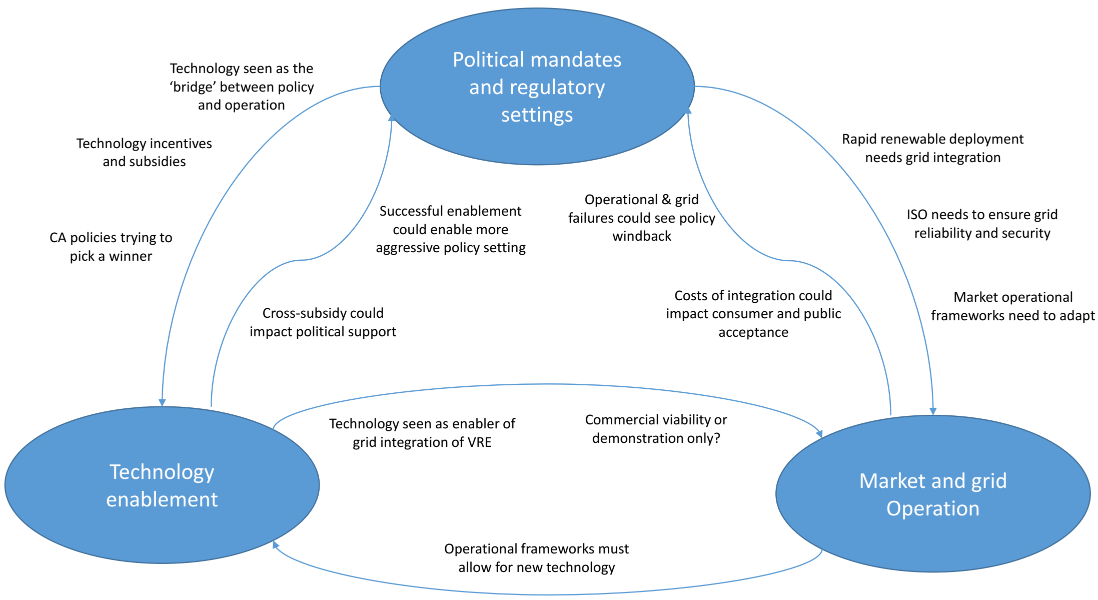
What are the risks to this accelerated energy transition, and how should they inform the management of change in the sector?

Kern and Smith, building on prior work by Geels [10], [11] assess energy transitions based on a socio-technical multi-level framework. Foxon develops a co-evolutionary approach for transition to a low-carbon economy [12], examining interplays between technologies, institutions, business strategies and user practises. This paper builds upon these frameworks to assess the Californian electricity system as co-evolutions of political mandates and policy goal-setting; grid operating frameworks and business models; and technology development and commercialisation trajectories.

First, the political mandate and policy settings are important as they set the broad approach to the transition and importantly the timeframe for change. Second, the policy goals need to be integrated into operational grid management and commercial models for reliability and security of supply. Third, the gap between current operational capabilities and the ambitions of the policy is expected to be met through ongoing and future technology development. Technology is seen as the enabler of the transition and the bridge between the 'old' and 'new'. Key issues include the timeframe for large-scale commercialisation of technologies, its market impacts and who the costs fall upon.

There are inextricable linkages between the three elements. For example, the pace of policy change affects the ability for CAISO and industry to integrate renewables. The inability to successfully integrate renewables could result in an unreliable grid – which could affect public support for the policies.

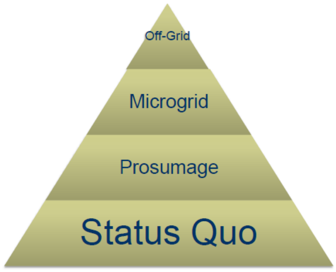
**Figure 5: Co-evolutionary interactions**




## 4 Key Stakeholders and Business Models

Consumers of electricity have historically been just that. They have adopted a passive approach to the market, with electricity as a purely consumption good. With advances in energy efficiency and distributed energy technology, the very nature of the 'consumer' is changing from pure consumption into that of a ‘prosumer’ - active and engaged management of consumption/production [13]. California already leads the nation in distributed energy, with over 5GW of rooftop solar [6]. Future opportunities lie in battery storage, demand response and microgrid development. There are also related stakeholders that are involved in the ‘prosumerisation’ of the value chain – such as aggregators, software developers, energy managers and transaction platforms. Finally, despite changing models, it is also important to give particular focus to those consumers who may be ‘left behind’ in the transition – such as those unable to afford, understand or be exposed to the changes. The impact of cross subsidies on this vulnerable group is also important from an equity perspective, as it can impact political mandates.

**Figure 6: Consumer pyramid**




Source: P. Sioshansi [13]

Given the mix of regulation and deregulation, generation roles in California are divided between independent power producers (“IPPs”) and utilities. IPPs operate in a competitive market for generation and face risks including stranded assets and merit order effects. Many have already begun to reposition towards greater renewable exposure, or in some cases to withdraw from the market.

Utilities operate in a regulated environment, though the risk of retail competition cannot be disregarded. With the changing role of the customer base, utility business models are moving away from network owners towards being platform providers that enable DER. This is a key element of the utility and network reform agenda being considered by the CPUC.

From a supply chain perspective, gas is the dominant commodity input in California with coal capacity virtually eliminated in the state[8]. While gas has been seen as a flexible generation fuel that could serve to balance intermittent renewables, the recent gas leaks at the Aliso Canyon has served to highlight some of the safety and emission challenges with gas. Gas suppliers will need to give particular focus to emissions management and supply issues.

At its peak, nuclear generation capacity was 4GW in California[8]. Due to operational issues at existing facilities, all remaining nuclear facilities in the state have been slated for retirement. Given the recent global events such as Fukushima, the prospects for a nuclear revival seem slim.

Governmental and regulatory institutions are a key stakeholder. Institutions such as CAISO have the job of implementing a reliable market in the face of change. While their traditional roles have been as independent operators and regulators, we observe an increasing acceptance within these institutions of their role in managing a clean energy transition.

Other key interested parties in the electricity value chain include:

- dependant sectors – such as electric vehicles
- support industries (manufacturers, contractors)
- lobby groups (environmental, industry)
- financial intermediaries (electricity traders, brokers, investment funds).
- general public

## 5 Policy mandates and regulatory settings in the 'Wild West'

### 5.1 Overview

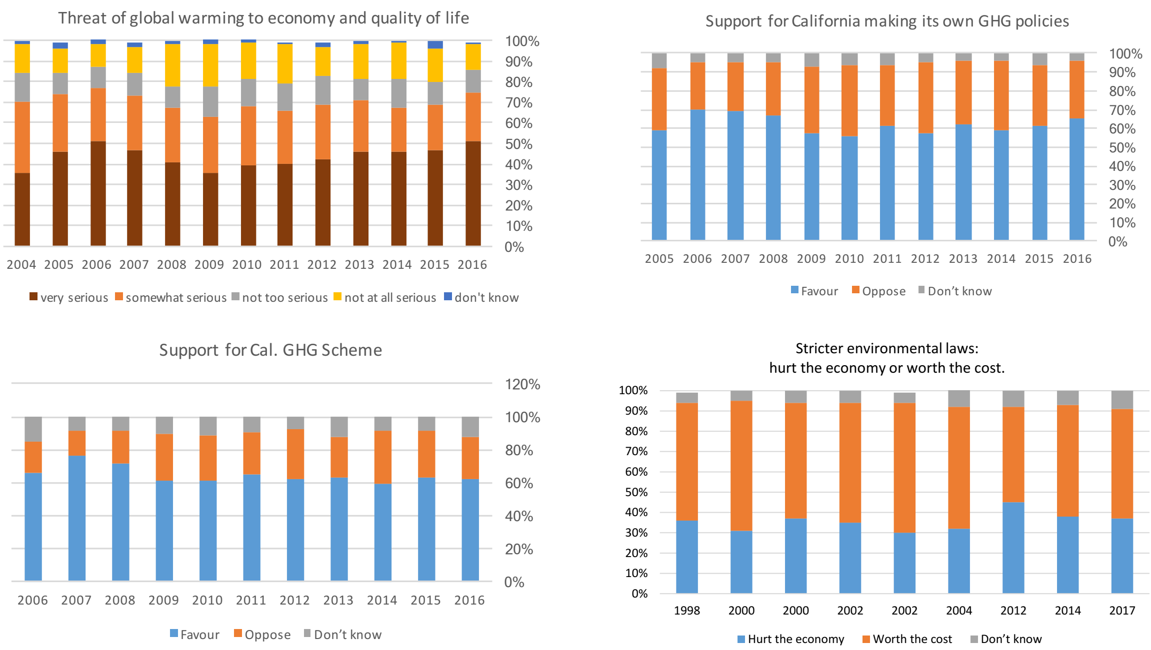
California has long adopted an aggressive stance in environmental policy settings and its approach to climate change and energy transition is no different. It has set high goals under a tight timeframe, which aims to challenge existing models of operation and force innovation through technology development. While California has been viewed as a national and international leader, the state is not immune to regulatory and political risk that could impact upon the achievement of the objectives. An overview of the regulatory dynamic is provided through a strength-weakness-opportunity-threat ("SWOT") analysis. Key themes relate to the interactions between the public, its regulators, the industry and the consumer.

| **Strengths** | **Weaknesses** |
|---|---|
| • Politicians appear to be given a clear mandate<br>• Institutionally embedded environmental goals<br>• Price signal on carbon | • Stop-start approach to regulatory reform<br>• Transition dependent on ongoing incentives |
| **Opportunities** | **Threats** |
| • Emergence of new business models<br>• Evolution of new market designs<br>• Setting a global example for energy transition | • Consumer impacts of higher energy prices<br>• Electricity unreliability and security issues<br>• Federal state environmental conflicts |

### 5.2 From the bottom up: Environmentally conscious voter base

Comprehensive research over several decades indicates that the majority of the Californian electorate is highly engaged on environmental issues and in general supportive of measures to improve environmental standards [14]–[17]. Studies by Kahn suggest a strong broad based demand for 'environmental goods' among the voter base. Recent surveys indicate strong majorities of the voter base support even stricter environmental and climate change standards, especially in the electricity sector, despite acknowledgement this may lead to higher cost. While surveys are not necessarily reflective of public opinion, the overall dynamic has given politicians the confidence to voice a clear mandate.

**Figure 7: Electoral survey results – Environmental Issues**

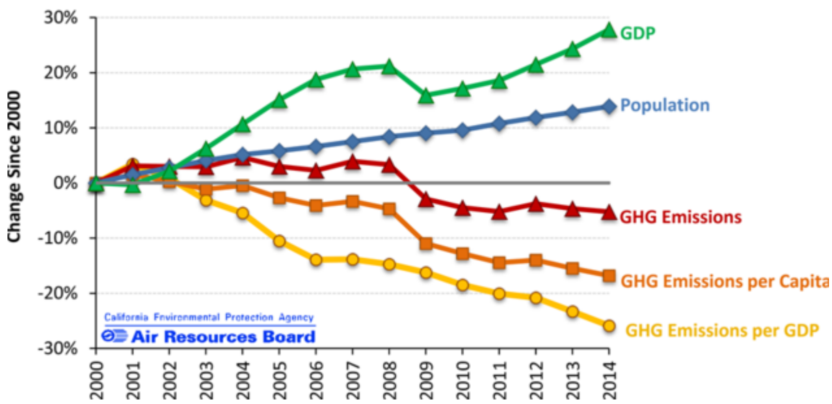



Source: Public Policy Institute of California

However, from a political risk perspective the ongoing public support for market transition depends on a variety of factors including perceptions on the economy and employment, social impacts and local environmental factors (an example being environmental opposition to the Ivanpah concentrating solar facility [18]). Furthermore, California's constitutional structure has a 'ballot proposition' mechanism in California, which allows voters to directly approve legislation via referendum bypassing traditional legislative mechanisms. Measures can be placed on the ballot by the Legislature or by voters themselves. This can serve as a source of political uncertainty as voters can attempt to undo the actions of legislators. An example of this was Proposition 23, which sought to unsuccessfully reverse Californian GHG legislation [19].

Recent data suggests that the California has been able to de-link emissions abatement from economic growth, boding well for near term public support [7].

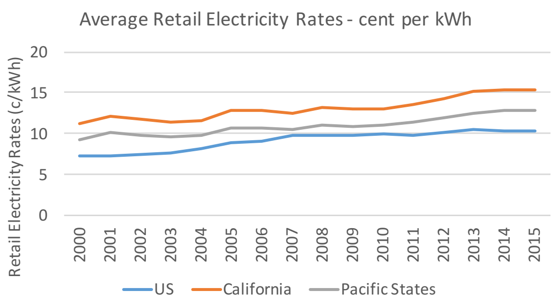
**Figure 8: Delinkage of emissions and economics**




Source: California Air Resources Board

In addition, from a price perspective Californian consumers have consistently faced retail electricity rates well in excess of national averages and regional averages. Retail rates in California are currently 50% more than the national average of 10 cents per kWh [20]. From a political perspective this is a double-edged sword as it may indicate that customers are used to a higher price environment, but it is unclear how far policy makers can stretch this price tolerance.

**Figure 9: Retail electricity rates and Wholesale Gas Prices**




Source: EIA

### 5.3 From top down: Environmental vision embedded in the regulatory mission

The strong mandate provided by voters has allowed for environmental goals to be directly incorporated within the goals of all three of its energy regulatory institutions, including that of the system operator. Excerpts from mission statements indicate that the transition to a low carbon grid is core to the role of each of the CPUC, CAISO and CEC [21]–[23].

**Figure 10: Excerpts from mission statements**

| | |
|---|---|
| CAISO | "Lead the transition to a low carbon grid" |
| CPUC | "Promote California's environmental sustainability goals" |
| CEC | "Committed to reducing …environmental impacts of energy use such as greenhouse gas emissions" |

Arguably, this approach provides clearer guidance for the market and the system operator and allows renewable integration to be a core goal of the market design and operational strategy. On the other hand, this may also lead to conflicts with other objectives such as system reliability and security.

### 5.4 'Trouble with the Feds' – State, national and international interactions

From an environmental perspective, California has typically adopted a more aggressive policy framework compared to the Federal government. It has developed levels of autonomy in environmental policy making within the United States and arguably should be considered a "subnational actor" [4], [24] comparable to the position of Germany within the European Union. To date, this position has received either direct or tacit support by the Federal government.

With the appointment of the Trump administration in Washington, the federal environmental dynamic has changed. The new administration has signalled a shift in policy direction and appears focussed on winding back key environmental and climate change regulations introduced by the Obama administration [1],[13], including the recent announcement of the intent to withdraw from the Paris Climate Accord.

The state executive has indicated it would fight any threats to its policy framework. As framed by California Governor Jerry Brown:

*"We've got the scientists, we've got the lawyers, and we're ready to fight… Whatever Washington thinks they are doing, California is the future."*[26]

California is much more likely to be aligned with international environmental developments and may lead international developments. For example, in 2015 California signed a multinational agreement with 11 other international states and provinces to limit greenhouse emissions below 2°C [27] well before the international agreement at COP21.

Given the political rhetoric it is possible that any challenges to existing frameworks would lead to litigation. Indeed California is part of group of states mounting a legal challenge to Federal efforts to wind back the Clean Power Plan [1]. This will result in political uncertainty for investors in the market, which in the near term could stall investment until market clarity is obtained.

One potential outcome is that California seeks to pre-empt Federal action by accelerating the pace of energy sector transition. Historical events such as the California energy crisis have shown that policy reforms that have been enforced at too rapidly have come at the expense of good policy design resulting in inadvertent risks on the market, ultimately at the expense of the consumer.

### 5.5 Stop start approach to regulation – The California Energy Crisis

It is instructive to briefly examine the 2001 energy crisis as it provides a case study of the risks of managing energy transition.

California was the first state to liberalise its energy markets and was seen as one of the leaders of sector reform. It rolled out an aggressive timeline for wholesale and retail market liberalisation to be achieved within 3 years [28]. The new power market and retail program began in 1998 and seemed to worked well for around eighteen months. However in 2000 in the face of extreme heatwaves, wholesale prices reached all time high's averaging around $200-300/MWh and several parts of the state were blacked out. Prior retail price caps had been removed leaving consumers directly exposed to the spot prices. Given the political backlash, the government spontaneously re-imposed a much more stringent retail price cap of 6.5 cents per kWh (relative to the prior cap of 16 cents per kWh). This inadvertently deepened the crisis as it left the utilities exposed to the high wholesale prices but prohibited them from passing the costs onto consumers. This forced them into major financial problems, with one utility, PG&E, filing for bankruptcy protection [3] [4].

The crisis was initially attributed to many factors crisis including weather, market manipulation, trading greed and the concept of deregulation itself [28]. Ultimately however leading scholars have suggested what unfolded was ultimately a 'crisis by design' [31]-[32]. Outcomes were made much more extreme as a result of poor market and operational design and implementation – such as the absence of vesting contracts, which left retailers immediately exposed to pool prices without an ability to hedge, and the political decision to impose price caps on retail markets but to leave wholesale markets uncapped. As part of the fallout, deregulation was held out in political discourse as a key cause of the crisis [30]. As a consequence, the government halted the deregulation process and wound back many of the reforms. This stalled retail market development for many years.

This case study illustrates that while California has sought in the past to lead market reform in the US, the pace of change it imposes upon the market has led to policy makers compromising the quality of the policy design leaving stakeholders and consumers exposed. The eventual crisis that have flowed have often resulted in the reforms being reversed.

This has parallels with the renewable transition, where the pace of regulatory change has been particularly stark. Over the thirteen year period from 2002, the RPS target was amended five times [33] with each amendment materially upping the requirement [34]. While the pace of change has been politically favourable to date [35], it has required extreme adaptability by industry to remain viable and from the system operator to ensure reliability. Stranded asset risk has been particularly relevant with certain IPPs forced to retire units well before the asset's useful life [36].

**Figure-11: Changes to California's RPS**

**Timeline of Changes to California's Renewable Portfolio Standards**

2002: Senate Bill 1078 establishes the 20% RPS by 2017.
2003: Action Plan I accelerates 20% deadline to 2010.
2005: Action Plan II recommends goal of 33% by 2020.
2006: Senate Bill 107 codified the accelerated 20% by 2010 deadline into law.
2008: Governor Schwarzenegger issues Executive Order requiring 33% renewables by 2020.
2011: Senate Bill X1-2 codifies 33% by 2020 RPS.
2015: Senate Bill 350 codifies 50% by 2030
2017: Senate currently debating SB584 which would set the RPS to 100% by 2045

## 6 Loading the dice: Grid Operation in a Variable Supply Market

### 6.1 Overview

On May 13 renewable energy set a new record in California generating over 67% of electricity demand [37] [38]. As more variable renewables comes onto the grid, often generating at zero marginal cost, this puts further strain on traditional models of generation and grid operation. California's lofty energy ambitions are in large part dependent upon maintaining reliable, safe and secure electric supply. The grid operator has had to adapt historical approaches to cater to these new realities. A SWOT analysis provides an overview of the opportunities and challenges of grid integration.

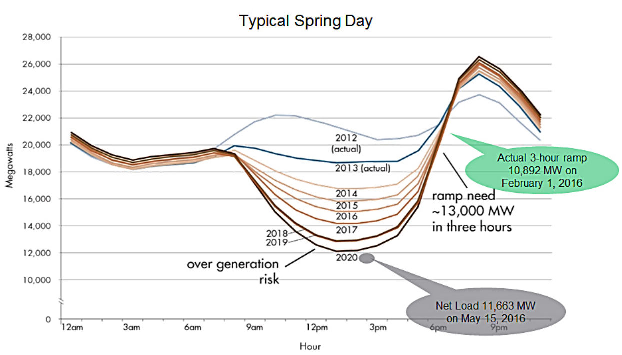
| **Strengths** | **Weaknesses** |
|---|---|
| • Early identification of problem by CAISO<br>• Regulatory structure allows CAISO ability to drive market design change<br>• Value put on flexible capacity<br>• Dispatchable reserve margins remain strong<br>• High degree of interstate interconnections | • Increasingly weak frequency performance<br>• Duck curve impacts: more balancing and flexible generation<br>• Risk of overgeneration<br>• Higher costs for consumers<br>• Limited transparency of the price of capacity |
| **Opportunities** | **Threats** |
| • Opportunity to be global pace-setter<br>• Engaged customer base provides opportunity to implement the 'prosumer' model<br>• Future system services markets<br>• Integration of demand response<br>• Expansion of balancing areas | • Further commercially driven retirements<br>• High renewable integration costs<br>• Pace of change too fast for industry response<br>• Fossil fuel retirements may strain capacity reserves<br>• Frequency control and reserve management |

### 6.2 Grid integration: the 'duck curve' and system reliability concerns

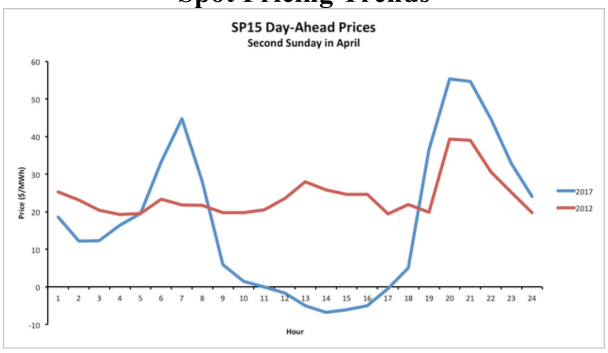
CAISO first identified the 'duck curve' issue in 2012, predicting that increasing levels of solar PV would change the intraday net load profile [39]. This would put increasing strains on existing dispatchable generation to ramp up and down during the day to meet the need. Indeed the pace of change has been so rapid that in 2016 the system already experienced ramp rates that were only expected in 2020. This has also resulted in changes to wholesale pricing trends with higher prices experienced during peak ramping periods but low or often negative pricing during other times [40].

**Figure 12: Duck Curve and Pricing Trends**

**Duck Curve – Net Load Trends**



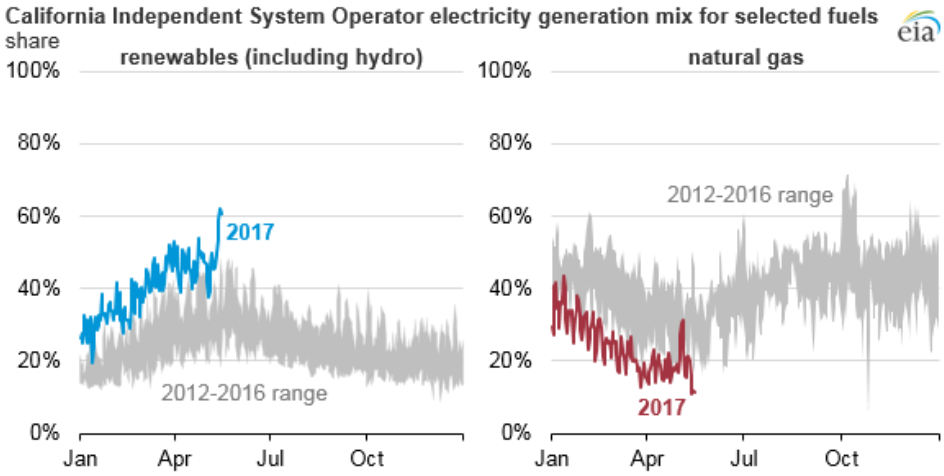

**Spot Pricing Trends**




Source: CAISO

The 'duck curve' trend highlights the increasing need for flexible dispatchable generation, such as fast-start gas generation, to meeting ramping and cycling needs. However, Figure 13 illustrates that as renewable penetration has increased the overall dispatch of natural gas generation has decreased [38]. This has meant that generation faces reduced capacity factors and is forced to recover more of its costs over shorter periods i.e. the generator 'death spiral', leading to mothballing or retirement of units. For example, the Sutter Energy Center, a 578MW CCGT was mothballed only 15 years into its lifespan as it was commercially unviable [41].

**Figure 13: Increasing renewables force natural gas dispatch to new lows**



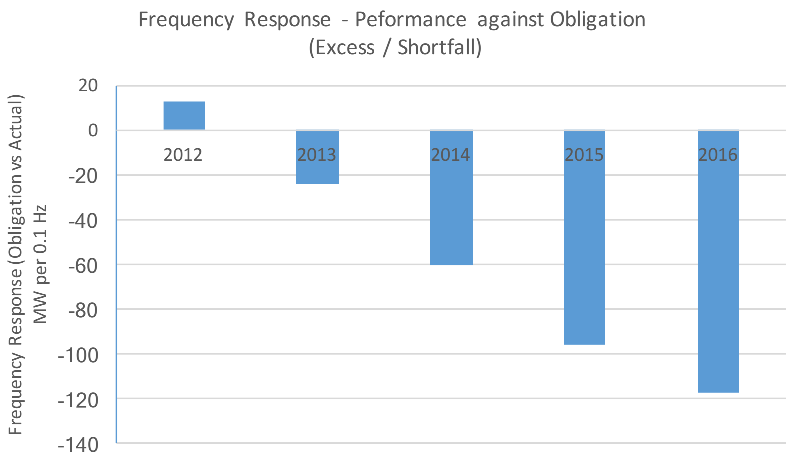

Source: EIA

More recently CAISO has also highlighted increasing concerns around the frequency response capabilities of the grid due to the displacement of conventional generators on the system. Figure 14 illustrates declining frequency performance against national reliability standards. Based on renewable projections for 2020 CAISO states that:

*"Under these operating conditions, the grid may not be able to prevent frequency decline following the loss of a large conventional generator or transmission asset."*

Frequency response underperformance is indicative of a market where the level of short term variability is difficult to manage using existing means. Solar generation in particular can have significant generation variability due to clouding and other weather impacts. Similar problems are being experienced in Australia, and is indicative of a system that has been stretched to its technical operating envelope.[42]

**Figure 14: Declining frequency response performance**




Source: CAISO

Together these issues highlight some of the operational difficulties of integrating renewable generation into the existing grid which must be managed and mitigated in order to move effectively towards higher penetrations.

### 6.3 Regulatory response: new markets, new money and central planning

To their credit, CAISO recognised this issue early in 2010-11 and began to adapt its market to the new paradigm. The governance and regulatory structure gives CAISO the authority to drive changes to market design and operational policy and in short order it began to develop mechanisms to deal with the duck curve issue. In times of transition, the ability for ISOs to respond to localised issues through operational policy development has been a beneficial element of the regulatory structure.

CAISO introduced a new ancillary service market for a 'flexible ramping' product, which allowed quick ramping technologies to earn a new spot market revenue stream [43]. In the short period since commencement, much of the ramping service has been provided by fast-start gas generators and hydro units [44]. Over the long term it is expected that battery and energy storage technology should also be able to participate in this market. CAISO also introduced a new procurement requirement for flexible capacity [45]. This builds upon existing capacity mechanisms, by requiring LSEs to contract for a certain amount of capacity from 'flexible sources'. This provides an additional capacity revenue stream to flexible generation, regardless of whether it is dispatched.

In response to frequency issue, CAISO is also examining the potential to develop a new ancillary service market for primary frequency control [42]-[43]. This service will provide near instantaneous response to frequency deviation and provides for improved operational control. Importantly the service is technology agnostic and can be supplied by batteries, but also by existing thermal generators through governor control.

In addition to market approaches, the energy regulator CPUC has also introduced centrally planned storage procurement, requiring the three major utilities to procure 1.8GW of 'viable and cost-effective' energy storage by 2020 (with installations no later than 2024). This is roughly equal to 5% of load [48]. Utilities have been given a degree of discretion to determine notions of cost effectiveness for sourcing additional storage though with oversight from the CPUC. Also of note is the exclusion of large-scale hydro pumped storage facilities[4], currently argued to be one of the most cost-effective forms of storage, from eligibility in the scheme given risk of crowding out emerging technologies and inhibiting market transformation. While these appear to be recognised compromises of the mandate in order to promote technology development it is concerning for consumers given the potential for flow-through into higher retail rates.

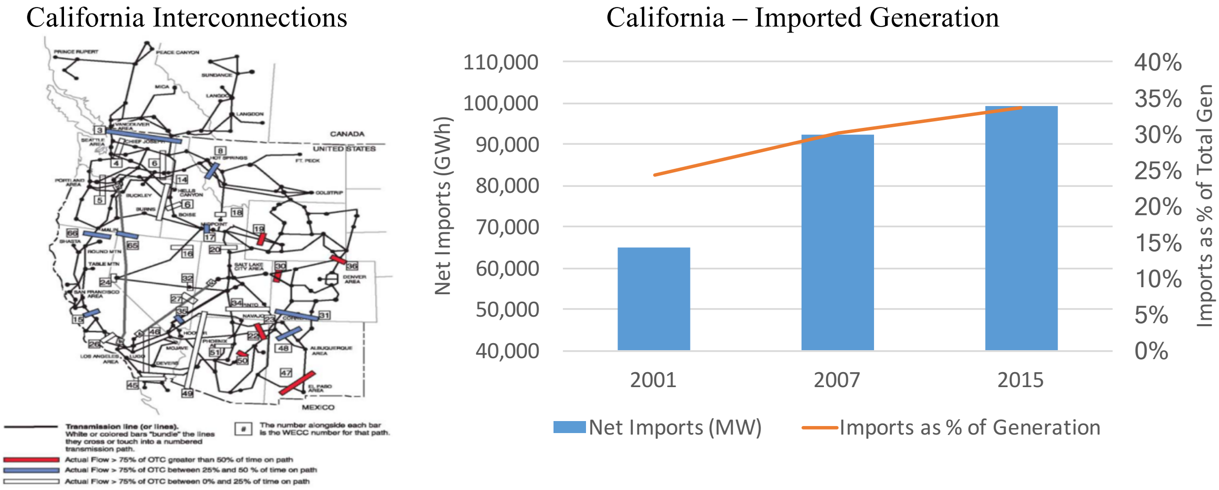
The Californian mix between competitive and regulation approaches seems to be replicated in the approach towards operational management, with the latter more concerning from a consumer and market efficiency perspective over the long term. From a broader energy change perspective this emphasises the importance of a public support base that has some tolerance for the cost impost of transition [49].

### 6.4 'Good neighbours' - Increased reliance on imports to meet renewable need

California benefits from over 10GW of transmission capacity linking it with neighbouring states and Mexico [50][51]. In recent times California has been increasingly reliant on imports of generation to meet its demand.

4 Large scale is defined as a facility with generation capacity in excess of 50MW. This exclusion was reviewed by the CPUC in April 2017 but no changes were made [60].

**Figure 15: Imported Power Generation in California**




Source: CEC, WECC

Having strong interconnections from multiple regions has been one reason why California has been able to manage such high renewable penetrations to date, as it allows for better management of peak periods and system balancing. The interconnections are also able to provide certain ancillary services (such as frequency regulation) into the Californian grid. This reliance on imports is likely to grow in future with more intermittency in the generation mix.

An analysis of path congestion by WECC in 2013 did not indicate any material congestion on transmission paths into California. Recent data from WECC suggests the number of system operating limit exceedances for paths has been declining given upgrades to infrastructure and load composition changes [52].

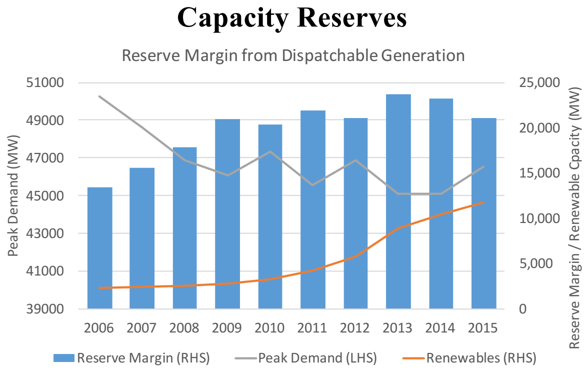
In addition CAISO is currently embarking on a regional expansion program that would seek to bring other states into its market framework [53]. Neighbouring regions would benefit from increased investment and energy development activity, but CAISO would also benefit from an increased ability to manage and balance renewable imbalances.

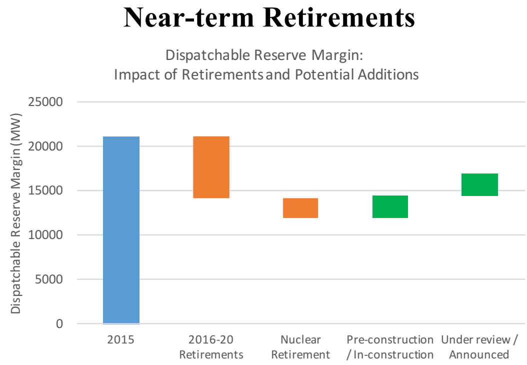
## 6.5 Excess of dispatchable capacity

California introduced a reserve capacity requirement in 2004 leading to large build out of over 8GW of natural gas generation capacity built out in the five years to 2009 [8]. This meant that California had an excess of generation capacity before the advent of renewables. When combined with the reductions in peak demand, California has continued to maintain a comfortable reserve of excess dispatchable capacity. In recent years, this capacity has provided a 'safety margin' which has allowed the state to better manage high amounts of variable and unpredictable generation.

However, the capacity and reserve adequacy dynamic is likely to shift over the next few years. State based environmental standards (such as regulations prohibiting once-through cooling on fossil generation) will likely result in retirements of over 5.7GW of fossil fuel plants in three years and an additional 2.2GW from the retirement of the Diablo Canyon nuclear facility by 2025 [54]. This does not incorporate any additional unit retirement or mothballing based on commercial decisions. Against this, there are currently 2.5GW of dispatchable projects either in pre-construction or under construction and an additional 2.4GW announced or under review which may offset some of the loss.

**Figure 16: Excess Generation Capacity and Retirement Risks**




Source: CAISO, CEC

In the face of higher renewable penetrations with zero or negative short-run-marginal costs ("SRMC") dispatch levels and capacity factors for gas-generation are likely to be lower. New gas-fired projects will depend more upon capacity and reserve based revenue rather than energy revenue in the current market. This underscores the need for increased transparency of price signals for reserve and capacity in the market. This of particular relevance in the near term given the criticality of gas generation fired generation for system balancing as long as other alternatives such as energy storage are yet to reach critical scale. Reliability pricing signals are also important for developing the economic case for storage. This is an area of further investigation in the next phase of work.

## 7 Technology development for the renewable transition

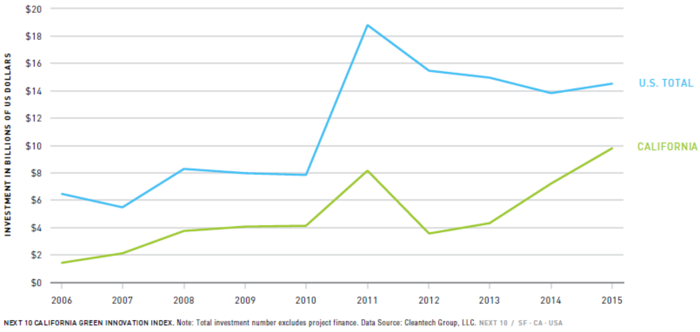
Technology development as critical to the long term success and achievability of California's energy goals. It has the potential to serve as a bridge between current operational frameworks and broader governmental policy objectives to move towards a grid that is dominated by renewable resources.

| **Strengths** | **Weaknesses** |
|---|---|
| • Strong track record of innovation<br>• Commercial and academic R&D programs | • Limited deployment of storage to date |
| **Opportunities** | **Threats** |
| • Demand response<br>• Energy storage<br>• Inverter dominated grids | • Reliant on technology funding<br>• Commercialisation timeframe |

Driven by its broader leadership in technology, California has led the nation in clean technology ("cleantech") investment. In 2015, California invested around $10 billion in clean energy technologies amounting to 70% of the investment across the nation and dwarfing the next highest state Massachusetts at $0.7 billion [55]. It also has the most cleantech patents in the US, just under four times that of New York. Commercial development is supported by a strong educational research and development program through leading universities.

**Figure 17: Cleantech Investment**

**Investment ($ billion)**




**Patent Rankings**

TOP RANKING STATES IN 2015

| RANK | STATE | NUMBER OF PATENTS |
|---|---|---|
| 1 | CALIFORNIA | 4,052 |
| 2 | NEW YORK | 1,215 |
| 3 | TEXAS | 1,172 |
| 4 | MICHIGAN | 1,150 |
| 5 | ILLINOIS | 800 |
| 6 | MASSACHUSETTS | 768 |
| 7 | PENNSYLVANIA | 683 |
| 8 | FLORIDA | 647 |
| 9 | WASHINGTON | 603 |
| 10 | OHIO | 574 |

NEXT 10 CALIFORNIA GREEN INNOVATION INDEX. Data Source: IP Checkups, CleanTech Patent Edge. NEXT 10 / SF - CA - USA

Source: Green Innovation Index

## 7.1 Technology for the new grid

What is the gap that technology development and innovation must bridge? When considering high penetration renewable electric systems, Kroposki et al [56] categorise the renewable integration challenges into two concepts: 1) dealing with increased variability and uncertainty, and 2) relating to the technical challenges of an inverter dominated grid.  While not mutually exclusive it provides a useful framework for understanding the current gaps in operating frameworks where additional research and development is required.

The first relates to the variability and uncertainty of generation resources that are dependent upon local weather.  Several studies have been conducted into the area of variability, and while further work is needed many solutions have been identified to cater to this issue [56].  These include:

- Geographic diversity in renewable siting and additional transmission augmentation
- Temporal shifting through energy storage
- Demand response, DER and integrated load management strategies
- Advanced renewable forecasting
- Increased need for frequency regulation and reserves, or alternative market products (such as flexible ramping reserves)

The challenges of an inverter-dominated or asynchronous grid are more nuanced.  Reduced levels of synchronous generation and consequently less inertia in the system has the potential to impact multiple facets of grid management including frequency and voltage.  From a power system stability perspective this has the potential to impact multiple areas such as frequency response, transient stability, oscillatory stability and voltage control [56], [57].

CAISO has begun trials to test the ability of asynchronous technologies such as solar PV to provide grid level ancillary services such as spinning reserve, frequency response, voltage support and ramping services [58]. Results from trials to date have been favourable, though further testing is required in areas such as the provision of fast-frequency response and synthetic inertia.

Additional technology development is likely required for a grid that is dominated by inverter or asynchronous technology.  For example, grid-following inverters that rely on a stable voltage and frequency may need to be replaced by grid-forming inverters that can themselves regulate frequency and voltage levels.  These technologies may take years or decades to develop, verify and commercialise [56].  Moving to a majority penetration of asynchronous renewables as envisioned by RPS has the risk of reliance on some undeveloped and unproven technology.

While California has a strong support institutional and commercial support structure for innovation, the pathway for energy transition is compressed and is reliant upon development of new technology, which can be affected by many factors out of governmental and industry control.

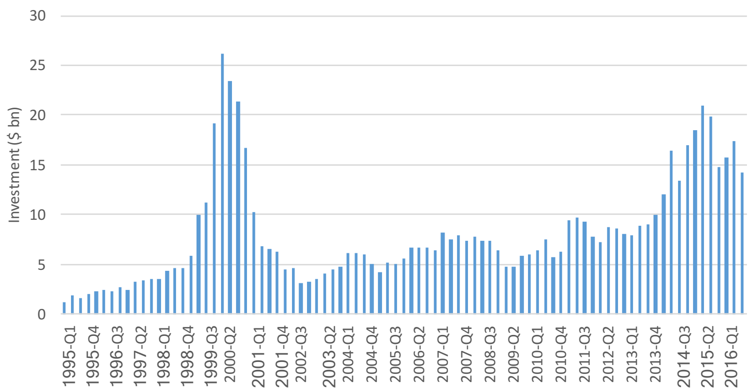
### 7.2 Dependence on the venture capital financing

The ability of technology to enable change is dependent upon a supportive financial environment for clean technology investment. Securing ongoing funding for investment enables newer technologies to be developed, piloted and commercialised.

Close to 60% of clean technology investment in California has been funded by venture capital [55]. Venture capital is sourced from investment funds with higher risk profiles and return targets, and depend upon rapid growth in the businesses they invest in. There is thus a strong link between venture capital and clean technology investment.

However, venture capital is a volatile and risky market as it depends on investors with higher risk appetite. Experiences from the 2000 technology crash indicate that investment can be impacted by market illiquidity. The 2007 financial crisis also saw reductions in venture funding though not to the same extent. Recent market data indicates that the level of investment is beginning to climb to heights not seen since the tech crash. The venture capital industry and by extension the clean tech sector is thus increasingly vulnerable to financial shocks. Any industry level economic shock would be likely to impact the pace and scale of investment in clean technologies and may affect the development and commercialisation of new energy technologies. There is thus an investment risk to California's energy trajectory.

**Figure 18: US Venture Capital Funding**




Source: PwC Moneytree [59]

## 8 Business Model Adaptation

For various stakeholder groups across the value chain navigating the new electricity market landscape requires a combination of adaptation, flexibility and financial resources. Stakeholders that are wed to existing approaches either by choice or necessity will be subject to transition risk.

The prosumerisation of electricity, encouraged by technology, provides an opportunity for consumers to play a more active role in the use, supply and trading of energy through distributed energy, energy efficiency and transactive energy models. Consumers have an opportunity to defray the high costs of environmental policy settings and subsidies by adopting newer operating models.

From an industry perspective, players that are likely to benefit are those that either directly exposed to renewables or those that play a role in supporting renewable integration. While in the short term, natural gas generation may have a role as a flexible fuel, it is impacted by safety concerns, reduced market dispatch and stranded asset risk. Revenue composition for gas is also likely to shift increasingly towards capacity based revenue over dispatch. Over the long term, depending on cost trajectories, energy storage technologies are likely to play an increased role, especially given the enforced buildout over the next seven years.

## 9 Conclusions and Further Work

In conclusion, three core themes underpinning the current electricity market transition in California were examined. There are strong interlinkages between each of the core themes primarily relating to the pace of change, existing operating frameworks and technology and market adaptation. While adaptation is required for all stakeholders, including the market operator, setting overly aggressive timelines can result in system unreliability which can impact political support and ultimately force reform rollback.

California is indeed an 'experiment in energy transition', but successful 'laboratory' results can only come from careful and deliberate testing of the system with due regard to key political, operating and technological risks. This paper identifies important risks in relation to frequency response, dispatchable reserves, technology development for inverter-dominated grids and venture financing that require further assessment particularly given the potential for further acceleration of the transition timeline. The next phase of work will examine each of these risks in detail and propose a comprehensive transition management framework that integrates policy setting, grid operations and technology development.

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