Large scale energy storage

CryoHub

Developing Cryogenic Energy Storage at Refrigerated Warehouses as an Interactive Hub to Integrate Renewable Energy in Industrial Food Refrigeration and to Enhance Power Grid Sustainability

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1. Executive summary

In the revised Work Plan, D10.2 was due to complete by October 2019. The deliverable was stated as 'Report on policy recommendations that would maximise the benefits of CyroHub and similar projects.' In the Work Programme, it is linked to WP10.2 'Policy assessment' (UB, CDR, EUREC):
"Whilst the technology offers the possibility of reducing costs and emissions for the user and the wider system, it is not clear that this value will be accessible such that a viable business case could be constructed. We will assess the policy and regulatory barriers that could prevent the technology from being deployed (at EU and national level) from desk-based research and interviews with industry and policy-makers, also drawing on the work of WP8. We will also consider how the technology, if deployed at scale, could impact other energy/food policy decisions. The same four countries used in 10.1 will be analysed in detail here, again with a description of wider applicability."

In part, our intention has been to work with CDR, to interview the stakeholders identified for WP8. This has not been possible as much as anticipated on the timescale we had set out. However, we have developed interview pro-formas for both refrigeration and energy sector specialists that have gone through the university's ethical approval process (Annexes A and B). Interviews have been held with UK refrigeration industry and energy sector representatives (under confidentiality agreements, we don't disclose who). We are asking CryoHub colleagues now for other stakeholders to interview in their countries and plan to carry these out in Q1 2020.
We have also carried out an analysis of international policies for energy storage (Annex C) that will inform our policy recommendations. We will continue to supplement this following further interviews.
After analysis of interviews and international policies, the full report will be prepared by Q2 2020 ahead of WP10.3 where we plan to engage with stakeholders as part of an event linked to the CryoHub demonstrator.

2. ANNEX A - Refrigeration sector survey questions

Q1. Regarding the generation and use of energy for your business, how important are each of the following issues:

☐ Lowering energy bills
☐ Accessing new, additional, revenue streams
☐ Lowering cooling demand
☐ Improving reliability of supply
☐ Reducing environmental impact (carbon emissions, pollution etc)
☐ Green branding and the promotion of sustainability

Please rate as Very important, important, minor importance, not important

Please explain the reasons for your answers.

Q2. Are there other business priorities that you think energy technologies might be able to help achieve?

Please rate these priorities as Very important, important, minor importance, not important

Please explain the reasons for your answers.

Q3. Are you aware of any benefits that my come from energy storage?

If yes, please describe.

Q4. What factors would affect decisions on the deployment of new energy technologies in your business?

☐ Capital expenditure

☐ Impact on running costs

☐ Integration with existing technologies/processes

☐ Lack of understanding of the new technology

☐ Maturity of the technology

☐ Other – please describe

Please rate as Very important, important, minor importance, not important

Please explain the reasons for your answers.

Q5. What is your attitude to testing or demonstrating pre-commercial energy technologies?

Select from: enthusiastic, reluctant, neutral

What factors would influence your decision?

3. ANNEX B - Energy sector survey questions

I. Flexibility

Q1. Assuming the EU maintains its current energy policy goals, do you believe that the need for flexibility in the energy system over the period to 2030 will:

- ☐ Increase substantially
- ☐ Increase slightly
- ☐ Stay about the same
- ☐ Decrease slightly
- ☐ Decrease substantially

Please explain the thinking behind your selection.

Q2. Rate the following as to their importance as a driver for increased energy system flexibility over the period to 2030:

- ☐ Increase in variable renewables (e.g. on- and off-shore wind and solar PV)
- ☐ Increase in electric vehicles
- ☐ Increase in electric heating (e.g. heat pumps)
- ☐ Increase in CHP and district heating
- ☐ Increase in space cooling

Rate as: Very important, important, minor importance, not relevant
Please explain the thinking behind your ratings.
Are there other factors not listed above that you would rate as either very important or important?

Q3. At what point in the future do you think that the current energy system will prove to be insufficiently flexible to cope with the developments identified in Question 2?

- ☐ Before 2020
- ☐ 2020 - 2025
- ☐ 2025 - 2030
- ☐ After 2030
- ☐ Not applicable (as Q1 did not reveal a belief that the need for system flexibility will increase)

Please explain the thinking behind your answer.

Q4. What role would you expect the following options to play by 2030 in providing flexibility to the energy system given the importance you assigned to the different drivers in Question 2.

- ☐ Storage
- ☐ Demand response
- ☐ Interconnection
- ☐ Back-up flexible fossil capacity

Rate each as Very significant, significant, minor, none and ask to quantify the role in each case if possible (e.g. Storage – very significant, 10 - 15 GW)
Please explain the reasons for your answers.

II. The role of energy storage

Q5. Thinking about the deployment of energy storage to increase system flexibility, what are three most important developments that could increase its role by 2030? What are the three most important developments that could decrease its role.
Please explain the reasons for your answers.

Q6. In which areas is energy storage the best-placed option to provide flexibility to the energy system, now, and in 10 years?

- ☐ Seconds e.g. Renewable generation introduces harmonics and affects power supply quality.

- ☐ Minutes e.g. Rapid ramping to respond to changing supply from wind generation affecting power frequency characteristics.
- ☐ Hours e.g. Daily peak for electricity is greater to meet demand for heat.
- ☐ Hours – days: Variability of wind generation needs backup supply.
- ☐ Months e.g. Increased use of electricity for heat leads to strong seasonal demand profile

Answer each as very likely, quite likely, possible, quite unlikely, very unlikely
Please explain the reasons for your answers.

Q7. How likely is additional energy storage to be situated on the following parts of the system?

- ☐ Generation level
- ☐ Transmission level
- ☐ Distribution level
- ☐ Customer level
- ☐ Don’t know

Rank as very likely, quite likely, possible, quite unlikely, very unlikely
Please explain the reasons for your answers

III. Energy storage innovation and policy

Q8. How important are each of the following barriers to the deployment of energy storage over the next 5-10 years?

- ☐ Technology cost and performance
- ☐ Uncertainty in future value
- ☐ Regulatory framework
- ☐ Market structure
- ☐ Lack of business models

Please rate as Very important, important, minor importance, not a barrier
Please explain the reasons for your answers.

Q9. What do you see as the most important priorities for innovations in energy storage technologies?
Please explain the reasons for your answers.

Q10. Governments should provide (further) explicit support for the development and/or deployment of storage over the next 5+ years as it does for a range of low carbon technologies

- ☐ Strongly agree
- ☐ Slightly agree
- ☐ Neutral
- ☐ Slightly disagree
- ☐ Strongly disagree
- ☐ Don’t know

Please explain the reasons for your answers.

Q11. How would you rate the desirability of the following forms of support for energy storage.

- ☐ Additional support for R&D
- ☐ Additional support for demonstration
- ☐ Regulatory reforms to remove barriers and create a more level playing field
- ☐ Deployment support (e.g. mandates, capital subsidies, operational subsidies etc.)

Select ratings from: Very desirable, desirable, not needed
Please explain the reasons for your answers.

Q12. How meaningful (e.g. desirable, important?) would it be to have a deployment target for energy storage?
Select from: Very meaningful, meaningful, not meaningful

4. ANNEX C - Review of international energy storage policy

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1 Germany

Over the last few decades Germany has been a frontrunner in developing and deploying renewable energy technologies and developed a feed-in tariff scheme which many countries have based their own schemes on [47]. Despite this relatively long term support for renewable energy the German energy systems transition to a renewable energy dominated system, known as the 'Energiewende' is generally accepted to have started in 2010 when the German government announced as part of their energy concept a series of progressive targets for greenhouse gas reduction and renewable energy consumption; resulting in targets for reducing GHG's by 80% from 1990 levels, and for renewable energy to meet 60% of gross energy consumption and 80% of electricity consumption by 2050 [48] [49]. Following the nuclear accident at Fukushima in 2011, further emphasis on the need for the adoption of renewable technologies was provided when the German government then announced that all nuclear power, which supplied 22.5% of Germany's power, would be phased out by 2022 [50].

This has led to an increase in the contribution renewable generation makes to Germany's energy supply from 2010 to 2015; from 9.7% to 13.8% of total primary energy supply, 14.4% to 22.4% of heat production, and 18.6% to 31.0% of electricity production [51]. This increase in renewable electricity production is largely down to the increase in solar PV and wind generation which from 2010 to 2015 rose from 1.9% (11,700GWh) to 6% (38,700GWh) and 6% (37,790GWh) to 12.2% (79,200GWh) respectively. This high penetration of wind and solar has led to stability issues, and increasing difficulty in balancing supply and demand, which has driven the installation of additional storage energy to mitigate these issues. Germany currently has 7.6GW of grid-connected storage, including 6.5GW of PHS, 0.5GW of CAES, 0.1GW of electrochemical batteries and small levels of thermal storage (1.5MW) [9].

Although Germany currently has no specific energy storage targets the growing need for energy storage since 2010 has led to a number of measures to promote energy storage. This includes the Federal Ministry for Economic Affairs and Energy's Energy storage initiative program which since 2012 has provided a total of over €200Million of research funding for around 250 energy storage projects [52], these projects have ranged in scale from distributed household storage systems, to multi-megawatt systems for use as part of a more centralised system. Stated areas of focus for the Energy Storage Initiative include batteries for distributed storage networks and thermal storage systems [52].

In addition to research funding, the German Government has also provided a number of measures and incentives to promote the uptake of energy storage systems. These include the updating of the energy act to allow electrical energy storage systems to participate in reserve markets and the exemption of electrical storage systems from a number of fees and charges including renewable energy levies and grid tariffs [5, 18]. It also includes a number of subsidy schemes to promote distributed storage systems alongside solar PV generation. Since 2013 a subsidy for battery storage systems to be used in conjunction with rooftop solar PV systems has been available, which up to 2016 provided €60Million to approximately 19,000 projects leading to a total investment in the region of €450Million [52]. This subsidy was initially expected to finish in 2016 but due to the success of the scheme confirmation has now been given that it will be extended until 2018 although in an adjusted format to allow for the falling cost of storage systems [53]. This subsidy accounts for up to 30% of the investment cost while a low-interest loan can be provided for the remainder of the cost, however systems are only eligible for the program if they help to reduce congestion (through load-shifting) on the local distribution network by not exporting to the grid during the mid-day hours [52].

Additional support for distributed energy storage may come from Time of Use Tariffs which are offered by many German electricity suppliers, however adoption rates are relatively low although a roll-out of smart meters, albeit only for relatively large consumers, may begin to change this [2, 54].

As with many nations, Germanys' adoption of thermal storage technologies is relatively low however Germany's heat demand makes up around 54% of their total energy consumption with most district heat networks powered by fossil-fuel CHP systems [55], so to meet decarbonisation targets much of this heat demand will have to be met by renewable sources in the future meaning there is significant potential for additional thermal energy storage. Unlike electricity networks the nature of heat networks means that any thermal storage employed by them will be distributed.

Although Germany is promoting energy storage across all scales and applications there is a slight preference towards distributed, residential scale storage [18] this makes it a useful case study for those trying to promote energy storage in other nations. Whilst Germany's Energiwende has seen a rapid and large adoption of renewable technologies and the subsequent adoption of energy storage systems it has, in the most literal sense, come at a cost with German energy consumers having some of the highest bills in Europe [49]. This has been deemed by successive German Governments (and their voters) to be an acceptable cost to achieve decarbonisation but it is questionable as to whether this would be the case for many nations.

2 UK

4.1.1. Energy policy

The UK Government has a nationally legislated target to reduce greenhouse-gas emissions by 80% by 2050 compared to 1990 levels, and from the EU for renewables to meet 15% of total energy demand by 2020 (which translates into approximately 30% of electricity from renewable sources) [1, 2].

To support the delivery of its objectives, while minimising the cost to the consumer the UK government has implemented Electricity Market Reform (EMR) [3]. Two key mechanisms introduced as a result of EMR are the Capacity Market and Contracts for Difference.

The Capacity Market will begin in 2018 and is designed to maintain security of supply and offers electricity capacity providers (including new and existing power plants, and electricity storage systems) a monthly revenue for providing electricity at times when required (usually when the system is under stress) [4]. As the electricity has to be provided on demand variable renewable energy generators cannot access the capacity market, however in principle electrical energy storage technologies can (barriers to this are discussed in section??). The capacity market is accessed by bidding in competitive auctions for a fixed level of capacity; it is hoped that this competitive process will keep costs as low as possible. Capacity auctions take place four years in advance the first taking place in December 2014, for delivery obligations that will begin in October 2018 [4].

Contracts for Difference (CfD) is an incentive for low-carbon generators (most recent CfD's exclude onshore wind and solar PV) where a strike price is agreed per unit of electricity generated, if the market price for electricity is less than this strike price then the difference is made up by the UK Government. It is designed to subsidise low-carbon generators but also protect energy consumers from paying high subsidies when the cost of electricity is already high [5]. Energy storage can be used in conjunction with low-carbon generators benefiting from CfD's and the rules for doing so were clarified in a Government response to a CfD consultation in 2017 [6].

The UK government has also introduced a number of energy policies for reducing greenhouse-gas emissions from heat, including the Renewable Heat Incentive the Green Deal and other energy efficiency, microgeneration and bioenergy strategies. The Renewable Heat Incentive provides subsidies for the production of heat from a number of renewable technologies [7], whilst the Green Deal, which closed in 2015 (although private sector equivalents now exist) provided loans for energy-saving household improvements such as solid wall insulation and double glazing [8]. However the success of these interventions have been variable with the Green Deal in particular being found to be overcomplicated [9, 10]

For electric vehicles, the UK government compensate up to 35% of the cost of an electric car, up to a maximum of £4,500 depending on the model, and 20% of the cost of a van, up to a maximum of £8,000 [11]. There are also grants available towards the cost of electric vehicle charge-points both at home and at the workplace as well as for local authorities [12].

4.1.2. UK Energy Storage Policy

In addition to these broader changes to energy policy the UK has also made a number of policy interventions targeted specifically at promoting energy storage. In the 2017 Smart Systems and Flexibility Plan the UK Government (and OFGEM) committed to a number of interventions around licensing, planning, connections and charging for storage, to remove regulatory and policy barriers to allow energy storage technologies to 'compete on a level playing field' [13].

These include:

- A revision to the charges placed on storage facilities;

  Consumers and generators are charged for using both the transmission and distribution networks through Use of System and Balancing Services Use of System charges. However because energy storage technologies consume and generate they are effectively double charged. This does not take into account the benefits of storage to the network in providing a balancing service rather than contributing to the congestion of the network; therefore through OFGEM's Targeted Charging Review these charges have been revised so that energy storage facilities only pay the generation charges [14].

- A regulatory definition of energy storage;

  Following on from above the UK Government intends to amend the Electricity Act to include a specific definition of energy storage as a subset of the generation asset class. Providing a regulatory definition of energy storage will not only confirm that it should be treated as a generating asset, but will also help to cement energy storage as an integral part of the electricity system [15].

- A clarification of the rules around co-locating energy storage with renewable energy;

  It can be beneficial to co-locate energy storage with renewable energy, however many renewable energy schemes receive subsidies either from Feed-in Tariffs, CfD's or their predecessor Renewables Obligations. The Government and OFGEM have subsequently published guidelines around co-location to clarify the process and ensure that only renewable generation is rewarded by the subsidy schemes [6, 16].

The policy interventions made by the Government are bringing forward deployment of energy storage technologies, however there are limitations to these interventions. The UK's focus has been on the electricity system with a lack of policy around the integration of electricity heat and transport systems .Furthermore, many countries are developing energy storage markets at a much quicker rate and so there are lessons for the UK to learn. This includes options to support/subsidies energy storage deployment including direct subsidies, competitive auctions (such as the EFR), and co-subsidies for renewables with energy storage. An additional option, although not tested anywhere in the world, would be some form of firm power auction as suggested in the 'Cost of Energy Independent Review' this would promote storage to allow variable renewable generation to provide firm power [17].

3 USA

The USA has the largest number of grid-connected (TES) energy storage projects in the world with a total installed capacity of just over 24GW [1], and is one of the leading innovators in energy storage policy [2]. The federal government have enacted a number of policies aimed at supporting the deployment of energy storage including:

- Energy Independence and Security Act 2007;
  Aimed to increase the USA's energy security by increasing the generation of renewable energy. Regarding energy storage, through the United States Energy Storage Competitiveness Act of 2007 it called for the founding of energy storage research labs, a new national committee to draft a five-year plan on energy storage and demonstration programmes for a number of storage technologies [2, 3].
- American Recovery and Reinvestment Act 2009;
  Provided financial stimulus through grants and loan guarantees for a variety of technologies including approximately $185million for energy storage projects [2, 4].
- Federal Energy Regulatory Commission (FERC) Orders;
  Over the last decade the FERC (the federal transmission and wholesale electricity regulator) has passed a number of orders to remove the barriers to energy storage including
    - *Order 890 (2007) which allowed non-generation sources including energy storage and demand response to be considered for ancillary services [4, 5].*
    - *Order 719 (2008) updated regulations to improve the operation of the wholesale electricity market, particularly around areas of demand response and market pricing during periods of low operating reserve. Also changed the way utilities calculate the minimum value of ancillary services (five-minute calculations), benefiting energy storage technologies with quick response times [2, 5].*
    - *Order 755 (2011) aimed to ensure a level playing field for energy storage technologies by requiring network operators to pay for capacity and performance when acquiring frequency response services [2, 5].*
    - *Order 784 (2013) allowed energy storage owners to provide ancillary services at competitive market based rates to public utilities [2, 5].*
- Clean Power Plan 2015;
  Aims to set targets for carbon reduction by power generation and promote renewable energy. Although not specifically a storage policy the promotion of renewable energy technologies would in turn drive the need for energy storage [3]. Note President Trump has stated his ambition to rescind this policy although it has not yet passed through the courts.

As well as these federal energy storage policies there are a number of state-level initiatives which are driving energy storage. The remainder of this section will focus on three particular states California, New York, Texas and/or Hawaii.

3.1 California

California has a history of leadership on environmental and energy policies and in 2011 the California Renewable Portfolio Standard (RPS) set a target requiring 33% of California's electricity to be generated from renewable sources by 2020 [6]. Then in 2013 it initiated its CO_2 cap and trade scheme aimed at lowering power producers emissions and increasing the value of clean energy sources [7]. The subsequent increase in intermittent renewable electricity has driven the need for energy storage and California has become something of a posterchild for energy storage policy with an ambitious target of 1.3GW of non-pumped hydro energy storage[1] by 2020 to be procured by the three largest utilities [4, 8]. It currently has 4.3GW of grid connected energy storage, although 3.9GW of this is large-scale (>50MW) PHS [9].

Table 2 shows California's energy storage targets to 2020, the targets are broken down by utility and the level of connection (transmission, distribution or customer), with over 47% of the total targeted energy storage coming from the distribution or customer level. It is important to note that although the utilities have to procure these levels of storage they are restricted to owning no more than 50% of the storage assets themselves, this subsequently opens the market up to non-utilities [2].

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[1] PHS under 50MW is included in target 4. International Renewable Energy Agency, *BATTERY STORAGE FOR RENEWABLES: MARKET STATUS AND TECHNOLOGY OUTLOOK*. 2015.

Table 2: California Energy Storage Targets (MW) [10]

Utility and level of connection	**2014**	**2016**	**2018**	**2020**	**Total**
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal	90	120	160	210	580
Pacific Gas & Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal	90	120	160	210	580
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal	20	30	45	70	165
Total	200	270	365	490	1,325

In addition to the targets there has been a number of policy measures put in place at the state level to help ensure these targets are met. The main subsidy scheme available to energy storage providers in California is the Self Generation Incentive Program (SGIP). The SGIP has been in place since 2009 [11], and offers a subsidy for advanced energy storage technologies, which decrease with capacity up to 6MWh [12]. The storage technologies can be either stand-alone or paired with a generating system but must be capable of discharging fully at least once a day [12]. With the relatively small cap on storage capacity and the decreasing nature of the subsidy the SGIP is of greater benefit to small/medium size energy storage projects at the distribution level or lower and so is effectively promoting more decentralised forms of energy storage [2].

In addition the California Solar initiative (CSI) provided funding for small-scale solar (solar PV and solar thermal) projects for domestic and commercial customers with an aim (which was met) of installing 1,940MW of solar capacity from 2007 to 2016 [13, 14]. Whilst not strictly a storage subsidy, small-scale storage systems could be installed as part of the solar installation [2].

With increased renewable generation there can be increased strain on electricity networks as periods of high and low demand do not always correspond with periods of high and low generation. To counter this the California Public Utilities Commission in conjunction with the three utilities in California have implemented a Permanent Load Shifting Program (PLSP) [15, 16]. The PLSP incentivises utility customers to install storage systems to be used for load shifting by paying up to $875/kW of installed load shifted capacity [15, 16]. TES systems such as ice and chilled water TES are particularly encouraged as the demand for cooling is usually during times of high demand and so allows for useful load shifting to take place [15-17].

To be eligible for the PLSP a storage owner must be on a Time Of Use tariff (TOU) which are offered by all three utilities [2], this provides an additional monetary benefit for the installed storage asset as the electricity used for cooling can be brought during periods of low demand when prices are lower. Additionally TOU tariffs can be used by storage systems, independent of the PLSP and provide an income through arbitrage.

Despite California’s success in promoting energy storage there have been several suggestions for improvement. These include an even greater focus from the SGIP on non-transmission level storage as it has more value at the household level where load variability is likely to be greater. As well as a warning that as the SGIP is particularly generous compared to other countries the funding organisations should ensure that the uptake of subsidies does not exceed the funding available so as to avoid a boom and bust cycle [18].

3.2 New York

New York's RPS set a target of 30% of the states' electricity being generated from renewable sources by 2015 [18], building on this the Clean Energy Standard was developed in 2016 committing the state to generating 50% of its electricity from renewable sources by 2030 [19]. To help meet the balancing need this creates New York currently has 1.43GW of grid connected energy storage. The vast majority of this is PHS, although there is 31MW of non PHS with an additional 28MW announced or contracted [9]. New York is traditionally an innovator in energy efficient buildings and demand-side management and its implementation of energy storage reflects this [2]. Since 2009 New York has put in place a number of measures to promote energy storage.

NYISO, the system operator for New York was, in 2009 the first system operator to allow energy storage technologies to provide frequency regulation services [2, 20-22]. Subsequently a 20MW flywheel system was commissioned in 2011 in Stephentown to provide frequency regulation to NYISO [23]. Energy storage technologies also have access to day ahead and real-time wholesale markets and so have access to a revenue stream through arbitrage [24].

In 2010 the New York Battery and Energy Storage consortium (NY-BEST) was created with seed funding from the New York State Energy Research and Development Authority with a mission '*to catalyse and grow the energy storage industry and establish New York State as a global leader*' [25].

In 2014 the Governor of New York announced plans to modernise New York's electricity industry, known as the '*Reforming the Energy Vision*' (REV). The REV calls for a market for distributed energy, known as the Distributed System Platform (DSP) to be created [18, 19]. In 2016 New York's main electricity supplier, Consolidated Edison produced Implementations plan for the DSP. The plan is wide-ranging but includes a five year roadmap for integrating approximately 800MW of distributed energy resources by 2020 with distributed battery storage expected to provide 4MW of load reduction capacity by 2020 [26].

As in California, the state's main electricity supplier (Consolidated Edison) offer a demand reduction program which incentivises electricity consumers to shift their load to help lower peak grid demand. The program is open to a range of load-shifting technologies which can shift a minimum load of 50kW including TES and battery storage. For 2018 the program will pay up to $1500/kW of installed load shifted capacity, Table 3 shows the eligible technologies and the maximum incentive they will get for 2018 and 2019.

Table 3: Consolidated Edison Demand Reduction Program Technologies and Incentive Levels 2018 & 2019 [27]

Technology Type	**2018 Maximum Incentive Level ($/kW)**	**2019 Maximum Incentive Level ($/kW)**
Thermal Storage	1,500	1,700
Battery Storage	1,500	1,350
High Efficiency Electric Chiller/HVAC/BMS/Controls	1,000	1,000
DR Enablement Controls	650	1,000
DR Enablement (for CHP, covers only incremental kWs that can be generated above base load level)	650	5,00
Steam Turbine Chiller, Double Stage Absorption Chiller, Gas Driven Chiller	1,000	1,000
Single Stage Absorption Chiller	600	600
Steam Turbine Chiller Control Panel for Improved Efficiency	500	500

TOU's are offered by Consolidated Edison allowing an additional savings to be provided by these storage assets [28]. TOU's can also be used by storage systems (including residential systems) to provide an income through arbitrage. Additionally, as in California, Coniston Edison provide a TOU specifically for Electric Vehicles.

New York clearly has ambitions to deploy significant levels of energy storage, however barriers to it realising these ambitions exist. These include uncertainty around the programs for supporting the uptake of energy storage and as in California a warning that the incentives under the demand reduction program may lead to a boom and bust cycle [18].

3.3 Hawaii

The majority of Hawaii's energy needs are currently met by expensive, imported, oil-fired generation resulting in electricity prices which are over twice that of the other US states [2, 18]. This alongside the high renewable resource potential of the state and isolated nature of the individual islands electricity grids which are not connected to each other, has led to the state actively pursuing the adoption of renewable energy technologies. Indeed Hawaii's RPS is one of the most ambitious, with a target of 40% of electricity sales coming from renewable sources by 2030, and 100% by 2045 [29], good progress is being made in achieving these targets with the Hawaiian Electric companies (who provide electricity to 95% of Hawaii's population) supplying 26% of their electricity from renewable sources [30, 31]. There has also been a drive for distributed solar PV generation which at the end of 2016 made up 33.5% of all renewable generation [32].

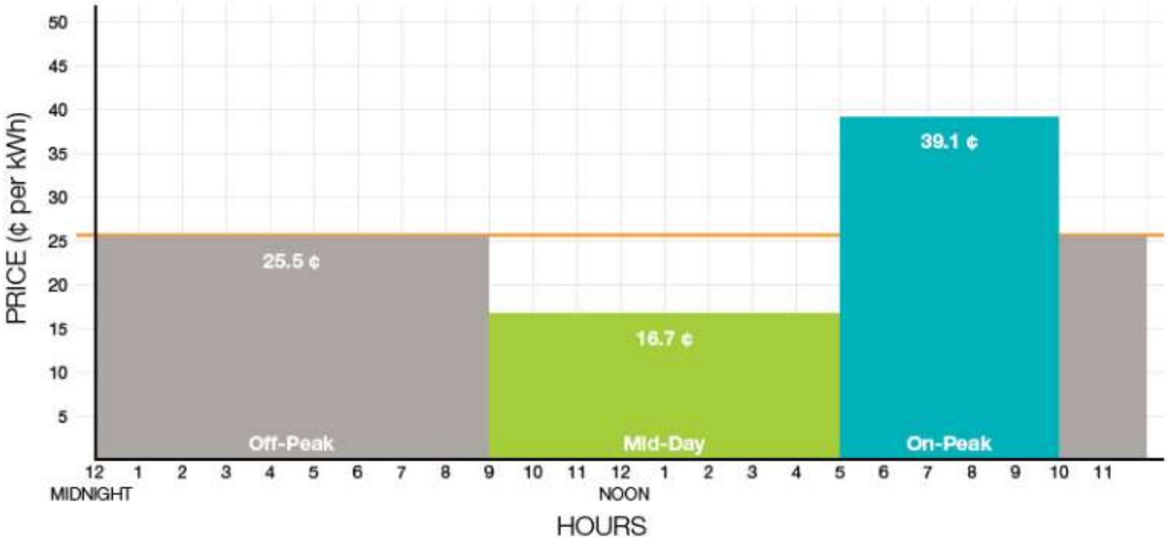
This increase in renewable generation has led to an increased need for balancing measures, including both centralised and decentralised energy storage, with Oahu (the island with the greatest population and electricity demand) experiencing issues with regulating voltage and frequency as well as the inefficient use of thermal generation to provide spinning reserve [18]. Hawaii currently has 44MW of grid-connected energy storage, with battery storage making up almost 93% of this capacity [9].

Currently Hawaii does not provide any support measures specifically for energy storage, however there are two programs; the Customer Grid-Supply program (CGS) and the Customer Self-Supply program (CSS) which support the growth of decentralised rooftop solar generation systems (less than 100kW) , which may include a storage system. The CGS is the successor to the net energy metering program and allows any excess power generated by a PV system to be exported to the grid; the customer is then given credits (ranging from 15c/kWh to 28c/kWh depending on the island) of their electricity bills for each unit of power exported to the grid.

The CSS allows for an expedited review and approval of applications for solar PV systems which are only expected to provide generation to the host property or to a storage system for use by the property later, as such any power exported to the grid is not compensated for. Due to the lack of export compensation the CSS is particularly likely to promote storage systems.

In addition to these measures the Hawaiian electric companies are currently piloting a TOU tariff. The TOU tariff rates for October 2017 are shown below in figure 1, unlike many tariffs the lowest price is in the middle of the day (when solar generation is at its greatest) rather than during the night. This provides an incentive to shift electrical consumption away from the on peak times by storing it during the low rate times for use at a later time.

Figure 1 Hawaiian Electric Companies TOU Tariff Rates October 2017 [33]



The inherently decentralised nature of Hawaii's electricity networks alongside the relatively large proportion of distributed solar PV generation makes it an important case study for those trying to promote decentralised energy storage in the UK. However an important difference is that the high electricity price in Hawaii makes renewable energy and subsequently energy storage more financially viable than in many places in the world, including the UK.

4 Japan

Before the accident at the Fukushima Daiichi nuclear plant in 2011 Japan was the third largest producer of nuclear power with its nuclear power fleet providing 26% of the country's electricity supply [18]. Following Fukushima all 54 nuclear reactors were shut down, although 10 of these reactors are now operating or expecting to begin operating soon nuclear generation is no longer expected to make the contribution that it once did [34, 35]. This in addition to Japan's high dependence on imported fossil fuel reserves (in 2012 it was the largest global importer of LNG, the second largest of coal and the third largest of oil [36]), had led to the Japanese Government aiming in successive strategic energy plans to expand its level of renewable generation to replace much of its nuclear generation and meet decarbonisation targets [37, 38]. A number of measures were put in place to drive the installation of renewable energy including a FiT with a particularly high rate for solar PV [5, 39]. This has led to an increase in the contribution renewable generation makes to Japan's energy supply from 2010 to 2015; from 4% to 5.8% of total primary energy supply and 11.5% to 16.9% of electricity production [40]. This increase in renewable generation is largely down to the growth of solar PV generation which went from providing 0.33% of the electricity demand in 2010, to 3.44% in 2015 [40].

This rapid increase in solar PV generation has led to a pressing need to increase the flexibility of the energy system which has begun to drive the need for centralised and distributed energy storage [41]. In addition to this push for renewable generation, Japan's energy suppliers offer residential TOU tariffs with relatively large price differentials, which as discussed in section 3.1 can help to drive the uptake of distributed energy storage.

Due to its nuclear generation legacy, Japan has high levels of pumped hydro storage capacity (28.25GW) [9]. The remainder of Japan's grid-connected storage is made up exclusively of electrochemical batteries, much of it relatively new but some of it such as around 100MW of sodium sulphur batteries developed for assisting with balancing the baseload nuclear generation [9, 18]. Although the large PHS capacity is used to store the additional solar PV generation produced during the day, the increased flexibility needed is driving new policy measures to develop additional energy storage capacity.

The focus for this additional storage capacity is on batteries with the fourth strategic energy plan (2014) setting Japanese companies the target of capturing a 50% share of the global battery storage market by 2020 [42, 43]. Since 2012, the Japanese Government through the Ministry of Economy, Trade, and Industry and the Ministry of Environment have launched a number of battery subsidy schemes which provide payment for up to 2/3's of the cost of a battery system (predominantly focused on lithium-ion) and target a range of systems and scales from decentralised and residential to large-scale and utility [42, 44]. These subsidies encouraged over 100MWh of household battery storage installations by the end of 2013 alone [4, 45].

In conjunction with these subsidies innovative business models are also being used to drive the uptake of distributed energy storage, for example One Energy Corporation, a collaboration between three large Japanese corporate institutions (ORIX Corporation, NEC Corporation and EPCO Incorporated), offers residential owners of PV systems the opportunity to lease domestic scale battery systems for a monthly fee rather than having to pay a large upfront cost for a battery system [4, 46].

As already discussed, due to its once high levels of nuclear generation, Japan has a history or promoting energy storage (PHS and Sodium-sulphur batteries). However the events at Fukushima have given Japan a unique driver for rapidly installing additional renewable generation which in turn is driving the need for energy storage. Although Japan has provided a range of support measures for energy storage they are almost entirely focused on Lithium-ion batteries; focusing on one technology allows Japan to become a world leader in that technology and is similar to the UK approach to offshore wind. However energy storage is a rapidly developing sector and this approach may be seen as a high risk strategy as it provides a level of technology lock-in which may be undesirable if Lithium-ion batteries are superseded by a superior, but significantly different storage technology.

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